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Designing Interfaces for Older Users: Effects of Icon Detail and Semantic Distance

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Abstract:

Older users are increasingly using digital means (especially the Internet and mobile devices) for work and leisure. Yet, until recently, researchers have not paid sufficient attention to how one can adapt the human-computer interface to older users. In this paper, we propose an approach to adapting interfaces to older users that is based on the knowledge of design and knowledge of age-related capabilities and needs. We concentrate on icons, which are perhaps the most common means of controlling human-computer interaction. First, we determined age-related cognitive impairments that might affect icon identification and selected two icon attributes that we could adapt to overcome performance degradation. We then conducted an experiment to test the hypothesized differences between young and old adults in terms of the impact of icon design on user performance. The two attributes of icon design were level of detail in the icon (i.e., the number of elements that constitute the icon) and its semantic distance (i.e., the distance between the meaning of the icon and function it represents). We found that both attributes affected the performance of older users more strongly than they did young users except for an extreme case in which the negative impact on young users when adapting for older users was devastating. We believe that these results demonstrate that adaptation of icons for older users is desirable and feasible but must be done with caution. We need more research to determine the nuances and limitations of adaptation to understand the adaptation of other design attributes by going beyond the cognitive aspects to the physical, affective, and social aspects of human computer interaction.

Keywords: Icon Identification, Age-related Impairments, Semantic Distance, Level of Detail.

1 Introduction

While adaptation of human-computer interfaces, particularly personalization (Arazy, Nov, & Kumar, 2015), has become an almost universal design principle, research on adapting interfaces to older users has until recently been limited (Vines, Pritchard, Wright, Olivier & Brittain, 2015) and all but absent in information systems. This paucity of research on adaptation for older users is disturbing because, on the one hand, elderly users often exhibit well-documented cognitive, affective, and social characteristics that directly restrict their interaction with common interfaces, and, on the other hand, experts predict that soon people over 60 will constitute a third of the workforce in many of the world’s countries. Older adults are the fastest growing computer and Internet user group in both personal and workplace contexts (Wagner, Hassanein & Head, 2014). Indeed, the recently growing body of research on older users of computer systems may be due, at least in part, to the growing use of the Internet by older users for general purposes such as seeking information and communicating socially and for age-related needs such as chronic medical care. Adapting the human-computer interface to older users will likely be both beneficial to these users and economically worthwhile to organizations and economies. As such, we need to understand age related impairments to determine how to adapt interfaces for older users.

The basic cognitive functions that age most affects are attention and memory. Perceptual functions, which include perceptual vision, also show significant age-related declines attributable mainly to declining sensory capacities, which could affect cognitive functions later in the processing stream (Glisky, 2007). In relatively short and routine tasks that are accomplished in relatively fast human-computer interaction, the speed of perception, cognition, and attention and the limitations of time and space on memory are often the source of the age-related decrease in performance. This explanation is in line with the literature on aging, which associates cognitive and visual age-related impairments to general slowness of brain function and the ability to process visual and semantic information (Glisky, 2007).

Some adjustments in human-computer interaction are obvious and common. It makes sense for designers of e-books or other electronic reading devices to set the default font size according to the expected user's age category. For example, books for the elderly are printed in larger letters. Nevertheless, more subtle design decisions are less obvious. For instance, how, if at all, should one adapt the design of icons to older users? Such design decisions must rely on a knowledge of older users’ reading capabilities and preferences.

In this paper, we concentrate on the tailored design of icons for older users. We chose icon design because it is a ubiquitous mechanism of control and communication nowadays and relevant to most contemporary media. Small improvements in the efficiency and effectiveness of using icons will likely result in significant improvements in using computers and mobile devices to complete tasks (Gatsou, Politis, & Zevgolis, 2012). We propose a framework and hypotheses for explaining the effect of the interaction between age and icon design on user performance, and we test the hypotheses in a laboratory experiment. If we can demonstrate the utility of adapting icon design to older users, other elements of the human-computer interface will undoubtedly also become targets of future research to better design the interface for the elderly.

This paper proceeds as follows. In Section 2, we review the relevant theoretical basis of human information processing at older ages and recent work on icon design in human computer interaction. We also combine the two aspects to generate hypotheses related to the design characteristics of icons. In Section 3, we describe the method of a laboratory experiment in which we manipulated the icon design and tested the impact on performance for young and older users. In Section 4, we report the results and, in Section 5, discuss the results and consider practical implications.

2 Theory

2.1 Cognition in Older Users

Older adults’ needs and concerns as computer users differ from those of younger users because of the natural changes associated with aging. We focus here on the cognitive changes that come with aging. Cognitive changes create a need for interfaces that have fewer distractions, provide memory cues, and are simple to learn and understand (Wagner, Hassanein & Head, 2014). One approach to studying the design of human-computer interaction for older users is to examine the limitations that older users face in relation to their needs. We regard these limitations as age-related impairment.

Although age-related cognitive impairment may already begin in young adulthood, it usually becomes more evident in older adults (Salthouse, 2012). There are many different age-related impairments such as processing abstract constructs, drawing inferences, and making sense of new information, all of which have implications for human-computer interaction performance (Pak, Czaja, Sharit, Rogers & Fisk, 2008). In relatively short and routine tasks, such as identifying menu items, the lower speed of perceptual and cognitive processing and the limitations of short term memory often inhibit performance. This connection between cognitive impairment and decrease in performance is in line with the findings on older adults that exhibit cognitive impairments, general slowness of brain function, and a reduced ability to process visual and semantic information (Glisky, 2007). Furthermore, research on age-related impairment has found a deterioration in short-term memory (Wingfield, Stine, Lahar, & Aberdeen, 1988), control over attention (Engle, 2002; Verhaeghen & Cerella, 2002), and perceptual processing (Verhaeghen & Salthouse, 1997). Therefore, we take a closer look at age-related impairments that affect icon identification by limiting visual perception, selective attention, and semantic memory.

Visual perception is the ability to interpret the information and surroundings from the effects of visible light reaching the eye. With age, the accommodative ability of the human eye decreases, and the optical performance of the eye declines progressively (Lindberg, Nasanen & Muller, 2006). Further, visual acuity, which is the ability to see fine details, declines (Fozard, 1990). This reduction in acuity can impede recognition (Higgins, Wood & Tait, 1998), and the reduction in recognition may impede the identification of intricate icons. Additionally, the ability to recognize fragmented and embedded objects decreases with age (Frazier & Hoyer, 1992; Capitani, Della, Lucchelli, Soave, & Spinnler, 1988), which again may be particularly relevant to identifying complex icons.

