# Age Differences in Exploratory Learning from a Health Information Website

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#### **ABSTRACT**

An empirical study was conducted to investigate how older and younger users learned by performing exploratory search of health information using an interface that recommended relevant links based on browsing histories. While older and younger users gained both factual and structural knowledge about the health topics, significant age differences were observed. Our results showed that processing of recommended and regular Web links imposed distinct demands on cognitive abilities, which at least partially explained the observed age differences in the search process. The use of recommended links was positively associated with general knowledge, while the use of regular Web links was positively associated with processing capacity. Results also showed that the recommended links benefited both younger and older adults by broadening the exploration of information, which led to better learning. Implications on designs of health information interfaces that facilitate exploratory search and learning for different age groups were discussed.

#### **ACM Classification Keywords**

H.3.3 [Information Systems]: Information storage and retrieval-Search process; H.5.2 [Information Systems]:User interfaces- Theory and methods; J.4 [Computer Applications]: Social and behavioral sciences-psychology; J.3 [Computer Applications]: Life and medical science.

#### **General Terms**

Experimentation

#### Keywords

Aging, Exploratory Search, Knowledge Structure, Learning, Recommended links

## INTRODUCTION

According to recent Pew reports [1], in the United States, almost 80% of the Internet users have used the Internet to search for health information. At least 31% of the users claim that they have been significantly helped by following

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*CHI'12*, May 5–10, 2012, Austin, Texas, USA. Copyright 2012 ACM 978-1-4503-1015-4/12/05...\$10.00 the medical advice or health information gathered from the Internet [7]. Indeed, online health information websites have become an important source from which people gather healthcare information from distributed Web pages to acquire relevant medical knowledge for self-care. Because older adults (age 60 or above) constitute a notable group of Internet users who regularly search for health information [1], research on the impact of age-related differences on search strategies and performance will highlight how information technologies should be designed to better fit the needs of this growing population of users.

People search for health information for various purposes. While there has been abundant research aiming at facilitating information retrieval, relatively little has been done to understand how information technologies can be designed to facilitate both searching and learning, such as when one is acquiring health knowledge about a broad topic (e.g., diabetes) to help them better understand and monitor his or her conditions, or to make treatment decisions [3]. The current study is focused on age differences in exploratory search and learning from a health information website that recommends links based on users' browsing histories. While previous research has primarily focused on how recommendation of links may widen the exposure of relevant information to users, our focus is on how older and younger adults may use the recommendations differently, how these differences may influence learning, and how the differences may lead to age-sensitive designs.

# Age differences

Cognitive development has different trajectories across our life span. While processing capacity (broadly including processing speed, attentional span, and working memory) often declines with the aging process, crystallized knowledge (including general knowledge and domain-specific knowledge) tends to sustain [2]. The processing limitations influenced older adults' online information search routines in many levels, such as imposing extra difficulties in moving the mouse, tracking the cursors, anchoring the links, remembering browsing histories, etc. These difficulties may be reasons why older users are often believed to be less efficient in Web search, as studies showed that they tended to browse less information, spend more time to extract information, and give up search earlier than younger users [3,4,13,15].

Despite the limited processing capacity of older adults, crystallized knowledge tends to sustain and even grow as people age. While there are many ways that knowledge can be defined, for the current purpose we divide knowledge into *general knowledge*, which is the general verbal ability that we acquired from education or daily reading routines; and *domain-specific knowledge*, which is the topical knowledge that we accumulated from various sources in a specific domain, such as knowledge related to healthcare, finance, or others. Knowledge is important for people to effectively transform their information needs to query terms during search, as well as judge whether information (or links) is relevant.

#### Search processes

Research shows that the interplay of processing constraints and knowledge shapes users' information search processes and eventually impact performance [3,15]. For example, older adults may face a higher search cost, as measured by the longer time spent to click a link, than younger adults. The higher search cost may be one reason why older adults tend to look up less information and evaluate information more carefully than younger adults. Older adults may also rely more on their crystallized knowledge to evaluate the relevance of links than younger adults. Research has found that, compared to older adults, younger adults tend to adopt bottom-up interface-driven search strategies (following the information layout on the interface) to quickly visit many webpages until the target information is found. Older adults, on the other hand, tend to adopt top-down knowledge-driven search strategies by following their crystallized knowledge to evaluate the relevance of links. As a results, older adults are often found to click a smaller subset of, but more relevant, links as they perform exploratory search [3,4].

Recent research showed that, because of limited processing capacity, older adults could benefit more from a system that provided links across layers, in which the information could be accessed through multiple routes, than from a hierarchical system where information could be accessed only under certain predefined routes determined by the layers of directories dictated by the designer [13]. It is therefore possible that, if each page is linked to other relevant pages in ways that lower the search cost (such that the average number of clicks to go between any two pages is reduced), older adults may be able to access relevant information more efficiently to meet their needs.

