The impact of age on website usability

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A B S T R A C T

As the general and working populations age in most developed nations, the study of website usability for older adults is becoming increasingly relevant. Website usability is concerned with both utilitarian (i.e. functional) and hedonic (i.e. pleasure-related) aspects. A new website usability model is proposed that considers the effects of age on website usability through cognitive antecedents that are most relevant to age-related effects. Specifically, spatial ability is the declining cognitive skill of particular interest in this research. A laboratory experiment was conducted where younger and older participants interacted with an experimental website. The results suggest that age has a pronounced impact on performance as a mediated effect through declining levels spatial ability and mental model accuracy as well as through a direct effect suggesting the presence of other objective and subjective changes associated with aging that could impact performance. Perceived disorientation was also examined within the proposed website usability model, revealing both expected and surprising findings.

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1. Introduction

The population of most of the world's developed nations are experiencing an increase in average age (OECD, 2006). A similar trend has been observed among users of computers and the Internet with older adults now making up the fastest growing consumer segment of Internet users (Chevalier & Rossetti, 2010; Stevens, 2010). As older adults remain in the workforce longer (Mitzner et al., 2010), many are using computers and the Internet on a daily basis to do their jobs (Nord, McCubbins, & Nord, 2006). Thus, as the Internet is becoming an increasingly integral part of the lives of older adults, the study of Internet usability by older adults is becoming an increasingly relevant field of study.

Usability has been recognized as an important aspect in the study of online behaviors in Information Systems (IS) and Human Computer Interaction (HCI) literature (Venkatesh & Agarwal, 2006). For individuals, usability has been associated with important outcomes such as error reduction and positive attitudes (Venkatesh & Agarwal, 2006), and has been shown to increase users' intentions to use computers as well as subsequent usage behavior (Legris, Ingham, & Collerette, 2003; McCloskey, 2006; Venkatesh, Morris, Davis, & Davis, 2003). Usability also has many important impacts

for organizations such as improved job performance, higher productivity and reduced costs (DeLone & McLean, 2003).

To date, a considerable amount of effort has been dedicated to exploring website usability issues for older adults and a number of guidelines have been developed (Morrell et al., 2003; Zaphiris, Kurniqwan, & Ghiawadawala, 2007). While some of these guidelines are very specific (i.e. font size, typeface, colors, etc.), the recommendations for other aspects, such as navigation systems, site topologies, and accommodation of changes in cognitive abilities, are much vaguer. Further, many of these guidelines are based on extrapolations from the study of older users using offline applications, as well as general research on aging, as opposed to empirical studies using websites. In addition, most of the guidelines are focused on functional or utilitarian (functional) aspects of website usability and fail to consider a holistic approach that incorporates hedonic (pleasure-related) aspects. This lack of empirical testing creates many opportunities for future research in the area of website usability for older users. To help fill this gap, we seek to answer the following research question: How does age impact website usability? More specifically, how do declining cognitive skills associated with aging impact website usability? In this study, spatial ability is the declining cognitive skill of particular interest.

The remainder of this paper proceeds as follows: the theoretical background for the research is presented; the research model and hypothesis development are discussed; the research methodology is described; the results of the experiment are presented; and finally, the results are discussed and conclusions drawn.

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2. Theoretical background and research model

2.1. Usability

Although usability is a key concept of HCI research (Hornbaek, 2006), its application in the IS literature has been limited to date (Venkatesh & Ramesh, 2006). More recently, usability is gaining traction in IS as researchers realize its potential to bring new perspectives to IS research (Tung, Xu, & Tan, 2009). For example, in a study of websites Venkatesh and Ramesh (2006) found that the usability theoretical lens outperformed the popular Technology Acceptance Model (TAM) in terms of richness and variance explained in a website study.

Although usability has been defined in a variety of ways in numerous contexts (Tung et al., 2009), the definition developed by the International Standards Organization (ISO) is most often adopted. The ISO defines usability as the "effectiveness, efficiency, and satisfaction with which specified users can achieve goals in particular environments" (ISO, 1998, p. 2). In practice, effectiveness and efficiency are often referred to collectively as performance (Coursaris & Kim, 2011). These definitions have previously been applied in IS research when examining technology artifacts and experiences through an HCI or usability lens (Agarwal & Venkatesh, 2002; Venkatesh & Agarwal, 2006). As such, we employ this popular definition in this research: *usability is the performance achieved and satisfaction experienced by system users*.

Usability is a multifaceted concept in that it considers both the utilitarian and hedonic dimensions of a system. Utilitarian dimensions are concerned with function, are goal directed and performance based (Childers, Carr, Peck, & Carson, 2001; Kim, Malhotra, & Narasimhan, 2005). Utilitarian dimensions may be measured through perceived assessments of the system (e.g. perceived usefulness) or objective measures resulting from system use (e.g. task timing). Hedonic dimensions, on the other hand, are concerned with entertainment, enjoyment, and fun (Davis, Bagozzi, & Warshaw, 1992; Kim et al., 2005), and are measured solely through perceived scales (e.g. perceived satisfaction). Hedonic dimensions are more subjective and personal than utilitarian dimensions (Babin, Darden, & Griffin, 1994), referring to a personal assessment of self and evoked through the experience. Although a system as a whole may be categorized as utilitarian (e.g. a productivity application) or hedonic (e.g. a game) in nature, the use of any system will result in both utilitarian and hedonic assessments of usability.