A further cognitive impairment relevant to icon identification is selective attention, which is the ability to focus on stimuli relevant to the task at hand while disregarding irrelevant stimuli (Glisky, 2007). Older adults have trouble maintaining attention over long periods, especially with tasks requiring continuous scanning attention to relevant information in the presence of distracting information (Vercruyssen, 1996).

The third impairment relevant to icon identification is the reduction in semantic memory. According to structural theories of memory, memory is a cognitive construct that comprises several distinct abilities brought into play in different tasks: short-term memory, working memory, and long-term memory (Hawthorn, 1999). Long-term memory is divided into the following categories: episodic memory, which involves specific events; procedural memory, which involves knowledge of the way in which tasks are carried out; and semantic memory, which involves information about the meaning of components of one's world. Normally, older people experience a strong decline in their ability to process items in short-term memory and working memory and a decline in episodic and procedural memories in contrast to only a mild decline in semantic memory until extreme old age (Howard & Howard, 1996). As we note below, icon identification relies heavily on semantic memory more than other types of long-term memory, but it appears that older adults have problems in using contextual cues when the context is loosely related to the target item (Park, Smith, Morrell, Puglisi, & Dudley, 1990).

In sum, we can expect an age-related decline in visual perception and selective attention, in memory capacity and retention, and in the speed of processing new information, particularly visual information.

2.2 Icons

An icon is a small picture used to depict a physical object, concept, or function. Syntactically, icons comprise one or more graphic elements such as lines, letters, and simple shapes. Interfaces employing icons provide a relatively easier interaction with computerized systems by reducing the perceived system complexity and the user's cognitive load (Goonetilleke, Shih & Fritsch, 2001). Before pointing or clicking on an icon, the user needs to identify the right icon for a particular function. We define icon identification as the process of finding, from a set of icons, the one that represents a specific function, concept, or object. Users should be able to easily identify what the icon represents and what it means in the context in which it is used, which is especially important for people with cognitive impairments that limit their ability to process information (Schroder & Ziefle, 2008).

Table 1. Cognitive Icon Characteristics and their Common Operationalization (Adapted from Ng & Chan, 2008)

Concreteness	the extent to which an icon depicts real objects, materials or people (abstract / concrete)
Familiarity	the frequency with which an icon has been encountered (familiar/unfamiliar)

Table 1. Cognitive Icon Characteristics and their Common Operationalization (Adapted from Ng & Chan, 2008)

Semantic distance	the closeness of relationships between an icon and the function it represents (semantically close/ distant)
Complexity	the amount of detail or intricacy in an icon (simple/complex)

Both physical characteristics, such as font size, and cognitive characteristics, such as the familiarity of the icon, affect icon identification. We focus on cognitive icon characteristics (see Table 1) because their impact on icon identification is substantial in that it accounts for up to 69 percent of the variance seen in performance (Isherwood, McDougall & Curry, 2007). However, as we show in Section 4, the impact of cognitive characteristics on performance can be subtle and complicated.

Extant research has found that concreteness and complexity may affect user performance in different ways and independently of one another (McDougall, Curry & De Bruijn, 2000). At the same time, familiarity, concreteness, and semantic distance are strongly interrelated, whereas icon complexity does not correlate closely with any of the above (Ng & Chan, 2008). Therefore, we concentrate on complexity and one of the three interrelated characteristics; namely, semantic distance. Complexity relates to the *syntax* of the icon (i.e., the number and composition of the elements that make up the icon), while the semantic distance of an icon relates to its *semantics* (i.e., the meaning of the composition of elements). We test the notion that design for older users has to consider both the syntax and semantics of icons as a means of communication between human and computer.

Complexity has two main effects that sometimes conflict. On the one hand, complexity adds detail that can make it easier to identify the icon. For instance, additional detail can make the icon more distinctive (Green & Barnard, 1990), more concrete (Garcia, Badre, & Stasko, 1994), and more similar to known objects and, therefore, easier to retrieve from memory and easier to make sense of (Biederman, 1987; Lloyd-Jones & Luckhurst, 2002; Lloyd-Jones & Nettlemill, 2007). On the other hand, research on complexity has traditionally suggested that it is easier to retrieve and compare simpler icons and easier to locate them in a visual search (Byrne, 1993). More specifically with regard to icons, high complexity may create high cognitive demands that slow down icon identification (Humphreys, Riddoch, & Quinlan, 1988; Ellis & Morrison, 1998; Alario et al., 2004; Schroder & Ziefle, 2008). Intricate icons whose additional detail is difficult to perceive may be particularly demanding. Nevertheless, recent research suggests that the visual complexity of icons has an important role to play in searches but is not directly involved in icon identification (McDougall et al., 2000). We can reasonably assume, therefore, that, when additional detail is needed, it will enhance performance as long as the level of complexity is not too high.

Complexity in communication that increases beyond some point inhibits the speed and quality of information processing in general and during human-computer communication in particular (Katz & Te'eni, 2014). However, at lower levels of complexity, additional details may help to reduce ambiguity and, therefore, reduce processing time and errors. We assume that icons built of one to four elements can safely be categorized in the lower range of complexity (well below the famous magical seven plus minus two limitation that Miller (1956) coined). Therefore, we examine icons that are either simple or detailed but not highly complex (we provide the operational definitions below).

For example, one could represent the action “zoom” with a picture of a magnifying glass. Additional textual detail could be the label “zoom”. Additional graphic detail could be an enlarged part of the background under the magnifying glass, which suggests the function of enlarging and, thereby, reduces ambiguity in regards to what the icon represents (Figure 1). In a sense, the additional detail reduces the semantic distance between the icon and the function “zoom” (Ng & Chan, 2008).

Figure 1. Adding Detail to a Magnifying Glass to Clarify its Function

In this study, we investigate the impact of two cognitive characteristics of icons on performance when using icons as a means of communicating certain functions the user has to invoke. Performance includes both the accuracy and speed of identifying the appropriate icon. The two cognitive characteristics are the icon's level of detail (complexity) and the icon's semantic distance. The former is a matter of syntax and, relatively speaking, is easier to adjust by simply adding detail to an existing icon (e.g., a character). The second characteristic is semantic and may be more difficult to adjust, especially in some cases such as when the function is highly abstract and has no immediate analogy.

The two icon characteristics affect the icon identification process, which comprises two components executed in four steps (see Figure 2):

1. Visual search, which involves active scanning the visual environment for a particular icon (the target) among other icons (the distractors) (step 1 in the figure).
2. Icon recognition and identification, which involves identifying the objects that make up the icon, retrieving a matching representation of the emerging image, and linking it to its corresponding function or name via referential connections that reside in the long-term memory (steps 2-4).