# Knowledge structures and learning

While a number of studies have showed age differences in information search [13,15], few have investigated its relation to learning, especially in terms of how users' knowledge structures (i.e., organization of knowledge in memory) are related to their search patterns, or how the organization of information on an interface may impact users' knowledge structures. This is particularly important for people who, for example, are chronically ill and need to repeatedly look for health information. Repeatedly

searching for health information online may implicitly or explicitly lead to learning of health knowledge by, for example, learning of category and link structures among medical concepts (e.g., symptoms, disease) in a website, in addition to learning from contents of Webpages.

Users often have prior knowledge of health-related concepts, which may influence how they evaluate the relevance of links. For example, if a user knows that patients with obesity are prone to diabetes, the mental distance between the concepts of diabetes and obesity will be small, which may increase the likelihood that the user may actively look for information about diabetes when he or she is looking for information related to obesity. Without such knowledge, a user may learn that the two concepts are related if they are, for example, listed under the same category on a Web page. Therefore, in addition to contents, the link structures of a health website may also support users to learn the relationship among health concepts, which may also help them to guide their search.

# Recommending links to users

There have been a growing number of methods to provide recommendation of information to users in different domains such as e-commerce, news, or online social networks. When users are navigating in a Web site, recommendation of links may allow users to explore more information that are believed to be relevant to the users. In general, recommendations can be determined by some forms of association between items. For example, in ecommerce, a company can estimate the associations between products by calculating how likely two products are purchased together, and when users purchase one of these two products, the other product can be recommended to the user. Other methods of association include the use of semantic relatedness of topics contained on two Web pages (such that pages that contain similar topics can be recommended), or similarities of social profiles (e.g., the overlap of social circles between two persons).

While there has been much success in developing new methods in these recommendation systems, the current focus is on how people with different cognitive profiles may *use* these recommendations differently. In particular, we are interested in how older and younger adults may use links recommended by a Web site differently, and to what extent these differences can be attributed to the differences in their cognitive profiles or background knowledge.

#### The current study

We implemented a link recommendation system to provide additional link structures based on users' browsing histories. We used a battery of cognitive tests to measure individual differences of older and younger adults, and we measured how these individual measures were associated with their search behavior (e.g., how they decided which links to click, how much time they spent on each page, how and when they decided to use the recommended links, etc), and how differences in search behavior could account for any

learning effects after they performed exploratory search for different health topics using the Web site. Our goal is to unpack the complex interactions among individual differences between age groups, exploratory search behavior, and learning outcomes. Results will provide useful information for designs of intelligent health information systems that adapt to different demands of users with different profiles.

#### **METHOD**

#### **Participants**

Forty-seven participants were recruited. 27 college students (Mean=20.96, s.d.=2.07; 60% were female) and 20 older adults (Age of 60 and older, Mean=65.60, s.d.=7.30; 85% were female) were invited to this study. The gender imbalance was due to the random sampling of the study. (There were no main effect of gender or interaction of age and gender on cognitive measures or search behavior.) Data from one younger adult was lost due to a technical problem. All participants had completed high school education. Most (76%) younger adults were college students. Most (80%) older adults had more than high school degree.

#### Search interfaces

We created two versions of an interface mainly based on the materials from two well-known public medical information websites WebMD (http://www.webmd.com) and MedlinePlus.gov (http://medlineplus.gov). There were roughly 350 short essays about diseases and 100 short essays about how to maintain self-care including topics in nutrition, exercise, etc. In the *parts* interface, we categorized these symptoms based on body parts (e.g., head, chest, limbs); in the systems interface, we categorized symptoms based on the functional body systems (e.g., circulatory system, brain and nerve system, etc).

The two information organizations showed different associations between symptoms [4]. For example, in the systems interface, hearing problem and balance problem were clustered in the same category of "brain and nerve system". However, hearing problem and balance problem were organized in different categories in the parts interface, namely, "nose, mouth and ear" and "limb", respectively.