In the ISO definition of usability provided above, utilitarian and hedonic aspects are considered through performance and satisfaction respectively. Hence, in order to have a complete picture of the usability of a website, both utilitarian and perceived hedonic assessments should be considered (Agarwal & Venkatesh, 2002; Hornbaek, 2006). Historically, usability evaluation has primarily concerned itself with performance-based measures of usability (Hornbaek, 2006; Otter & Johnson, 2000). More recently, however, researchers have emphasized the importance of bringing more focus to the hedonic considerations (O'Brien and Toms, 2008). Both utilitarian and hedonic benefits are important drivers of technology use (Venkatesh, Thong, & Xu, 2012) and the effect of hedonic dimensions should not be underestimated (Zhang & Li, 2005).

2.2. Usability for older adults

Age, as defined by a person's chronological or calendar age, is a frequently studied individual difference in many disciplines, including IS. Although the study of age seems a logical and straightforward topic on the surface, it is in fact quite complex. Aging is not a homogeneous process, and thus individuals at the same chronological age may differ in any number of ways. Despite this fact, extant research

in IS and many other disciplines use chronological age (Carstensen & Turk-Charles, 1994). Some researchers have suggested that this is an oversimplification and, therefore, a limitation of the study of age differences (Morris & Venkatesh, 2000). Kooij, deLange, Jansen, and Dikkers (2008) discuss five conceptualizations of age that take a variety of factors into consideration: chronological or calendar age; functional or performance-based age; subjective or psychosocial age; organizational age; and the life span concept of age. In the present research, chronological age is used in the main research model for consistency with existing literature. Other conceptualizations, however, may be relevant in the context of website use and therefore were collected to enable exploratory analysis of the findings. Specifically, there is some evidence to suggest that functional age (related to health status) may impact a user's performance, and subjective age (how old someone feels) may influence feelings about a website. Therefore these two conceptualizations were collected for post hoc analysis in addition to the collection chronological age for inclusion in the research model.

A long line of research exists that examines changes among individuals based on chronological age (Morris & Venkatesh, 2000). Extant literature shows that such changes can be both subjective and objective in nature (Mroczek & Kolarz, 1998). Subjective changes are typically psychosocial in nature and refer to systemic changes in personality, needs, expectations, behavior and perspectives (Rhodes, 1983). For example, researchers have suggested that subjective well-being may improve with age (Carstensen, 1995; Carstensen & Turk-Charles, 1994). Older people see the future as being more bounded, which may cause them to gear their lives toward maximizing positive and minimizing negative affect (Mroczek & Kolarz, 1998). Gibson and Klein (1970) indicate the positive correlation between age and overall life satisfaction can be due to changing needs, a mellowing process, and changing cognitive structures associated with age. These changes in personality, needs, expectations, behavior and perspectives may impact perceptions of computer experiences and interface usability.

From an objective point of view, scientists have reported various physical and cognitive changes associated with the natural biological aging process. Such changes have implications for the usability of computer interfaces. For example, physical changes associated with aging include declines in vision, hearing, and psychomotor coordination (Höök, Dahlbäck, & Sjölinder, 1996). Thus, interfaces will be more usable for older users if they make use of features like larger fonts, sounds within certain frequency ranges, and layouts that require less precise mouse movement. Similarly, cognitive changes such as reduced attention span, declines in memory, and changes in spatial abilities create a need for interfaces that have fewer distractions, provide memory cues, and are simple to learn and understand (Höök et al., 1996).

Spatial ability is one aspect of cognitive ability that is known to decline with age (Salthouse, 1982). It refers to an individual's ability to conceptualize relationships between objects in space as well as awareness of location within a space relative to other objects (Sjolinder, 2006). Spatial ability has been examined in a number of studies and has been found to impact the performance of computer tasks, including website navigation (Benyon & Murray, 1993; Egan & Gomez, 1985; Höök et al., 1996; Vicente & Williges, 1988). Since spatial ability is resistant to training (Salthouse, 1982), it is an especially important consideration in web usability for older users.

Spatial abilities are believed to advantage website navigation performance by enabling users to construct a proper mental representation, or mental model, of the system's structure (Mayer, 1986; Nielsen, 1995; Sein, Olfman, Bostrom, & Davis, 1993; Ziefle & Bay, 2006). This mental model of the system assists individuals in understanding, explaining, or predicting how the system works (Slone, 2002). In a website context, mental model refers to the

users' understanding of how the nodes within the hierarchy of the site relate to one another (Simpson & McKnight, 1989). As a result of declining spatial abilities, older adults have more difficulty forming mental models of websites (Lin, 2003), which can lead to a feeling of disorientation or being lost.

Disorientation refers to a feeling of lostness that occurs when a user loses one's sense of location and direction in a non-linear document (Ahuja & Webster, 2001; Conklin, 1987). As per Otter and Johnson (2000), within a website this lostness can be manifested in different ways, including not knowing where to go next; knowing where to go, but not knowing how to get there; not knowing where one is in the overall website structure. Disorientation has been recognized as one of the most significant issues with web navigation (Webster & Ahuja, 2006).

2.3. Theoretical model and hypotheses

This study explores the website use of older adults, compared to younger adults, through the lens of usability. As such, we explore the performance (efficiency and effectiveness) and satisfaction experienced by older adults compared to younger adults during web use. We investigate the effects of decline in cognitive ability associating with aging (specifically, diminished spatial ability) on website usability. Although spatial ability is a salient contributor to age-related differences in computer and Internet use, there are many other objective and subjective changes associated with aging (as discussed in Section 2.2). These other objective and subjective changes associated with aging are captured in direct paths between age and website usability components.