Based on both reviewing icon characteristics and age-related cognitive impairments, using Figure 2, we integrate the two aspects to formulate our hypotheses. According to McDougall et al. (2000), visual complexity determines the speed of visually searching and locating an icon, which is associated with step 1. Semantic distance, which measures the degree to which icons and function labels are related, is an index of the closeness of the referential connections between the semantic information accessed at step 3 and the function label accessed at step 4.

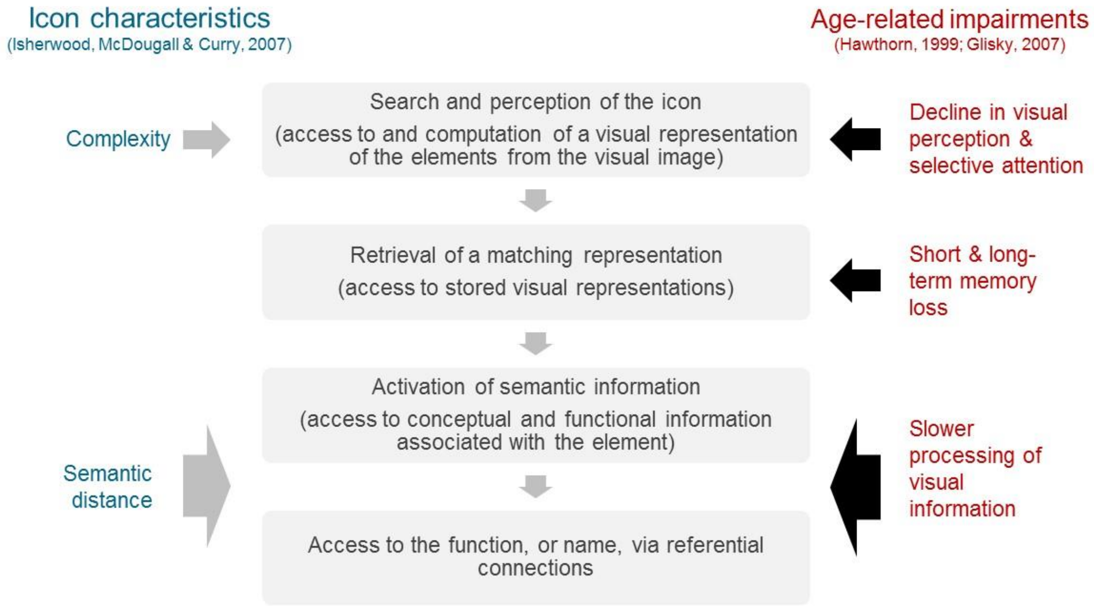


Figure 2. Combining Icon Characteristics and Age-related Constraints

As we note above, because older adults find it hard to identify incomplete objects (Frazier & Hoyer, 1992; Capitani et al, 1988; Higgins et al., 1998), additional detail should help older users identify icons compared with young adults who do not suffer from these impairments.

Hypothesis 1: The positive impact of icons' additional detail on user performance is stronger for older than younger users.

Because older adults have problems using contextual cues when the context is loosely related to the target item (Park et al., 1990), older users will find it more difficult to identify semantic distant icons compared with young adults who do not suffer from this impairment.

Hypothesis 2: The negative impact of icons' semantic distance on user performance is stronger for older than younger users.

Both Hypotheses 1 (syntax) and 2 (semantics) predict stronger impacts for older users (although the impacts are formulated in opposite directions in the hypotheses). When combining the two icon characteristics, which is the normal practice, we must consider two forces. On the one hand, the possible tradeoff between the two impacts may affect the end result. As we note above in reviewing age-related impairments, semantic memory declines mildly and appears forcefully only at extreme old age (Howard & Howard, 1996). On the other hand, the interaction effect between the two cognitive limitations will probably diminish older users' decline in performance even further. We can only conjecture that, when combining the effects of additional detail and semantic distance, the impact of additional detail may outweigh the impact of sematic distance but, at the same time intensify, the overall performance decline of older users versus young users.

Hypothesis 3: The combined syntactic (additional detail) and semantic (semantic distance) impact on user performance is stronger for older than younger users.

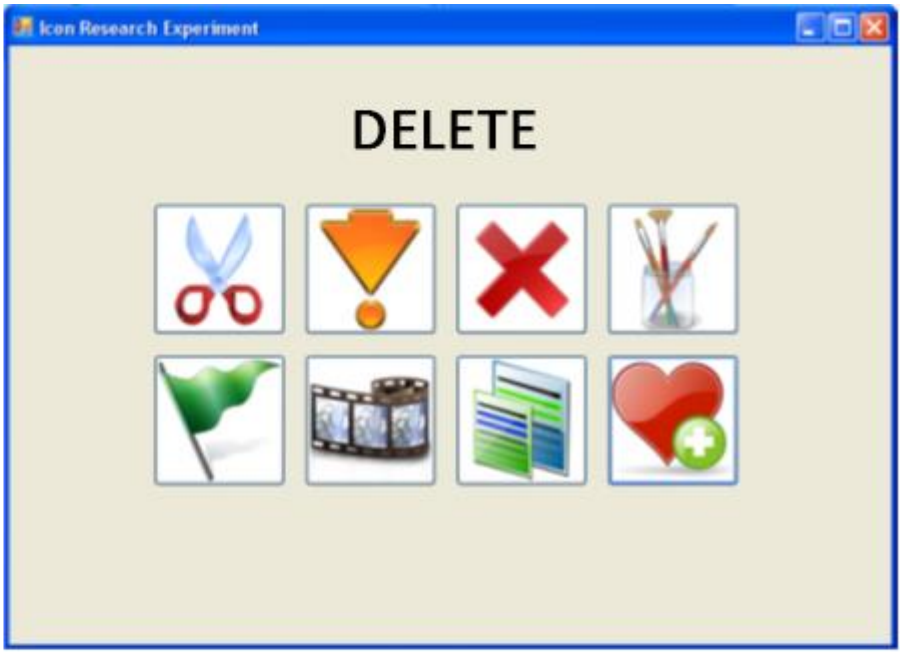
3 Method

We conducted a lab controlled experiment with age as the between group factor and the two icon characteristics as the within-subjects factors. Sixty participants formed two groups of 30 each: 1) normal older adults aged 65 and above and 2) young adults aged 20 to 35 years. All participants had previously used the Internet. The young adults worked or studied, while the older adults were mostly retired or involved in voluntary work. Table 2 lists the variables employed in the experiment.