As Figure 1b and 1c showed, only the main page and symptom page were different in the two interfaces. The use

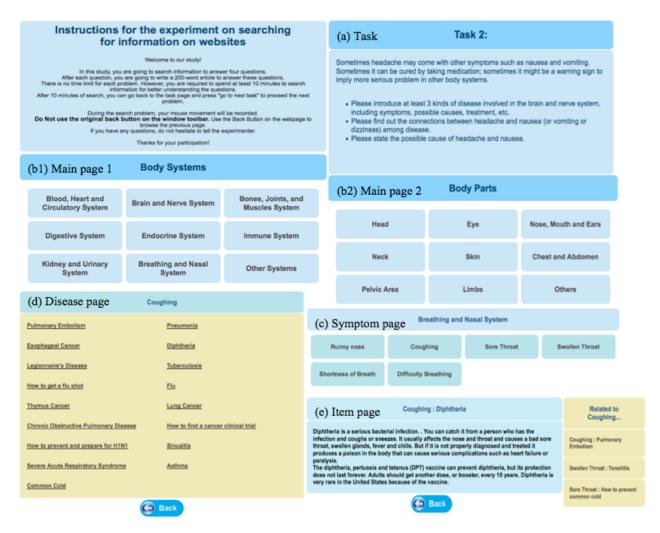


Figure 1. The flow of webpages in the website

of two interfaces was to test whether the change of structural knowledge was dependent on the information organization of the interface. The order of links presented on the website was randomized for each participant. There was no positional benefit for any of the links. Half of the participants from each age group performed the tasks in the parts interface, and the other half performed in the systems interface. For both interfaces, the contents were identical, only the categorization was different. Font size and font color also followed the guidelines for elderly-friendly design [6].

#### The recommended links

After participants clicked on the main category, they would be taken to the *symptoms* page, which listed symptoms that belonged to the chosen main category (part or system). For example, as shown in Figure 1c, participants could see "coughing" and "runny nose" after clicking on the main category "Breathing and Nasal System". When participants clicked on a symptom, they would be taken to the disease page, on which there was a list of diseases and related howto tips that were associated with the chosen symptom (Figure 1d). Participants could then click on one of the diseases or how-to tips to see a brief description about this item, which would contain information about the disease definition, possible symptoms, prevalence rates, and the risk factors of this disease (Figure 1e). For how-to tips, the brief description would include a list of how-to procedures to establish self-care behavior.

The main feature to be tested was the recommended links, as shown on the right column of the item page (see Figure 1e). The presentation of recommended links on an item page was contingent on the symptom clicked by the participant prior to reaching that item page. For example, for the item page that described "Brain Cancer", the participant could reach this page after clicking on the symptom "Nausea", or clicking on the symptom "Balance Problem". Depending on the symptom that they clicked before reaching the item page, the recommended links could be different. In particular, the recommended links were symptoms and diseases that were related to the clicked symptom (see Figure 1e for an example). The exact calculations of the recommended links will be described below.

We were interested in how existing knowledge structures may interact with the information organization of the Web site as recommended links were used. Because the health information was categorized by symptoms in our website, we measured users' knowledge structures in terms of how they perceived the symptoms were related to each other.

To generate the recommended links, we first obtained the semantic relatedness matrix from the 53 X 53 symptoms using latent semantic analysis (LSA) [9]. Then each symptom was paired with the other two symptoms that had the highest semantic relatedness to it. The assumption was that the LSA scores would indicate how likely these symptoms co-occur in other contexts (thus were likely

related to each other). Once people clicked on an item of a symptom, the program would display other three items under the selected symptom and the paired symptoms as the recommended links.

As an example, from LSA, we found that the symptom "headache" had the highest relevance to symptoms "dizziness" and "nausea". If a participants clicked on "headache", then the disease "Encephalitis", the interface would display "Headache: Stroke, Dizziness: Anemia, and Nausea: Brain cancer". In addition to the semantic relatedness among the symptoms presented in the recommended links, the symptoms could either be in the same or different categories as defined by the interface. Following the previous example, because "headache" and "dizziness" were under the same category "brain and nerve system" as defined by the interface, while "nausea" was under a different category "digestive system", we called the recommended link "dizziness" (after "headache" was clicked") an interface recommended link, while "nausea" a non-interface recommended link. By comparing how often older and younger participants clicked on the interface and non-interface recommended links, our goal was to test how different age groups may use these two types of links differently. About 60% of the recommended links were interface recommended links. The order of links presented was randomized.

# **Exploratory search tasks**

Participants were given four health related open-ended search tasks in a random order. These tasks required participants to broadly explore a health topic in our website. The tasks were designed such that participants need to actively process information on the Web pages, and perform extensive integration and elaboration on the information. In contrast to simple fact retrieval tasks, the current tasks could not be solved by browsing a single web page or a single domain category (i.e., one body part or one body system). For each task, participants were required to spend at least ten minutes to search to better understand the topic. After each search task, participants answered openended questions about each search topic. To exclude the confounding factor of individual differences in memory capacity, participants were allowed to take notes during the search. There was no upper time limit for the exploratory search tasks.

Here is an example of the search task:

More than 80% of adults have low back pain at some time in their life. While back pain is usually acute (short-term), back pain can often be chronic. For those chronic back pain, they might be caused by other physical problems.