The extant literature is rather sparse on theories that speak to website usability and in particular website usability for older adults. After a thorough investigation, we draw on the work of Webster and Ahuja (2006) as the basis for our theory and model development. Webster and Ahuja (2006) examine the influence of user disorientation on website performance. As mentioned above, older adults have more difficulty forming mental models of websites compared to younger adults (Lin, 2003), which can lead to a feeling of disorientation. As such, the work of Webster and Ahuja (2006) is an appropriate base from which to develop our model on the impact of age on website usability, via the effects of declining cognitive ability. While this base model includes utilitarian user performance as a measure of usability, it does not

consider the corresponding hedonic dimension. In our work, we employ a more holistic approach to usability by considering both its utilitarian and hedonic dimensions of performance and satisfaction, respectively.

As discussed earlier, there are several objective and subjective changes that occur as we age (Mroczek & Kolarz, 1998), one of which is degeneration of spatial ability. In the context of website navigation, degeneration in spatial ability is salient, as spatial ability is believed to advantage website navigation performance through the development of an accurate mental model. As such, spatial ability and mental model accuracy are included in our proposed model to augment and contextualize the Webster and Ahuja (2006) model for older adult considerations. The inclusion of these constructs helps to provide deeper insights into the mechanisms through which age influences website usability dimensions.

The resulting research model is shown in Fig. 1. The remainder of this section describes the theoretical justification for each of the hypotheses in our proposed model in detail.

2.3.1. Age and cognition

As discussed earlier, age is operationalized as chronological age in this research, and individuals experience a number of changes as a result of the aging process. Cognitive changes associated with the natural aging process include declines in aspects such as attention span, working memory, automated response, and spatial ability (Hawthorn, 2000). In this study, the focus is on declining spatial ability and its indirect impact on website usability.

As defined earlier, spatial abilities are cognitive abilities measuring an individual's capability to conceptualize the relationships between objects in space (Dillon, Richardson, & McKnight, 1990; Sjolinder, 2006; Westerman, Davies, Glendon, Stammers, & Matthews, 1995). They also enable awareness of location within a space relative to other objects (Sjolinder, 2006). Some use the term spatial ability interchangeably with visualization ability (Zhang & Salvendy, 2001). These abilities have clear relevance for web use, creating the ability to understand the relationships between pages in a website, and the awareness of which page is currently being viewed in relation to the other pages in the site (Ziefle & Bay, 2006). Spatial abilities have consistently been found to increase during adolescence, reach their peak during the second or third decade of life, and then decrease steadily (Salthouse, 1982), thus it is hypothesized that:
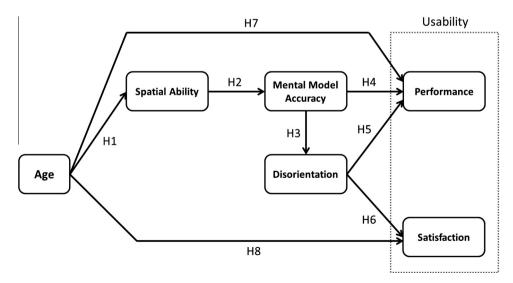

Fig. 1. Research model.

H1. Older adults will exhibit lower levels of spatial ability than younger adults.

Spatial ability is a distinct but related concept to mental models (Höök et al., 1996). In a general context, users with lower spatial ability tend to have more difficulty creating a mental model of an environment (Egan & Gomez, 1985; Kim & Hirtle, 1995; Vicente & Williges, 1988). In the most general sense, a mental model is "an internal, symbolic representation of some part of the external world" (Danielson, 2003). This symbolic representation aids individuals in understanding, explaining, or predicting how things work (Slone, 2002). Mental models consist of the objects and semantic relationships that an individual constructs as they process new information (Lee, Kang, & McKnight, 2001). They are acquired through experience and create frames of reference for new experiences (Otter & Johnson, 2000).

Mental models can be conceptualized at any number of levels. For example, a computer user may apply the understanding that they have of how one software application works when using a different application; e.g. have a conviction that clicking on the "x" in the top right-hand corner of an application window will generally close it. Their mental model of the system is an understanding of how the system works (Fein, Olson, & Olson, 1993). In a web context, mental models can be conceptualized as an understanding of the structure of a website, or how the nodes within the hierarchy of the site relate to one another. Edwards and Hardman's (1989) hypertext experiment concluded that individuals appeared to be attempting to create cognitive representations of hypertext structures in the form of a survey-type map. Subsequent studies termed this map a mental model of hypertext (Simpson & McKnight, 1989) or a mental model of a website (Otter & Johnson, 2000). Thus, we define mental model accuracy (MMA) in this study as the extent to which a user develops a correct understanding of the underlying structure or hierarchy of a website.

Spatial abilities specifically advantage performance when navigating hypertext by supporting users in constructing a proper mental representation of the systems' structure (Mayer, 1986; Nielsen, 1995; Sein et al., 1993; Ziefle & Bay, 2006). Studies have shown that individuals with low spatial ability were more likely to report being confused within the structure of a system because they could not understand it (Ziefle & Bay, 2006), which implies that their mental model was poor. Therefore it is hypothesized that:

H2. Higher levels of spatial ability will lead to higher levels of MMA.

Although older adults have been found to have more difficulty developing accurate mental models than younger adults, a path is not included in the research model between age and MMA. The reason for this is that the influence of age on MMA is expected to be fully mediated by spatial ability. In other words, it is the individual's spatial abilities (which are influenced by their age) that allow them to develop a more accurate mental model, as opposed to their chronological age itself.

Disorientation often is estimated through objective action-based measures such as number of repeated visits to a particular node during the same search task. Some argue, however, that disorientation is best measured by user perceptions since user actions are not necessarily reflective of the intention of their actions (Smith, 1996; Webster & Ahuja, 2006). Thus, this notion of perceived disorientation is used here.