Table 2. Experimental Design Variables

Variable	Measurement	Data collection
Level of detail	Binary (simple/detailed)—the amount of detail in the icon.	Manipulated within subject
Semantic distance	Binary (close/distant) - the closeness of meaning between icon and function.	Manipulated within subject
Age group	Binary (young/old)—old above 65	Assigned to experimental groups
Performance-time	Continuous—time to complete the task	Automatically recorded and calculated
Performance-accuracy	Continuous—fraction of correct answers	Computed according to answer sheet

The experimental design, apparatus, and procedure followed Isherwood et al. (2007), but we added the age factor as a between-subject factor. The research design was a between-groups repeated measures design: two groups (age group) repeated on icon complexity (two levels) and semantic distance (two levels). We repeated each of the four (2*2) combinations 10 times for a total of 40 tasks; thus, each subject performed 40 tasks. Each task presented the subject with eight icons from which to detect the icon that describes a given function (see Figure 3). The correct icon represented one of the four combinations of characteristics (simple/close, simple/distant, detailed/close, detailed/distant), and the remaining seven icons were distractors. We positioned the icons randomly. The two dependent variables representing performance were time, which was the time to detect and indicate the correct icon, and accuracy, which was binary. Time could be anywhere between 0 and 20 seconds. After 20 seconds, the accuracy was set to zero, and a new display appeared.



DELETE

Figure 3. Eight Icons Presented for the Function “Delete”

3.1 Tool Calibration

We used a pool of 80 icons (4x2, 96x96 pixels each). We selected and evaluated the pool as follows:

3. We collected 165 icons representing known functions that we drew from the Internet and popular software and hand-held devices
4. Fourteen people (seven experts and seven non-experts) rated the icons according to perceived complexity and semantic distance. They used bipolar adjectives on a one to five scale (McDougall, Curry, & De Bruijn, 1999).
5. We formed four groups of ten icons each. Specifically, we used 40 icons of the original 165 icons with the highest and lowest values of complexity and semantic distance. Each of the four groups represented the four possible combinations of complexity and semantic distance. Figure 4 shows an example of each combination: (a) simple/close contains only one element (the red “X”), and it is strongly associated with the function delete; b) simple/distant contains one element (the squared arrow), and it is weakly related to the function “full screen”; c) detailed/close comprises four elements (the envelope, the white note inside the envelope, the yellow letter, and Earth) and, together, closely relate to “send email”; d) detailed/distant comprises three elements (Earth, the circle in the center, and the power plug embedded in the circle), all of which do not immediately depict “Internet connection”.
6. We conducted a series of one-way analyses of variance (ANOVAs) followed by Tukey's honest significant difference (HSD) with alpha .01 to ensure that ratings differed in accordance with the requirements of each experimental condition. Table 3 summarizes these analyses and shows that complexity and semantic distance were orthogonally varied in this experiment: simple semantic and simple non-semantic icons indeed had higher complexity ratings than detailed semantic or detailed non-semantic icons. Similarly, simple semantic and detailed semantic icons had higher semantic distance ratings than simple non-semantic and detailed non-semantic icons.
7. We selected a set of 40 icons from the same sources mentioned above to serve as distractors in the experiment. The complexity level of each distractor icon was medium (not too detailed), which helped to minimize the effect of the distractors’ complexity on identifying the target icon. In addition, the selected distractor icons had no resemblance in terms of meaning and visual similarity to any of the target icons.

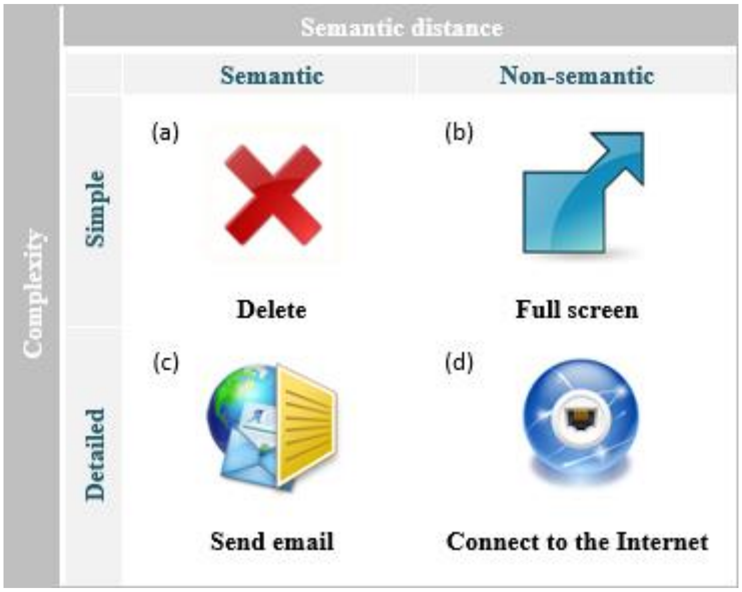


Figure 4. Examples of the Four Different Types of Icons: a) Simple and Close b) Simple and Distant, c) Detailed and Close, and d) Detailed and Distant

Table 3. Mean Ratings and Standard Deviations for Icon Characteristics in Each Experimental Condition

	Simple/ close	Simple/ distant	Detailed/ close	Detailed/ distant	F* Tukey
Perceived complexity	1.94 (.41)	1.63 (.35)	3.82 (.26)	3.81 (.32)	121.79 [1]
Perceived semantic distance	1.86 (.34)	4.12 (.29)	2.13 (.33)	3.95 (.37)	117.69 [2]

Note: SC = simple and close, SD = simple and distant, DC = detailed and close, DD = detailed and distant.
* $p < 0.001$
[1] Simple/close, simple/distant < detailed/close, detailed/distant
[2] Simple/close, detailed/close < simple/distant, detailed/distant

3.2 Experimental Procedure

As we note in Section 3, with our experiment, we sought to identify one of the eight icons that best represented a particular function. Each participant performed 40 such tasks in random order in less than ten minutes. Participants had to mouse click as quickly and accurately as possible on the correct icon. They had 20 seconds to respond in each experimental trial before being shown a new function and set of icons. We counted a non-response as an error. Before the experiment, we held a demonstration session using icons not part of the experimental task, which we did to verify that the subjects understood what they were required to do.

Computer software specifically developed for experimental purposes controlled the presentation of the icons and recorded the participants' responses. Participants responded using a mouse set to a default (medium) tracking speed. An LCD 17-inch (43.2cm) monitor, which was set to a resolution of 800 by 600 pixels, displayed the arrays of eight icons

4 Results

Table 4 reports the performance, response time (measured in seconds), and accuracy (a fraction of correct answers) across icon complexity (simple or detailed), semantic distance (close or distant), and age group (young adults or older adults).