- Find out the connections between back pain and other bone disease, such as osteoporosis, arthritis, osteoarthritis, etc.
- Find out the connections between back pain and health problems except bone disease.
- Provide some methods to relieve back pain.

#### Cognitive measures

Three cognitive measures were given before the search

task. Processing speed was measured by Letter Comparison test [16]; working memory was measured by Letter Number Sequencing [18]; general knowledge (vocabulary) was measured by Advanced Vocabulary test [5].

# Factual and structural health knowledge measures

Factual and structural health knowledge was measured by T/F questions and card sorting respectively. For factual health knowledge, we created 12 True/False questions about the search topics. All participants took this questionnaire before the search task. A false example item is," The H1N1 swine flu virus spread in two ways. It is like the seasonal flu virus, can become airborne if you cough or sneeze without covering your nose and mouth. It can also spread by contacting or eating the contaminated pork".

We also used card sorting to measure knowledge structures of the participants. Card sorting is a standard methodology to measure knowledge structures (e.g., [8,10,11,12]). In card sorting, participants were asked to use their own rules to put the paper cards into piles. Each card was written with a symptom. Participants were told that there was no correct answer for clustering and the purpose of the task was to understand how they think about the relationship among these symptoms. Twenty-three common symptoms were selected from the health information website, such as the balance problem and chest pain. Each participant did the card sorting twice, once before and after the search tasks..

# **Experimental design**

A 2X2X2 mixed factor experimental design was conducted. There were two between-subject variables: Age (young/old) and Interface (parts/systems), and one within-subject variable (pretest/posttest). Half of the participants were assigned to perform the tasks in the parts interface and the other half in the systems interface. All participants completed four search tasks in their assigned interface.

# **Procedure**

All participants completed the demographic questionnaire, performed the cognitive measures, and completed the health knowledge questionnaire. Then the card-sorting task was given before the search tasks. Participants would then be assigned to either the parts or systems interface. All participants first read the instruction page of the experiment (see Figure 1), and the first task problem would be presented (Figure 1a). Participants then clicked on "Begin" to start the task, which would take them to the main categories page. They could use the "Back" button anytime to go back to the previous page. After 10 minutes, participant could go back to the main page and click on "Done" button when they finished one task. After each task, participants answered a set of open-ended questions. After four search tasks, participants were given the card-sorting task again. The whole experiment took about 3 hours.

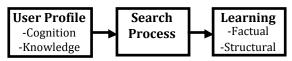


Figure 2. The theoretical approach of analysis

Table 1. A list of definitions of variables

Recommended links Interface Recommended links	The links listed on the item page with semantic relevance to the item  The subcategory of the current recommended link (i.e. its symptom) was in the same category with the subcategory of previous item
Proportion of recommended links clicked	Number of recommended links clicked divided by the number of items clicked
Proportions of interface recommended links clicked	Number of interface recommended links clicked divided by the number of recommended links clicked
Mental Interface Match Index (MIMI)	Measures of harmony between the relational matrices of participants and the ideal sorting suggested by the interface
Semantic Index	Concordance scores between the relational matrices of participants and the ideal proximity matrix suggested by Latent Semantic Analysis

#### **RESULTS**

As guided by Figure 2, we first analyzed age differences in users' cognition, knowledge and search process. We then examined the associations between the search process and users' cognitive abilities and knowledge, before we analyzed effects of learning in factual and structural health knowledge (as measured by the open-ended questions and results from card sorting, respectively). Finally, we investigated the association between search process and learning outcome. A summary of the definitions of variables was in Table 1.

## Cognitive abilities and internet experience

All participants used the Internet more than twice a week. However, younger adults used the Internet more often than older adults (U=187.5, p<0.005). Consistent with cognitive aging literature, younger adults performed better in the measures of processing capacity (speed and working memory) than older adults (t(43)=4.79 &3.06. p's<.01). Older adults, however, were better in the measures of general knowledge (vocabulary) than younger adults (t(43)=-4.34, p<.01).

### Age differences in factual health knowledge

Older adults performed better in the health knowledge test in the questionnaire than younger adults (t(43)=-2.09, p<.05), showing that older adults had better understanding about the assigned medical topics than younger adults.