Perceived disorientation, defined earlier as a feeling of "lostness", can be caused by different factors. For example, disorientation may result when cognitive overheads are high due to distractions or side-tracks or when the user is inexperienced with the practice of learning by browsing (Otter & Johnson, 2000). Additionally, several authors posit that an inaccurate mental model

representation can result in feelings of disorientation or lostness (Galletta, Henry, McCoy, & Polak, 2006; Otter & Johnson, 2000; Woods, 1984). As described in Woods (1984), a cause of disorientation is when "the user does not have a clear conception of relationships within the system" (Woods, 1984, p. 229). Users who are familiar with the structure of a website, or have a more accurate mental model, are less likely to feel confused or lost (Galletta et al., 2006; Otter & Johnson, 2000). Thus it is hypothesized that:

H3. Higher levels of mental model accuracy will lead to lower levels of disorientation while using a website.

2.3.2. Indirect effects of age on usability

As illustrated in Fig. 1, age is expected to have indirect effects on both the utilitarian (performance) and hedonic (satisfaction) aspects of usability through its impact on cognition, specifically through spatial ability. In this research, performance is defined as efficiency (speed of task completion) and effectiveness (accuracy of task completion) (Coursaris & Kim, 2011). Satisfaction is defined as website user satisfaction. Specifically, it is "an affect, captured as a positive (satisfied), indifferent, or negative (dissatisfied) feeling" (Bhattacherjee, 2001) regarding the use a website.

In terms of performance, the negative impact of age on spatial ability, and subsequently on MMA, is expected to have a negative impact on performance. In other words, older adults who have lower levels of spatial ability will have less accurate mental models, which will have a negative impact on their website performance. The accuracy of the mental model that a user develops has been found in previous studies to impact the effectiveness and efficiency (i.e. performance) of their navigation in hypertext (Galletta et al., 2006; Sjolinder, 2006; Ziefle & Bay, 2006). Thus, it is hypothesized that:

H4. Higher levels of mental model accuracy will lead to higher levels of user performance within a website.

Further, MMA is expected to have additional negative impacts on performance through its impact on disorientation. Specifically, older adults with less accurate mental models are expected to feel more disoriented, and this perception of disorientation will have a negative impact on their website performance. As mentioned earlier, objective measures of disorientation examine apparent inefficiencies in user navigation. By this definition, less efficient navigation results in poorer performance, indicating a causal relationship between objective measures of disorientation and performance (Galletta et al., 2006; Lee & Boling, 2008; McDonald & Stevenson, 1996; Otter & Johnson, 2000; Roca, Chiu, & Martinez, 2006). Interestingly, some studies have found that the relationship between perceived disorientation and performance is stronger than the relationship between objective measures of disorientation and performance (Otter & Johnson, 2000). Thus it is expected that participants that perceive themselves to be disoriented will have poorer performance in this study.

H5. Higher levels of disorientation while using a website will lead to decreased user performance with the website.

The indirect impact of age on satisfaction is also expected to result from result from perceptions of disorientation. Specifically, older adults with less accurate mental models are expected to feel more disoriented, and this feeling of disorientation will have a negative impact on their feeling of satisfaction with the website. Although the relationship between disorientation and satisfaction has not yet been explicitly been studied in experimental research, perceived disorientation has been described as a conceptually

similar yet distinct construct to perceived ease of use (PEOU). If a web site is easy to use, a user is less likely to feel lost (Ahuja & Webster, 2001). Thus, studies concerning PEOU and satisfaction can serve as an indicator of the expected relationship between perceived disorientation and satisfaction. A review by Roca et al. (2006) found several studies where PEOU led to increased satisfaction, which was also confirmed in their own study and Sjolinder (2006). Since PEOU is conceptually similar to disorientation, it is hypothesized that:

H6. Higher levels of disorientation while using a website will lead to decreased user satisfaction with the website.

2.3.3. Direct effects of age

In addition to the indirect effects of age on usability through its impact on spatial ability (the declining cognitive skill of particular interest in this research), this study also examines the direct relationships between age and the usability constructs of performance and satisfaction. Although spatial ability is a salient contributor to age-related differences in computer and Internet use, there are many other objective and subjective changes associated with aging (as discussed in Section 2.2) that will likely impact performance and satisfaction.

As summarized in Wagner, Hassanein, and Head (2010), a large portion of the literature concerning computer use by older adults focuses on performance evaluation. Although performance is measured in a number of ways (including measures of efficiency and effectiveness), there is consistent evidence that performance declines as age increases, including in a website context (see Wagner et al., 2010 for details). While declines in spatial ability will influence performance via MMA, there are other age-related effects that can impact performance. For example, declines in vision, psychomotor coordination, attention span and memory due to aging can negatively impact performance (Czaja, Sharit, Ownby, Roth, & Nair, 2001; Dyck & Smither, 1996; Höök et al., 1996). As such, a direct path between age and performance is hypothesized to encompass age effects beyond the decline in spatial ability which are not covered in this research:

H7. Older adults will have lower levels of user performance within a website than younger adults.

In contrast to the volume of studies examining the impact of age on performance with computers and websites, few have examined the direct impact of age on satisfaction. Although age is often noted in the demographic description of participants in studies concerning satisfaction, it seldom is used in the data analysis. Since satisfaction is a hedonic consideration, it is the subjective changes associated with aging that will likely have an impact rather than the objective changes that impact performance. In Palvia and Palvia (1999) it was hypothesized and observed that older users experience less satisfaction than younger users since they are more likely to have a fear or level of discomfort with the technology. Therefore we hypothesize that:

H8. Older adults will experience lower levels of satisfaction with a website than younger adults.