Table 4. Descriptive Statistics on Time and Accuracy across Task, Semantic Distance, and Age Group

		Young		Old	
		Time	**Accuracy**	**Time**	**Accuracy**
Simple	**Distant**	7.565 (1.912)	0.817 (.095)	9.781 (2.425)	0.483 (.149)
	Close	3.988 (1.506)	0.940 (.077)	8.429 (2.506)	0.670 (.121)
Detailed	**Distant**	6.082 (2.482)	0.900 (.105)	7.859 (1.965)	0.817 (.129)
	Close	4.065 (2.047)	0.967 (.007)	7.384 (1.808)	0.767 (.154)
Average		5.42	0.907	8.36	0.684

For both performance measures, young users scored significantly better than the old users. It took 5.42 seconds on the average for young adults to identify an icon versus. 8.36 seconds on average for older adults. Moreover, young adults correctly identified 90.7 percent of the cases compared with older users who correctly identified only 68.4 percent of cases.

Table 5 shows the percentage of answers that are correct or incorrect and classified as fast (under 9 seconds) or slow (over 9 seconds). The time limit was 20 seconds, which automatically set the answer to incorrect. The median time to identify a correct answer was 6.33 seconds for the older adults and 3.86 seconds for young adults. We used the Mann-Whitney U-test to compare performance measures between older and younger adults. In regards to differences in accuracy, the Z-score was -5.9064, significant at $p \leq 0.01$ (the U-value was 50). For differences in time, the Z-score was 4.8123, significant at $p \leq 0.01$ (the U-value was 50).

Table 5. Distribution of Correct and Incorrect, Fast and Slow Answers according to Age Group

	Old	**Young**
Correct under 9 sec.	51%	81%
Correct over 9 sec.	18%	10%
Incorrect under 9 sec.	14%	4%
Incorrect over 9 sec.	13%	3%
Reached time limit 20 sec.	4%	2%

Figure 5 depicts the means of Table 4 graphically to highlight the relative effects on performance produced by level of detail and semantic distance according age group. For both young and older adults, detailed icons increased accuracy for both semantically close and distant icons. However, young adults differed from older adults with regard to response time. For older adults, detailed icons reduced response time for both semantically close and distant icons. In contrast, for young adults, the level of detail interacted with semantic distance; that is, detailed icons reduced response time only when the icons were semantically distant but not when they were semantically close. As Hypothesis 1 hypothesizes, the average decrease in response time due to higher detail was stronger for older adults (around 19% decrease) versus young adults (around 14 % decrease). In contrast, the effect of semantic distance on performance was not stronger for older adults as Hypothesis 2 hypothesizes because of the interaction between level of detail and semantic distance for young adults described above with respect to time (not accuracy). We discuss this finding in greater detail in Section 5.

With respect to accuracy, the effects of both level of detail and semantic distance were stronger for older adults. However, the average effect of semantic distance for older adults was only slightly stronger than that for young adults (around 11% vs. 10%, respectively). The average effect of additional detail for older adults was noticeably stronger than that for young adults (43% vs. 6%, respectively). Here, too, there was an interaction effect, but, this time, it was for the older adults for whom additional detail was of paramount importance. Without additional detail, older adults plummeted to 48 percent accuracy when semantic distance was high. We discuss this finding in greater detail in Section 5.

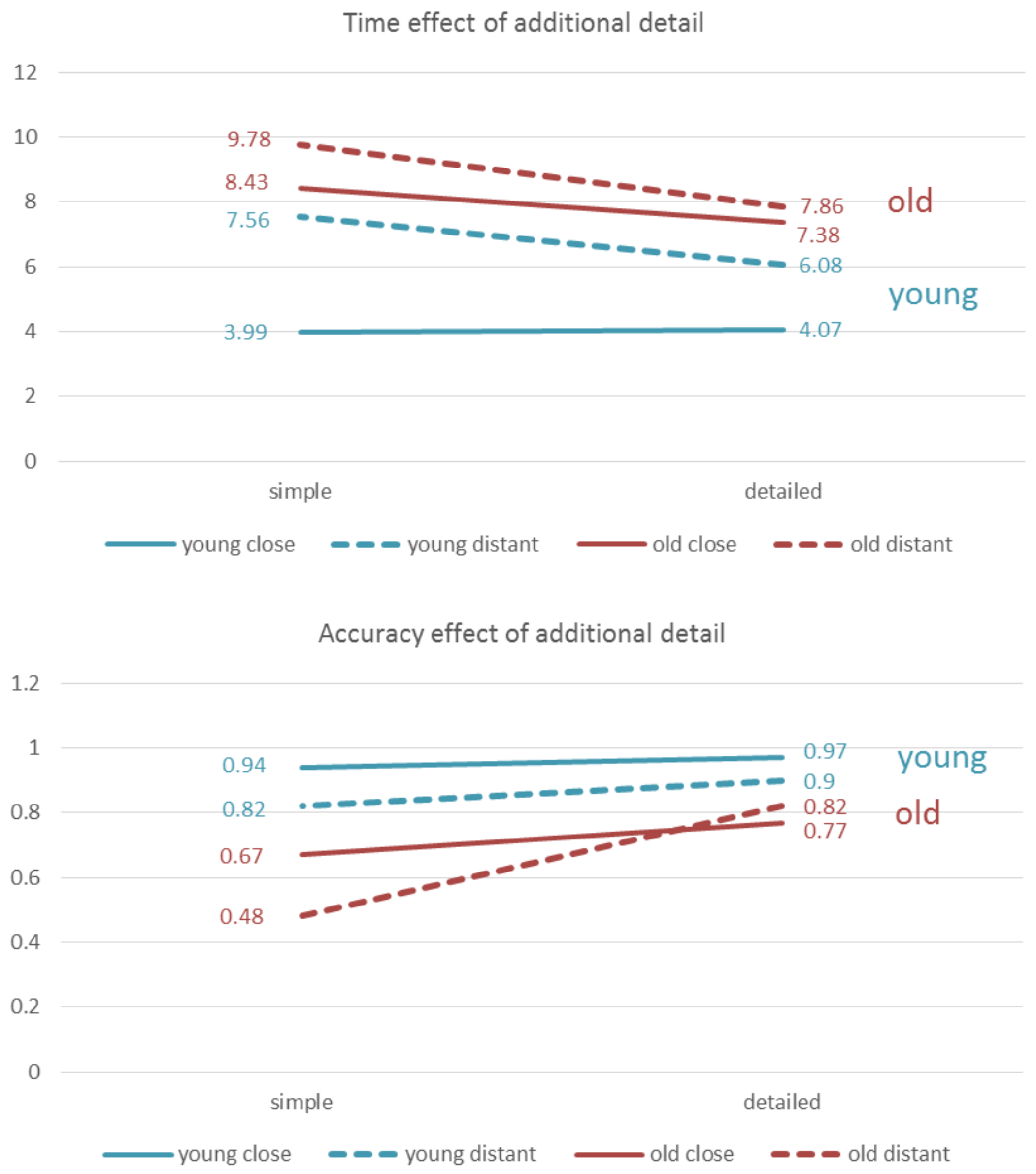


Figure 5. Chart Showing Means for Time and Accuracy According to Age Group, Level of Detail and Semantic Distance