#### Age differences in structural health knowledge

We also used card sorting to examine the structural health knowledge of participants. Card sorting has been used to investigate the organization of knowledge in our memory and the amounts of learning in the psychology literature ([10, 11]). In our study, we used the free sorting procedure to measure the structural knowledge of medical symptoms. Participants put 23 symptom-cards into piles, and the number of piles was not limited. Based on the

Table 2. Age differences in the search process

Per search task	Young	Old	F(1,41)
	mean (s.d.)	mean (s.d.)	
Total clicks	37.18 (16.45)	28.13 (10.23)	4.85*
Total time (sec)	637.30	736.325	4.30*
	(132.77)	(185.55)	
Average time to	7.93 (4.02)	12.01 (3.93)	12.97**
decide a link click			
(sec)			
Number of items	13.39 (5.09)	10.13 (3.83)	5.82*
looked up			
Number of	2.98 (1.99)	2.74 (2.13)	0.16
recommended links			
clicked			
Proportion of	0.23 (0.13)	0.25 (0.15)	0.32
recommended links			
Proportion of interface	0.65 (0.04)	0.58 (0.1)	1.17
recommended links			
Average time to read	53.89 (42.84)	78.04 (51.05)	3.02^
an item (sec)			

<sup>\*\*</sup>p<.01, \*p<.05,^ p<.10

categorization of cards, we inferred the mental distance between each pair of symptoms in participants' knowledge. For example, if a participant put chest pain, difficulty breathing, and irregular heartbeats in the same pile, the symptoms of chest pain, difficulty breathing and irregular heartbeats might be closely connected or frequently co-occurred in his/her health knowledge structures, and thus the mental distance among them is small.

#### Semantic Index

We first transformed the clustering data into a 23X23 "relational matrix" with entries representing whether two items were put in the same category (1) or not (0). Based on the relational matrix, we calculated the *Semantic Index* to operationalize the measure of relational knowledge of the participants. The criterion knowledge structure used was the measure of semantic relatedness among symptoms generated from latent semantic analysis (LSA) [9]. LSA was shown to captured the general semantic relatedness of words well, and thus, we used it to further validate how well participants' judgment on how two terms were related was similar to the general semantic relatedness calculated by LSA.

We first created a proximity matrix consisted of the LSA scores obtained from each pair of symptoms used in the card sorting task. We then compared each participant's relational matrix to the LSA proximity matrix by calculating the inner products of the entries between the two matrices. The square root of the summation of these inner products was the *Semantic Index*. A higher semantic index would reflect that the judged relatedness among the symptoms was more similar to the semantic relatedness calculated by LSA.

We found that there was no age difference in the Semantic Index in the pretest (t(43)=-0.47, p=0.64) showing that older and younger adults do not differ in their relational

health knowledge before the search. We will use the semantic index to compare the change of knowledge structures before and after the tasks.

#### Mental Interface Match Index

To quantitatively measure the extent to which the knowledge structures of health concepts matched those in the interface, we created another variable called the *Mental Interface Match Index (MIMI)* based on the measure of harmony ([17], cited in [11]). Similar to the semantic index, based on the card sorting data, we calculated the relational matrix, which was compared to the interface matrix, which represented the organization of information in the interface (the one that participants were assigned to). Similar to the relational matrix, the interface matrix was a 23X23 matrix with entries representing whether the pair of symptoms were presented in the same category in the interface (1) or not (0).

We created two interface matrices to represent the structures in the parts interface and the systems interface. The MIMI was calculated by the summation of the inner products between entries in the participant's sorting matrix and the interface matrix, then normalized by the sum of positive entries in the matrix from the interface. The MIMI index therefore indicated the extent to which the participants' knowledge structures of symptoms were similar to the information organization of symptoms in the interface. Therefore, participants with higher MIMI had the knowledge structures more similar to the information organization in the interface than those with lower MIMI. Older adults had higher MIMI in the pretest than younger adults showing that their internal knowledge structures were more similar to the interface before the search tasks (t(43)=-2.70, p<0.01). We will use the MIMI to measure the extent to which participants' knowledge structures became more similar to those in the interface before and after the

#### Age differences in the search process

Search process variables were summarized in Table 1 and Table 2, including the number of total links clicked in one task, the average time (measured in seconds) spent in one task, and the average time spent to decide on a link click. In addition to these global measures, we did further analysis on the item pages participants visited (Figure 1e). We first measured the number of items clicked in one task to measure the breadth of exploration. We then measured the number of recommended links clicked as well as the proportion of recommended links clicked (i.e., the number of items pages clicked) to examine the usage patterns of recommended links.

### Older Users Conducted Less Exploration

A MANOVA was performed to investigate age differences in the search process (through variables in Table 2). We found that younger adults tended to click more links, leave a page more quickly, and decide to click more quickly than older adults. Older adults spent longer time to decide on a link and look up fewer items than younger adults, which replicated findings in previous studies [3, 4].

#### No Age Difference in Clicks of Recommended Links

The total number of item page visits (Figure 1e) included the case when people clicked an item on the disease page (Figure 1d) and when they clicked on one of the recommended links. Interestingly, younger adults visited more item pages than older adults. However, there was no age difference in both the number and proportion of clicks on recommended links, suggesting that older adults clicked the recommended links as frequently as younger adults (Table 2). Among all the item page visits, there were about a quarter of the item pages being accessed by the recommended links for both younger and older adults.