3. Research methodology

In order to test the theoretical model discussed in the previous section, a laboratory experiment was conducted. Since exploring the differences between older and younger users is a primary concern of this study, participants across a wide age range were recruited for the experiment. Specifically, half of the participants

were between the ages of 18–35 and the other half were over 55. These age groups were selected based on the age at which declines in spatial ability occur (Salthouse, 1982). Since decline begins after the third decade of life, significant differences between the older and younger groups on this important measure were expected. A total of 101 participants (equally older and younger) were recruited for the experiment, however four participants were excluded from the final data set (one participant was excluded for failing to complete a key experimental activity, while the other three were excluded as they were found to be both univariate and multivariate outliers, as recommended by Tabachnick and Fidell (2001)). Participants were recruited through a variety of sources: postings on two campus websites, posters at two campus research centres, and posters in local seniors' centres, libraries, and in a few local small businesses. Most of the younger participants responded to website advertisements, whereas most of the older participants responded to a variety of ads. Of all of the demographic items collected, very few differed between the age groups: older adults had been using the Internet for more years and were more familiar with the topic; younger adults were using the Internet for more hours per week. There was no difference in education level or overall health status between the groups. The demographic are described further in Table 1.

Measurement of the participants' MMA required that participants had not seen the experimental website before. Thus, a new website was designed and built for this experiment. The content chosen for the experimental websites was healthy living information since it is believed that this topic should have fairly equal appeal to the older and younger participants. In their review, Wagner et al. (2010) indicated that health information was one common domain used in multiple studies comparing older and younger adults. Although Otter and Johnson (2000) suggest that disorientation does not appear to be related to the content of hypertext, it is relevant in this study since users' engagement is often triggered when the topic is of personal interest (O'Brien and Toms, 2008). To ensure the quality of the content of the site, a panel of six subject matter experts were consulted concerning the correctness of the content, logic of layout, and appropriateness of labels. Also carefully considered in the design of the experimental website was the underlying structure in terms of breadth and depth since the site needed to be complex enough for participants to perceive some disorientation, yet simple enough for participants to complete the MMA exercise (which is described in detail below) in a timely fashion. Finally, website usability guidelines were consulted in the development of the site including Morrell (2005) and Zaphiris et al. (2007) to ensure that the websites did not disadvantage older adults in such aspects such as font size and color, background, contrast, etc. A sample of the experimental website, HealthyBurlington.ca, is shown in Fig. 2.

Table 1
Demographic descriptors of participants.

		Younger	Older
Count		50	47
Age	(mean)	22.74	66.47
	(s.d.)	3.58	6.75
Gender	(male)	26	15
	(female)	24	32
Education	(1–6)	3.40	3.57
Health status	(1–5)	4.00	3.94
Internet use	(years)	11.10	13.96
	(hrs/wk)	21.73	8.98
Topic familiarity	(1–7)	5.70	6.19

The experimental procedure had a number of steps. Upon arriving at the experiment, participants were provided a brief description of the experiment and requested to sign a consent form. Next, they completed a demographic questionnaire, which asked questions concerning their gender, age, well being, Internet experience, education, and subject matter expertise. Then two paper-based assessments of spatial ability were administered, where participants were required to mentally fold and rotate the shapes illustrated. Finally participants were provided with a laptop (with the experimental website open in the browser) and instructed to explore the website for five minutes. Once the participants were done browsing, they were asked to complete six search tasks within the website. These tasks were selected to ensure that the participants visited all of the deeper levels of the website at least once.

After the tasks, the participant moved on to the MMA exercise. Here they were provided with a large magnetic white-board and a set of 39 small cards with magnets on them. Each card had the label from one of the pages in the website on it. The participants were instructed to arrange the cards on the board in order to recreate the hierarchy of the website as they understood it. A similar methodology has been used in previous studies (Edwards & Hardman, 1989; Otter & Johnson, 2000; Simpson & McKnight, 1989). Participants were assured that the order of pages within a section was not important and they should only be concerned with creating the correct parent–child relationships between the pages. Participants are allowed up to fifteen minutes to complete the exercise. This length of time was deemed to be reasonable as a result of the pilot study. Finally, participants were asked to complete the post-experiment questionnaire. This questionnaire collected their responses concerning the perceived constructs in the research model (disorientation and satisfaction) and two open ended questions.

The constructs in the research model are both formative and reflective in nature. Spatial ability and performance are modeled as formative. Spatial ability is indicated by the participant's scores on VZ-2: Paper Folding (Spatial1) and S-1: Card Rotations (Spatial2) from Ekstrom, French, Harmon, and Dermen (1976) Kit of Factor-Referenced Cognitive Tests. Performance is indicated by the number of tasks completed correctly (Correct) and the total time taken to complete all of the six tasks (Time). Disorientation and satisfaction are modeled as reflective constructs and measured using previously validated scales from Ahuja and Webster (2001) and Bhattacherjee (2001) respectively, which are shown in Table 2.

Age and MMA are single item, objective constructs. Age is measured as the participant's chronological age (range: 19–82). MMA refers to the score that participants received for their recreation of the website hierarchy, which was assessed using a tree edit distance (range: 3–38). This method is used in a variety of disciplines for calculating the difference (or distance) between two hierarchical trees (Bille, 2005) and the difference between card sorts (Deibel, Anderson, & Anderson, 2005), but had not been used previously in Information Systems or for assessing users' mental model of a website. Essentially, a tree distance algorithm calculates the number of moves required to get from one tree to the other, or in this case from the participants hierarchy to the correct hierarchy. To implement this scoring method, a java applet was acquired which implements Zhang and Shasha's (1989) algorithm for ordered trees. The steps for processing each participant's tree and a graphical example of this process are outlined in Appendix A.