Statistical analysis supports the visual impressions above. We first performed two separate repeated-measures analysis of variance (ANOVA) for response time and accuracy. Response time was affected by level of detail (Wilks' lambda $F_{1,58} = 47.273$, $p < 0.001$), semantic distance (Wilks' lambda $F_{1,58} = 158.04$, $p < 0.001$), and age group ($F_{1,58} = 38.23$, $p < 0.001$). We also found support for our claims that age group interacts with level of detail (Wilks' lambda $F_{1,58} = 6.02$, $p < 0.001$) (which supports H1) and with semantic distance (Wilks' lambda $F_{1,58} = 40.72$, $p < 0.001$) (which supports H2). Additionally we found a significant interaction between level of detail and semantic distance (Wilks' lambda $F_{1,58} = 15.8$, $p < 0.017$).

Similarly, we found significant main effects on accuracy for level of detail (Wilks' lambda $F_{1,58} = 132.82$, $p < 0.001$), semantic distance (Wilks' lambda $F_{1,58} = 50$, $p < 0.001$), and age group ($F_{1,58} = 106.15$, $p < 0.001$). In addition, we found the following interactions to be statistically significant: age group with level of detail (Wilks' lambda $F_{1,58} = 46.64$, $p < 0.001$), level of detail with semantic distance (Wilks' lambda $F_{1,58} = 33.37$, $p < 0.001$), and a triple interaction between level of detail, semantic distance, and age group (Wilks' lambda $F_{1,58} = 12.56$, $p < 0.001$). In contrast, we found no significant interaction between semantic distance and age group.

We also ran a mixed-model analysis (McCulloch, Searle, & Neuhaus, 2008) for performance time as a function of accuracy, age group, semantic distance, complexity, and all of their combinations as factors (researchers do not recommend MANOVA for the combination of a continuous time variable and a binomial accuracy variable).

The results (see Table 6) reiterate the significant effects of semantic distance and level of detail on time and the significant interaction of age group with semantic distance (significant effect of 1.62). However, we found no significant interaction of age group with level of detail due to the opposing effects of additional detail under low or high semantic distance as we explain above. Examining the relationship between time and accuracy shows that they were negatively related (a value of -4.40), which we expected, but distorted the meaning of the correlation when ignoring the interaction with age group. Moreover, for responses of 20 seconds (the time limit), the relationship was meaningless because the answer was automatically set to be incorrect.

The expectation of a tradeoff between speed and accuracy did not appear to hold in our case. Researchers have previously discussed the dilemma of how to examine time and accuracy simultaneously: some have suggested that tradeoffs between the two variables will probably differ when response times are very short and that one can reasonably use an integrated measure such as an inverse efficiency score (Rach, Diederich, & Colonius, 2011). Table 7 shows the integrated measure as time over accuracy calculated for the 10 tasks pertaining to each of the four combinations of level of detail and semantic distance. The results are consistent with the message of Table 4, which shows the effects on time and accuracy separately. Again, combining semantically distant and syntactically simple icons shows poorer performance for the young and a devastating performance for the older adults. Adding detail to the icon boosts performance. We also calculated the correlation between the time and accuracy for all the subjects in the same age group (correlations appear in parenthesis). Clearly, correlations differed between older and younger adults, but they also differed between treatments so that, for the more challenging combinations, performance fell on both time and accuracy dimensions simultaneously (particularly for the older adults).

Table 6. Mixed Model for Performance Time: Estimated Values for All Factors

Parameter	Estimate	Std. Error	df	t	Sig.
Intercept	11.01	.482	265.71	22.850	.000
Age group	.51	.594	157.47	.866	.388
Detail	-.88	.417	2336.47	-2.120	.034
Semantic distance	-2.45	.413	2335.43	-5.946	.000
Accuracy	-4.40	.389	2342.68	-11.317	.000
Age group * detail	-.29	.295	2331.88	-.989	.323
Age group * semantic distance	1.62	.296	2332.05	5.477	.000
Age group * accuracy	1.10	.424	2347.78	2.593	.010
Detail * semantic distance	.72	.285	2331.32	2.525	.012
Detail * accuracy	.07	.382	2338.56	.185	.853
Semantic distance * accuracy	-.30	.383	2337.10	-.787	.431

Table 7. Combined Measure of Performance and Correlations Between Time and Accuracy

		Young	Old
		Time/accuracy	**Time/accuracy**
Simple	**Distant**	0.95 / -0.01)	4.37 / -0.73)
	Close	0.66 / -0.01)	1.53 / 0.12)
Detailed	**Distant**	0.48 / -0.28)	1.34 / -0.66)
	Close	0.45 / -0.15)	1.13 / -0.62)

5 Discussion

5.1 Making Sense of the Findings

We investigated the impact of adapting the human-computer interface and, more specifically, icons to older adults. To this end, we tested users' performance in identifying icons as a function of the interaction between age and two characteristics of icons; namely, level of detail and semantic distance. Our findings on the main effects of age were in line with previous research on human-computer interaction in general and on icons in particular (Isherwood et al., 2007). Indeed, we found that the median performance time was 6.33 seconds for older adults and 3.86 seconds for young adults—the latter being in the range found previously for populations of young adults (Isherwood et al., 2007).

We also expected the main effects of level of detail and semantic distance. First, additional detail enhanced performance, particularly in more challenging situations. Indeed, previous research has shown that additional detail can remove ambiguity without increasing complexity to the extent that it inhibits information processing (e.g., Lloyd-Jones & Nettlemill, 2007). Second, greater semantic distance diminished performance, which, again, follows extant research (e.g., Bates et al., 2003; Isherwood, McDougall & Curry, 2007).

Table 8. Results

Hypotheses	Overall	Findings
H1: The positive impact of additional detail on user performance is stronger for older than younger users.	Supported	Response time decreased 19% for older adults versus 14% for young adults. Accuracy decreased 43% for older adults versus 6% for young adults. For high semantic distance, accuracy dropped to 48% for older users in the absence of additional detail.
H2: The negative impact of semantic distance on user performance is stronger for older than younger users.	Partially supported	The overall decline in response time due to semantic distance was not significantly stronger for older adults. Young adults slowed down 89% (from 3.99 to 7.57 seconds), while older users, starting out very slowly, slowed down a further 16% (from 8.43 to 9.78 seconds). For accuracy, the negative effect of semantic distance for older adults was slightly stronger than that for young adults (10% versus 11%, respectively).
H3: The combined syntactic and semantic impact on user performance is stronger for older than younger users.	Supported	Comparing extreme cases (close with additional detail versus distant without detail), combined performance differences were 1.13 versus 4.37 (387%) for older users and 0.45 versus 0.95 (211%) for young users.