#### Individual differences and search process

Pearson Correlation was conducted to examine the relationship among the cognitive measures and search behavior. There was a significant association between the number of symptoms (subcategories) clicked and working memory (r=0.37, p<0.05). People with better working memory browsed more symptoms. This association confirmed that people with higher capacity tended to look up more information, which might be because they could mentally process more information and thus had lower cost in performing exploratory search (as they consumed less cognitive resources relative to their capacity).

# Processing Demands, Knowledge, and Accesses to the Item Pages

Results showed distinct relations between cognitive abilities and the number of item page visits from either the disease page or the recommended links. When participants visited the item pages from the disease page, there was a positive association between the number of item page visits and processing speed (r=0.31, p<0.05). When participants visited the item pages through the recommended links, there was no association between the number of visits and the processing capacity measures. Rather, there was a marginally significant association between item page visits and general knowledge (i.e., verbal, r=0.29, p=0.056). The results were consistent with the notion that visiting the item page from the disease page required more processing capacity than through the recommended links, as participants who had higher processing capacity tended to visit the item page more from the disease page, but the same association was not found when participants visited the item pages through the recommended links. Rather, knowledge was related to how likely the recommended links were used, presumably because knowledge allowed participants to more correctly judge the relevance of the recommended links. Given that older participants tended to have lower processing capacity but better knowledge, it was possible that older adults benefited from the recommended links. We will come back to this idea later.

The Influence of Knowledge Structures on Clicks of the Interface Recommended Links

Table 3. Multiple regressions on the proportion of interface recommended links clicked with age and cognitive measures as predictors

Adjusted R square	Predictors	Standaradizd Beta Coefficients	t
K square		Coefficients	
0.195	Age	-0.36	-1.69
(F=2.28,	Speed	-0.29	-1.51
p=0.05)*	Working memory	0.13	0.74
	General knowledge	0.35	1.96
	Medical knowledge	-0.37	2.25*
	Pretest MIMI	-0.13	-0.76
	Age X Pretest MIMI	0.44	2.68*

\* p<0.05

As stated in the Introduction, we assumed that knowledge structures would influence how one would use the interface. To test this, we investigated who clicked the interface recommended links by a multiple regression model, which was conducted with the proportion of interface recommended links clicked as the dependent variable, and age, cognitive abilities, and structural knowledge before the task (pretest-MIMI) as the predictors. The model explained 19.5% of the variance (F=2.28, p=0.05) (See Table 3). There were two significant predictors: medical knowledge and the interaction term between age and pretest-MIMI while controlling for age, processing capacity (speed and working memory), and general knowledge (verbal ability). We found that people with less knowledge tended to click more interface recommended links. It was possible that participants with less knowledge might be more reliant on the suggested links, while those with better knowledge would tend to adopt a more top-down knowledge-driven strategy when searching for related information, which was consistent with previous findings (e.g., [3]).

The significant interaction between age and pretest-MIMI suggested that younger and older adults with different knowledge structures searched differently. We used Simple Slope Techniques [14] to visualize the interaction effect between age and pretest knowledge structures (i.e., pretest MIMI). The interaction term was decomposed into a simple regression of proportion of interface recommended links clicked onto pretest-MIMI for younger and older adults (Figure 3). Results showed that pretest-MIMI was positively associated with the proportion of interface recommended links clicked for older adults (B=1.81; B for the slope), but was negatively associated with proportion of interface recommended links clicked for younger adults (B=-1.41).

Results suggested that older adults whose knowledge structures were less similar to the information organization in the interface tended to click fewer interface recommended links. However, younger adults whose knowledge structures were less similar to the information organization in the interface, were more likely to click on the interface recommended links. There was no difference on the use of interface recommended links for people who

have similar knowledge structures to the interface between two age groups. Therefore, younger adults were more exploratory, in the sense that they had a higher tendency to click on links when those links were clustered differently from their knowledge structures (perhaps to explore for information that they did not know). For older adults, on the other hand, they tended to be less exploratory, in the sense that they tended to click links that were consistent with their knowledge structures. Similar to previous findings (e.g., [3]), the search strategies of younger adults were more interface-driven (bottom-up), and the ones of older adults were more knowledge-driven (top-down).