The analysis of the research model was conducted using Structural Equation Modeling (SEM), specifically Partial Least Squares (PLS). PLS was chosen over the alternative covariance-based techniques for a number of reasons. In particular, PLS supports both confirmatory and exploratory research and the simultaneous modeling of formative and reflective constructs. Further, the sample size is relatively small and insufficient for covariance-based analysis (see (Gefen, Rigdon, & Straub, 2011; Gefen, Straub, & Boudreau 200,0) for details). A larger sample was not feasible due to the length of the experiment for each participant.

The minimum suggested sample size for PLS modeling is the greater of (1) ten times the number of items in the most complex construct in the model, or (2) ten times the number of paths leading to the dependent variable in the model with the most independent variables (Chin, 1998; Gefen et al., 2000). In this case, the most complex construct in the model has seven items (disorientation) and performance has the most independent variables with three. Thus, according to the guideline, the minimum suggested sample size is 70. This study collected data from 101 participants of which 97 were included in the final analysis. Thus the final sample size was sufficient for data analysis using PLS.

4. Analysis and results

4.1. Measurement model

Prior to running the PLS analysis, the model constructs were assessed for validity. In the case of the reflective constructs (disorientation and satisfaction), content validity, convergent validity, and discriminant validity were all assessed. Content validity was ensured by using previously validated measures. Convergent validity was assessed by verifying that: (1) all item factor loadings are

Fig. 2. Screen shot of experimental website.

Table 2
Scale items for reflective constructs.

Scale	Items
Disorientation (Never 1 . . . Always 7)	While I was browsing the experimental web site: 1. I felt lost 2. I felt like I was going around in circles 3. It was difficult to find a page that I had previously viewed 4. Navigating between pages was a problem 5. I didn't know how to get to my desired location 6. I felt disoriented 7. After browsing for a while I had no idea where to go
Satisfaction	How do you feel about your overall experience using the web site? Very Satisfied 1 . . . Very Dissatisfied 7 Very Pleased 1 . . . Very Displeased 7 Very Contented . . . Very Frustrated 7 Absolutely Delighted 1 . . . Absolutely Terrible 7

significant and greater than 0.70; (2) average variance extracted (AVE) is greater than 0.50; and (3) composite reliability index for each construct is greater than 0.80 as recommended by Fornell and Larcker (1981). Discriminant validity was assessed by verifying that the square root of AVE for each construct was greater than its correlations with all other constructs (Fornell & Larcker, 1981). Also, the internal consistency of the constructs was found to be sufficient since Cronbach's Alpha statistic was greater than 0.70 (Cronbach, 1951). The results of these checks are shown Tables 3–5, and the item cross-loadings are shown in Table 6.

The formative constructs with more than one indicator (spatial ability and performance) were evaluated for indicator collinearity by ensuring that when the items from the formative measure are regressed onto its endogenous construct, the Variance Inflation Factors (VIFs) are below 3.3 (as recommended by Petter, Straub, and Rai (2007) and that the inter-item correlations are all below 0.8 (as recommended by Stevens (1996)). The results are shown in Tables 7 and 8.

Finally, common method bias was assessed through Harman's one-factor test (Podsakoff, MacKenzie, Lee, & Podsakoff, 2003) and Liang, Saraf, Hu, and Xue (2007). For the Harman's one-factor test, the unrotated factor solution was examined against Podsakoff et al.'s (2003) assertion that a common methods variance exists if "(a) single factor will emerge from the factor analysis or (b) one general factor will account for the majority of the covariance among the measures" (p. 889). More than one factor emerged to explain the variance in our analysis, with the first factor explaining 39.2% of the variance, indicating that common methods biases are not a likely contaminant of our results. Additionally, the Liang et al.'s (2007) method resulted in a substantive to method variance ratio of 59:1, indicating that common method bias is not an issue.

4.2. Structural model

The results of the PLS analysis are shown in Fig. 3. The level of significance of the parameter estimates (indicated by asterisks) were calculated based on the *t*-statistics from a Bootstrapping process (with 500 resamples). Six out of eight of the paths in the model are significant (at least $p < 0.05$) indicating that the model

Table 3
Overview statistics.

	AVE	Composite reliability	Cronbach's alpha
Disorientation	0.665	0.933	0.915
Satisfaction	0.862	0.961	0.946

is reliable overall. The variance explained of the two endogenous components of Usability are $R^2 = 0.510$ and $R^2 = 0.388$ for Performance and Satisfaction, respectively. This is deemed to be appropriate for model validity (Chin, 1998).

Although the PLS approach to SEM does not provide overall model fit indices equivalent to those available to covariance-based approaches (Chin, 1998; Gefen et al., 2000), a global fit measure has been suggested by Tenenhaus, Vinzi, Chatelin, and Lauro (2005). Recent research indicates that the GoF index can be used for formative models (Vinzi, Trinchera, and Amato, 2010), which is the case for the current study. The result is a number between zero and one where small, medium, and large effect sizes are GoF(small) = 0.1, GoF(medium) = 0.25, GoF(large) = 0.36 (Wetzels, Odekerken-Schröder, & Van Oppen, 2009). Using this measure, the GoF for the current study is 0.466, or the effect size is large, indicating that the research model performed well.

Table 4
Correlations with diagonal square root of AVE.

	Disorientation	Satisfaction
Disorientation	0.816	
Satisfaction	−0.617	0.928

Table 5
Item loadings and significance levels.