Not all went according to plan for the interaction of semantic distance with age group. Table 8 summarizes the results by hypothesis. We hypothesized that the positive impact of icons' additional detail (H1) and the negative impact of icons' semantic distance (2) on user performance is stronger for older rather than younger users. Overall, our results confirmed the hypotheses except for the unexpected impact; namely, the impact of semantic distance on the young adults' response time. Indeed, to make sense of the results, we separately analyzed the impacts on the two measures of performance (time and accuracy) by examining two extreme conditions. The average response time of young adults identifying simple icons increased by almost 90 percent when comparing their performance with semantically close versus semantically distant icons (from 3.99 to 7.57 seconds). This increase was much steeper than the increase for older adults (from 8.43 to 9.78 seconds), even though the final performance of the younger was still better than the older. For the older adults, semantic distance required even more effort to fulfil an already demanding task. The young adults shifted from a relatively undemanding task to one that required attention and effort and from a task that was quite automatic to one that was highly controlled. The older adults' cognitive impairment required that they engage in slower and controlled behavior rather than automatic behavior even for simple icons. Thus, we cannot see in older adults the shift between automatic and controlled behavior that we see in younger adults.

A second revealing (albeit expected) condition was the impact of additional data on accuracy. Additional detail to semantically distant icons increased older adults' average accuracy by 69 percent (from 48% to 82% accurate), which was much steeper than the increase for younger adults (from 82% to 90%). Older adults started out with a condition that was too difficult for them (icons that were both simple and semantically distant), and the additional detail made it manageable. Table 7 shows the same message via the combined measure of time and accuracy: the 4.37 value for old users suggests a different class of difficulty from all other conditions.

The combined effect of additional detail and semantic distance on performance was stronger for older users (H3). Looking at the combined measure of time and accuracy (see Table 7), the difference in performance between extreme cases for older users was almost twice the difference for young users.

5.2 Practical Implications

We examined two icon design variables: level of detail and semantic distance. The first is the number of components that comprise an icon, which is a syntax issue that has a bearing on semantics. The second is the closeness of an icon's perceived meaning and the function it represents, which is a semantic issue. Level of detail is easier to adapt without changing the original icon dramatically. One may easily supplement Figure 1 with the enlarged text in the background without changing the picture of the well-known magnifying glass. However, one cannot so easily change semantic distance. In fact, semantic distance is often high because of the inherent difficulty in representing graphically certain concepts (e.g., using a "still" picture to show a certain movement or using a picture to show an abstract concept such as "morality").

Our findings suggest that additional detail play an important role in enhancing performance, especially for older adults. Moreover, additional detail may be essential when semantic distance is high because, without additional detail, older adults may not be able to perform satisfactorily. This practical conclusion agrees with the more general idea that adding contextual information in communication is beneficial only when semantic distance creates the need for the additional detail (Katz & Te'eni, 2014). Moreover, as the old users become more acquainted with the icons, it might make sense to reduce the detail because it will no longer be necessary. However, interface adaptation as experience grows is contentious, especially for older users. Generally, users prefer consistent interfaces even when they perform poorer (Te'eni & Feldman, 2001). Age-related limitations on memory may cause older users to value consistency even more. It may be that, for the old, old habits die harder. We certainly need more research to determine whether interfaces designed for older users should evolve over time. Given our growing technical ability to adapt interfaces to particular users under specific conditions, the temptation to do so grows, too. Therefore, we need future research on setting the design goals of adapting for older users but also on the costs and benefits of adaptation over time.

In this paper, we concentrate on the impact of icons' design on older users. Our findings demonstrate the important impact of level of detail and semantic distance on user performance. Age-related cognitive impairment affects many other aspects of the human-computer interaction: not only cognitive aspects but also physiological and affective aspects. For instance, the difficulties that older users encounter with small smart phones is a growing area of research (Harada, Sato, Takagi, & Asakawa, 2013). Another area in particular that has gained attention is the need to consider older adults' special social needs and capabilities. Furthermore, other aspects of human computer interaction, such as affective and social aspects, seem to be particularly relevant to older users of ubiquitous information technologies (Holtzman et al., 2004). It seems that designing for older users will become an important area of human-computer interaction (Vines et al., 2015).

References

Alario, F.-X., Ferrand, L., Laganaro, M., New, B., Frauenfelder, U. H., & Segui, J. (2004). Predictors of picture naming speed. Behavior Research Methods, Instruments, & Computers, 36, 140-155.

Arazy, O., Nov, O., & Kumar, N. (2015). Personalityzation: UI personalization, theoretical grounding in HCI and design research. *AIS Transactions on Human-Computer Interaction, 7*(2), 43-69.

Bates, E., D'Amico, S., Jacobsen, T., Székely, A., Andonova, E., Devescovi, A., Herron, D., Lu, C. C., Pechmann, T., Pleh, C., Wicha, N., Federmeier, K., Gerdjikova, I., Gutierrez, G., Hung, D., Hsu, J., Iyer, G., Kohnert, K., Mehotcheva, T., Orozco-Figueroa, A., Tzeng, A., & Tzeng, O. (2003). Timed picture naming in seven languages. *Psychonomic Bulletin & Review*, *10*(2), 344-380.

Biederman, I. (1987). Recognition-by-components: A theory of human image understanding. *Psychological Review*, *94*, 115-147.

Byrne, M. D. (1993). Using icons to find documents: Simplicity is critical. Proceedings of INTERCHI '93 (pp. 446-453). New York: ACM Press.

Capitani, E., Della, S. S., Lucchelli, F., Soave, P., & Spinnler, H. (1988). Perceptual attention in aging and dementia measured by Gottschaldt's hidden figures test. *Journal of Gerontology: Psychological Sciences*, *43*, 157-163.

Engle, R. W. (2002). Working memory capacity as executive attention. *Current Directions in Psychological Science*, *11*(1), 19-23.

Ellis, A. W., & Morrison, C. M. (1998). Real age-of-acquisition effects in lexical retrieval. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *24*, 515-523.

Fozard, J. L. (1990). Vision and hearing in aging. In J. E. Birren, R. B. Sloane, & G. D. Cohen (Eds.), *Handbook of mental health and aging* (pp. 150-170). San Diego, CA: Academic Press.

Frazier, L., & Hoyer, W. J. (1992). Object recognition by component features. *Experimental Aging Research*, *18*, 9-15.

Garcia, M., Badre, A. N., & Stasko, I. T. (1994). Development and validation of icons varying in their abstractness. *Interacting with Computers, 6*(2), 191-212.