#### Learning

Learning Factual Health Knowledge: Open-ended questions Each participant answered 4 sets of open-ended questions. If participants answered comprehensively and accurately, they would get 1 point for each question in the task; if they answered partial questions, they would get 0.5 points for each question in the task. The answers were scored by two

#### AgeXpreMIMI on the Use of Interface Recommended Links

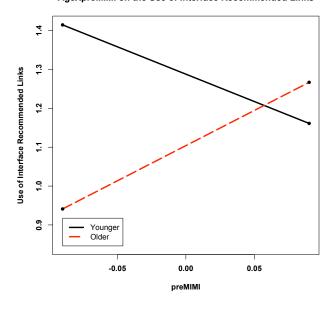


Figure 3. Relationship between proportions of interface recommended links clicked and pretest Mental Interface Match Index for younger and older adults

independent raters with good agreement (>90%). There was no age difference in the accuracy of answers (mean accuracy (SD) for younger and older adults: 0.88 (0.14) and 0.86 (0.11) respectively). Considering the accuracy scores for younger and older adults in the true/false health knowledge pretests, the mean accuracy for younger and older adults were 0.63 and 0.72 respectively. Although we did not use the same factual knowledge measures in the pretest and posttest (both have 12 questions), the growth in accuracy scores on the health knowledge measures suggested that participants had learned after performing exploratory search in the health information website.

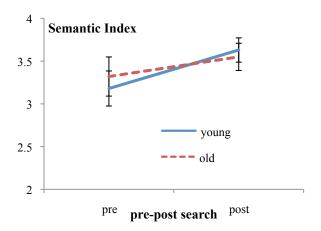


Figure 4. The semantic index for both younger and adults increased after the search tasks.

# Learning Relational Knowledge: Semantic Index

Since participants did card sorting before and after the search tasks, we calculated the pretest and posttest semantic indices to investigate the learning effects in relational health knowledge. A 2X2 Repeated Measures ANOVA was performed on the pretest and posttest semantic indices, with age as the between-subject variable. The results showed a significant main effect in the difference between pretest and posttest semantic indices (F(1,43)=8.13, p<0.01) (See Figure 4). There was a main effect of age (F(1,43)=.02,p=.90), but the age X pre-posttest interaction was not significant (F(1,43)=0.89, p=.35). Older adults showed a generally higher semantic index than younger adults. However, for both younger and older adults, the semantic indices were higher in the posttest than the pretest. In other words, both younger and older adults had more similar knowledge structures after the search tasks. Results therefore showed learning effects in the relational health knowledge for both younger and older adults.

#### Learning the Information Structure from the Interface

A 2X2X2 Repeated Measures ANOVA was performed on the pretest and posttest of the MIMI with the betweensubject variables of age and interface. There was no main effect or interaction effect associated with the interface. However, there was an interaction effect of age on the pretest and posttest MIMI (F(1,41)=4.72. p<0.05). As Figure 5 showed, the MIMI of younger adults increased after the search tasks, while there was no change for older adults. A post hoc test also confirmed that younger adults had higher MIMI after than before the search tasks (t(1,24)=-2.46, p<0.05); however, there was no difference in the pretest and posttest MIMI of older adults. Older adults started with a high MIMI and remained the same after the search tasks, while younger adults showed increase in the MIMI after the tasks, and reached the same level as older adults. Therefore, in addition to learning the semantic relatedness among health concepts during the exploratory search, younger adults also acquired the information organization of the interface through the interaction with

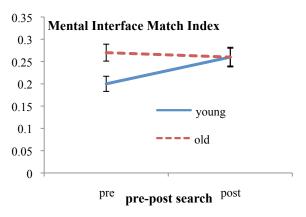


Figure 5. The interaction effect of age and pre-post test on the Mental Interface Match Index (MIMI)

the interface.

### Search process and learning outcome

Pearson correlations among accuracy scores of the open-ended questions and search behavior variables were calculated. Results showed that both younger and older adults who clicked on more relevant items (through both disease pages or recommended links) had higher accuracy scores for the open-ended questions (r=.38, p<.01). Relevant items referred to items that contained answers to the tasks. This at least partially validated the link between search and learning outcome – i.e., those who searched better (found more useful information) also learned better.

Although younger adults clicked more items than older adults, there was no age difference in the accuracy scores. In other words, even though younger adults visited more item pages than older adults in total, only the relevant item pages helped them answer open-ended questions. In other words, the more item pages that they browsed might not be all relevant. On the other hand, older adults browsed the same number of relevant item pages and achieved similar accuracy scores of the open-ended questions, even though the total number of visits of item pages was lower. This highlighted the reason why performance in open-ended search tasks was about the same for younger and older adults, which replicated the results from our previous study [3].