Construct	Item	Loading	*t*-Stat.	Sig.
Disorientation	dis1	0.797	14.689	0.000
	dis2	0.749	9.530	0.000
	dis3	0.849	25.847	0.000
	dis4	0.818	15.745	0.000
	dis5	0.881	26.253	0.000
	dis6	0.903	29.133	0.000
	dis7	0.716	10.870	0.000
Satisfaction	sat1	0.948	109.750	0.000
	sat2	0.949	67.949	0.000
	sat3	0.930	67.727	0.000
	sat4	0.885	29.417	0.000

Table 6
Item factor loadings for reflective constructs.

	Disorientation	Satisfaction
dis1	**0.777**	−0.492
dis2	**0.749**	−0.406
dis3	**0.849**	−0.548
dis4	**0.818**	−0.495
dis5	**0.881**	−0.552
dis6	**0.903**	−0.599
dis7	**0.716**	−0.432
sat1	−0.611	**0.948**
sat2	−0.565	**0.949**
sat3	−0.653	**0.930**
sat4	−0.447	**0.885**

Item loadings on their own construct are bolded.

Table 7
Spatial ability – MMA correlations and VIFs.

	MMA	Spatial1	Spatial2	VIF
MMA	1.000	0.469	0.452	
Spatial1		1.000	0.624	1.638
Spatial2			1.000	1.638

Table 8
Performance – satisfaction correlations and VIFs.

	Satisfaction	Time	Correct	VIF
Satisfaction	1.000	0.019	−0.049	
Time		1.000	0.399	1.189
Correct			1.000	1.189

4.3. Effect sizes

The predictive power of the model can be evaluated further by examining the impact of individual constructs on the variance explained by dependent variables throughout the model (as per Chin, 1998). The magnitude of the effect sizes can be assessed as per the ranges recommended by Cohen (1988). As shown in Table 9 each of the paths that is significant in the PLS model has significant effect size (at least $p < 0.05$).

4.4. Post hoc analysis

Some post hoc analyses were run in order to further explore the collected data. First, one-way ANOVAs were run, testing for significant mean differences between the age groups on each of the model constructs. As is evident in Table 10, older adults have lower levels of spatial ability, less MMA, and lower levels of performance, as expected. Interestingly, older adults reported less perceived disorientation than younger ones, which is counter to expectation. Finally, older adults were equally satisfied with the website.

To further explore the unexpected findings between age and disorientation, a histogram was compiled as shown in Fig. 4. Interestingly, the highest level of disorientation is reported by the youngest participants. In fact, within the group of younger participants, disorientation declines with age. This decline continues well into the older group, without an increase until the 70–74 age block of participants. The responses to the open-ended questions of those participants that reported disorientation greater than 3 were examined in detail in an effort to understand this finding. Interestingly, the comments made by the older adults were mainly positive, indicating that the website was "simple to use", "clear", and "straight forward." In fact, there were very few negative comments made by any of the older adults. The younger adults, however, had

plenty of negative feedback such as: "it wasn't intuitive", "I felt lost easily", "hard to find information previously viewed", "loss of navigation as you progress through the site", "boring", "not interactive", and so on. It seems that the youngest, most experienced users were missing navigation items not included such as breadcrumbs and search function, which may have led them to feel disoriented.

This investigation of the relationship between age and disorientation raises the issue that the impact of age on the various constructs may not be linear. In the case of disorientation, the source of this non-linearity appears to be caused by factors other than age. In the cases of spatial ability and performance, non-linearity may result from varying rates of change in the aging process. To investigate the impact that any non-linear relationships may have on the research model, the same research model was evaluated using WarpPLS, a software application that is able to fit nonlinear relationships in PLS calculations. This analysis showed that allowing non-linear relationships in the SEM model had essentially no impact on the PLS results.

Lastly, some post hoc analyses were conducted to explore the different conceptualizations of age described earlier. The results of these analyses are summarized in Appendix B.

5. Discussion and contributions

Extant literature is sparse on theories of website usability, and in particular website usability for older adults. In this research, we proposed and validated a new website usability model for older adults. The model takes a holistic view of usability by considering both its utilitarian (i.e. performance) and hedonic (i.e. satisfaction) aspects. The model also provides insights into the mechanisms through which age influences these usability aspects by building off of the work from Webster and Ahuja (2006) and incorporating the most salient age-related changes within the context of website navigation. Further, since most prior research has studied the model constructs using younger participants, this study provides some validation for the generalizability of these constructs to older age groups.

The results of this research provide a number of insights about website usability among older and younger adults. First, increased age was shown to have both a direct and indirect impact on website navigation performance. Older adults suffer from declines in
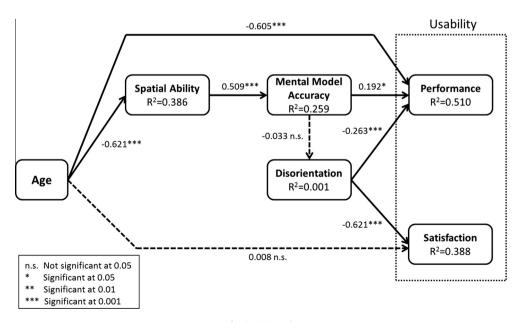

Fig. 3. PLS results.
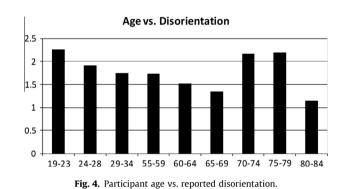
Table 9
Summary of findings of effect sizes.