Gatsou, C., Politis, A., & Zevgolis, D. (2012). The importance of mobile interface icons on user interaction. *International Journal of Computer Science and Applications*, *9*(7), 92-107.

Glisky, E. L. (2007). Changes in cognitive function in human aging. In D. R. Riddle (Ed.), Brain aging: Models, methods and mechanisms (pp. 3-20). Boca Raton, FL: CRC Press.

Goonetilleke, R. S., Shih, H. M., On, H. K., & Fritsch, J. (2001). Effects of training and representational characteristics in icon design. International *Journal of Human-Computer Studies, 55*, 741-760.

Green, A., & Barnard, P. (1990). Graphical and iconic interfacing: The role of icon distinctiveness and fixed or variable screen locations. In D. Diaper, D. Gilmore, G. Cockton, & B. Shackel (Eds.), *INTERACT '90 Proceedings of the IFIP TC13 Third International Conference on Human-Computer Interaction* (pp. 457–462). Oxford, UK: North Holland/Elsevier Science & Technology.

Harada, S., Sato, D., Takagi, H., & Asakawa, C. (2013). Characteristics of elderly user behavior on mobile multi-touch devices. *Human-Computer Interaction—INTERACT 2013* (pp. 323-341). Berlin, Heidelberg: Springer.

Hawthorn, D. (1999). Possible implications of aging for interface design. *Interacting with Computers, 12*(5), 507-528.

Higgins, K., Wood, J., & Tait, A. (1998). Vision and driving: Selective effect of optical blur on different driving tasks. *Human Factors, 40*(2), 224-232.

Holtzman, R. E., Rebok, G. W., Saczynski, J. S., Kouzis, A. C., Doyle, K. W., & Eaton, W. W. (2004). Social network characteristics and cognition in middle-aged and older adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *59*(6), P278-P284.

Howard, J. H., & Howard, D. V. (1996). Learning and memory. In A. D. Fisk & W. A. Rogers (Eds.), *Handbook of human factors and the older adult*. New York: Academic Press.

Humphreys, G. W., Riddoch, M. J., & Quinlan, P. T. (1988). Cascade processes in picture identification. *Cognitive Neuropsychology*, *5*, 67-104.

Isherwood, S. J., McDougall, S. J. P., Curry, M. B. (2007). Icon identification in context: The changing role of icon characteristics with user experience. *Human Factors, 49*(3), 465-476.

Katz, A. & Te'eni, D. (2014). The role of communication complexity in adaptive contextualization. *IEEE Transactions on Professional Communicatio*n, *57*(2), 98-112.

Lindberg, T., Nasanen, R., & Muller, K. (2006). How age affects the speed of perception of computer icons. *Displays*, *27*(4-5), 170-177.

Lloyd-Jones, T. J., & Luckhurst, L. (2002). Effects of plane rotation, task, and complexity on recognition of familiar and chimeric objects. *Memory & Cognition*, *30*(4), 499-510.

Lloyd-Jones, T. J., & Nettlemill, M. (2007). Sources of error in picture naming under time pressure. *Memory & Cognition*, *35*(4)*,* 816-836.

McCulloch, C. E., Searle, S. R., & Neuhaus, J. M. (2008). *Generalized, linear, and mixed models* (2nd ed.). New York: Wiley.

McDougall, S. J. P., Curry, M. B., & De Bruijn, O. (1999). Measuring symbol and icon characteristics: Norms for concreteness, complexity, meaningfulness, familiarity and semantic distance for 239 symbols. *Behavior Research Methods, Instruments and Computers*, *31*(3), 487-519.

McDougall, S. J. P., Curry, M. B., & De Bruijn, O. (2000). Exploring the effects of icon characteristics on user performance: The role of icon concreteness, complexity, and distinctiveness. *Journal of Experimental Psychology: Applied*, *6*(4), 291-306.

Miller, G. A. (1956). The magical number seven, plus or minus two: some limits on our capacity for processing information. *Psychological Review, 63*(2), 81-97.

Ng, A., & Chan, A. (2008). Visual and cognitive features on icon effectiveness. In *Proceedings of the International Multi Conference of Engineers and Computer Scientists* (Vol. II, pp. 19-21).

Pak, R., Czaja, S. J., Sharit, J., Rogers, W. A., Fisk, A. D. (2006). The role of spatial abilities and age in performance in an auditory computer navigation task. *Computer Human Behavior*, *24*(6), 3045-3051.

Park, D. C., Smith, A. D., Morrell, R. W., Puglisi, J. T., & Dudley, W. N. (1990). Effects of contextual integration on recall of pictures by older adults. *Journal of Gerontology: Psychological Sciences, 45*, 52-57.

Rach, S., Diederich, A., Colonius. H. (2011). On quantifying multisensory interaction effects in reaction time and detection rate. *Psychological Research, 75*(2), 77-94.

Salthouse, T. (2012). Consequences of age-related cognitive declines. *Annual Review of Psychology, 63,* 201-226.

Schroder, S., & Ziefle, M. (2008). Effects of icon concreteness and complexity on semantic transparency: Younger vs. old users. In K. Miesenberger, J. Klaus, W. Zagler, & A. Karshmer (Eds.), *Computers helping people with special needs, Lecture notes in computer science volume 5105* (pp 90-97). Berlin, Heidelberg: Springer.

Te'eni D., & Feldman R. (2001). Performance and satisfaction in adaptive websites: A laboratory experiment on search tasks within a task-adapted website. *Journal of the Association for Information Systems, 2*(3), 1-28

Vercruyssen, M. (1996). Movement control and the speed of behavior. In A. D. Fisk, & W. A. Rogers (Eds.), *Handbook of human factors and the older adult.* San Diego, CA: Academic Press.

Verhaeghen, P., & Cerella, J. (2002). Aging, executive control, and attention: A review of meta-analyses. *Neuroscience and Biobehavioral Reviews*, *26*, 849-857.

Verhaeghen, P., & Salthouse, T. A. (1997). Meta-analyses of age-cognition relations in adulthood: Estimates of linear and non-linear effects and structured models. *Psychological Bulletin*, *122*, 231-249.

Vines, J., Pritchard, G., Wright, P., Olivier, P., & Brittain, K. (2015). An age-old problem: Examining the discourses of ageing in HCI and strategies for future research. *ACM Transactions on Computer-Human Interaction*, *22*(1).

Wagner, N., Hassanein, K., & Head, M. (2014). The impact of age on website usability. *Computers in Human Behavior*, *37,* 270-282.

Wingfield, A., Stine, E. A. L, Lahar, C. J., & Aberdeen, J. S. (1988). Does the capacity of working memory change with age? *Experimental Aging Research*, *14*(2), 103-107.

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