# Learning the Interface's Information Structures through the Use of Interface Recommended Links

The final part of the results was the significant Age X Pre-Posttest intreaction on the MIMI. The effect suggested that, compared to older adults, the knoweldge structures of younger adults became more similar to the information organization of the interface after the search than older adults. To understand how this was related to the search process, we first calculated the deviance scores of MIMI (i.e., posttest MIMI minus pretest MIMI). Then we calculated the Pearson Correlation between the MIMI deviance scores and the search variables. We found that the proportion of interface recommended links clicked had the highest association with the MIMI deviance scores for

younger adults (r=0.53, p<0.05). (Such association was not significant in the older group since there was no significant change in the MIMI scores before and after the search.) As we expected, younger adults who clicked on the interface recommended links more were more likely to learn the information structures of the interface because the interface recommended links and item pages were not only relevant, but also clustered in the same categories in the interface. As Figure 5 showed, for younger adults who used the interface recommended links more, their original knowledge structures were more different from the information organization of the interface. So the adoption of this search strategy led to more learning effects in MIMI scores for younger adults.

#### **CONCLUSIONS and DISCUSSION**

The current study examined age differences as older and younger participants learned by performing exploratory web search. We explained the age differences in terms of the relationship among users' background knowledge, search behavior, and learning outcomes. Consistent with previous research, we found age differences in cognitive abilities and health knowledge – younger adults had better processing capacity while older adults had better health knowledge (both factual and structural). We also found age differences in search behavior – younger adults were more exploratory, as they clicked more links, but visited and left a page more quickly, than older adults. Older adults did more focused search, as they clicked fewer (but more relevant) links and spent longer time deciding on a link.

Our results showed that search behavior was related to cognitive abilities. Specifically, we found that users who browsed more pages tended to have higher processing capacity. Perhaps because the use of the recommended links was associated with knowledge but not with processing capacity, older adults used and benefited from the recommended links as much as younger adults. It is also possible that, because younger adults tended to perform a broader exploratory search, they learned more from the information structures of the interface than older adults. Most interestingly, the amount of learning was associated with how often they clicked the interface recommended links (i.e., recommendations that were consistent with the interface's categorical structures of symptoms).

There were two main contributions of the current study. First, the study demonstrated the success of having recommended links as an intervention that aimed at supporting the use of *knowledge* for older users. As research has consistently shown, knowledge tends to be more resilient to the aging process, while processing capacity tends to decline with age (e.g., [2]). While testing the effects of different recommendation methods is not the focus of the current study, our results did demonstrate the benefit of recommendation methods that allow older adults to better utilize their often superior knowledge while minimizing processing demands and search costs (e.g., by reducing the number of clicks and the need to remember

hierarchical link structures). Results have important implication for design of recommendation systems that better fit the needs and limits of older users.

The second major contribution of the study was the use of multiple measures to access exploratory learning. Our results showed that in exploratory search, not only did participants learned from the contents of Web pages, they also could learn from the category and link structures in the Web site. We found that while contents of Web pages could lead to learning of factual health knowledge, exploring for information by following links in a Web site could also lead to learning of relational knowledge about medical concepts, as the interface's categorical and link structures allowed users to infer the extent to which different concepts were related. This has important implication to design of health information systems, as when patients are exploring and learning about medical concepts from these systems, both factual and relational knowledge are important, as they are equally important for patients to make health-related inferences and decisions.

Human computer interaction research on designing senior-friendly technologies often focused on ways to offload processing demands to the interface, such as by providing browsing histories to aid older users' shorter span of working memory [6]. However, relatively little has been done to design intervention methods that facilitate the use of knowledge. Indeed, our results not only showed that the use of recommended links was associated with users' knowledge but not processing capacity, but also showed that these recommended links seemed to better fit the top-down knowledge-driven strategies adopted by older adults.

On the theory side, results from our study highlighted the importance of understanding the reciprocal relation and coupling between search processes and knowledge structures. This reciprocal relation is similar to the relation between reading comprehension and knowledge structures, as documented in the literature on text comprehension [11] – while knowledge structures may influence how a reader extracts topical structures of an essay, knowledge structures of the reader can also be influenced by the organization of texts. In our study, users learned and updated their knowledge structures through exploratory search in the Web site by interacting with its links structures, but it was also found that their knowledge structures influenced how they conducted the search.

Future research will investigate how to more intelligently cluster the information based on users' knowledge structures, such that the recommendation of health information can be adapted to the users' knowledge structures and their information needs to facilitate search and learning. Also, we will extend the topics to non-health contexts and low-domain-knowledge older samples to test if we can generalize our findings to whether interaction with the interface can induce direct and indirect learning.

Overall, the study guided interface design in two aspects, age-sensitive interfaces and learning through exploratory

search. The study suggested that older users' search behavior might be promoted with more flexible information structures that adaptively estimated the ways users conceptualized the terms in their knowledge. User models that keep track of their interactions may therefore provide better recommendations of links to older adults. Given that repeated exposure to the interface would promote better learning, an interface that adapts to the user profiles over time will benefit knowledge acquisition for domains in which long-term gain in knowledge is useful, such as for chronic-ill patients.

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