Independent variable	Dependent variable	R^2		ΔR^2	f^2	Effect
		Included	Excluded			
Disorientation	Satisfaction	0.388	0.035	0.353	0.577	Large
Age		0.388	0.388	0.000	0.000	n.s.
MMA	Performance	0.510	0.480	0.030	0.061	Small
Disorientation		0.510	0.445	0.065	0.133	Small
Age		0.510	0.231	0.279	0.569	Large
Spatial Ability	MMA	0.259	0.000	0.259	0.350	Medium
Age	Spatial Ability	0.386	0.000	0.386	0.629	Large
MMA	Disorientation	0.001	0.000	0.001	0.001	n.s.

Table 10
Mean differences between older and younger on model constructs.

Construct	Older Avg.	Younger Avg.	Mean difference significance
Spatial ability	0.4588	0.6934	$p < 0.000$
MMA	−0.4444	0.4177	$p < 0.000$
Disorientation	1.6991	2.1429	$p < 0.029$
Performance	−0.6124	0.5757	$P < 0.000$
Satisfaction	5.3351	4.9800	n.s.

Fig. 4. Participant age vs. reported disorientation.

spatial ability, which influences performance via increased difficulty in forming accurate mental models (H1, H2, and H4 supported). The novel MMA assessment methodology presented here performs well in the model and is discussed further below. Beyond the salient effect of declining spatial ability, the direct negative impact of age on performance (H7 supported) is indicative of the presence of other age-related effects that could be detrimental to performance. For example, declines in vision, psychomotor coordination, attention span and memory due to aging can negatively impact older adult's website navigation performance. The impact of such factors would be interesting to explore in future research.

Second, age was found to have an indirect but not direct impact on the hedonic component of usability (satisfaction). As expected, participants who experienced higher levels of disorientation while using the website reported lower levels of satisfaction (H6 supported). Although it was hypothesized that older adults may experience lower levels of satisfaction due to their relative discomfort with web use, this was not observed to be the case (H8 not supported). This indicates that some other factors may mediate the impact of age on satisfaction during web use, which would be interesting to explore in future research.

Third, some interesting results were observed with respect to the disorientation construct in the model. Although disorientation impacted usability as expected, the impact of mental model accuracy on disorientation was unexpected. Specifically, participants who experienced higher levels of disorientation had poorer performance (H5 supported) and reported lower levels of satisfaction (H6 supported). However, participants with better mental model

accuracy did not experience lower levels of disorientation (H3 not supported). So the ability to understand the underlying structure of the website did not influence feelings of lostness while navigating. Further, the mean differences between older and younger participants on the model constructs (Table 10) pointed out that older participants perceived lower levels of disorientation than younger participants, even though they had lower levels of spatial ability, less accurate mental models, and worse performance.

This unexpected result in the disorientation construct may stem from two separate issues: (i) Younger adults might have over-reported their feelings of disorientation relative to older participants. Previous research suggests that younger web users prefer image-based communication style over text-based (Djamasbi, Siegel, Skorinko, & Tullis, 2011; Djamasbi, Siegel, & Tullis, 2010). Since the experimental website was primarily text-based, this may have affected their attention to information in the site and caused them to feel unsupported or more disoriented than in their average web navigation experience. Further, the experimental website did not provide additional navigation cues that they may be accustomed to, such as breadcrumbs or search functionality, which may have caused them to feel unsupported or more disoriented than in their average web navigation experience. In support of the notion that younger adults over-reported their disorientation is the fact that even though they reported higher levels of disorientation than older adults, their performance and mental model accuracy were clearly superior. (ii) Older adults might have under-reported their feelings of disorientation relative to younger participants since older participants have a tendency to focus on the positive aspects of their experience and report more positive feelings than observed by the experimenter (Sayers, 2004), and have more of a desire to be polite and socially desirable (Dickinson, Arnott, & Prior, 2007). In the current investigation, while the older adults reported lower levels of disorientation than younger adults, they were observed to appear to be more disoriented by the experimenter during the controlled experiment. In all likelihood, it is probably a combination of these two issues that resulted in the unexpected results with the disorientation construct in our model. These apparent inconsistencies would be an interesting topic for further investigation.

Another contribution of this work is the development of the MMA construct. The MMA of the participants was assessed by having participants recreate the hierarchy of the website as they understood it using a set of cards (with each card representing one page in the site). Although having participants create a mental model in this fashion is not a new concept, the scoring method implemented here is novel in a usability experiment context. Each participant's hierarchy was compared to the correct hierarchy using a tree distance algorithm, previously used in the computer science and biomedical computing disciplines, resulting in a score for the exercise. This scoring method is more sophisticated than that used in previous mental model studies, which only allotted one point for each node connected to the correct parent node,

and performed well by being positively influenced by spatial ability and having a positive influence on performance.

From a practical perspective, the findings around MMA are interesting, particularly for utilitarian websites such as those used in the workplace since encouraging users to develop accurate mental models will help them to improve performance. Also, the results illustrate some of the intricacies of designing websites for older and younger adults. Developers should provide the navigation cues that younger and experienced users have come to expect, while bearing in mind the simplicity that older users prefer. Further, it seems that websites designed to accommodate the needs of older adults may not be engaging to younger users. In contexts where the website is intended for utilitarian purposes, this is less important since younger users will be more concerned with the utilitarian aspects of the experience. It is in cases where the website is intended for hedonic purposes that this will be more of an issue since it may be difficult to please both age groups with a single website.

5.1. Limitations and future research

All research studies have some limitations, and this study is no exception. The first limitation is the population of older adults recruited. Although this study went beyond the typical recruitment of a limited range of ages, the sample of older adults used here is not likely representative of older adults in general. For example, older adults are generally less educated than younger ones (Dickinson et al., 2007), but that was not observed here. It appeared that the older adults who were willing to participate were more educated and experienced than average, which limits the generalizability of the results since more educated older adults are more likely to use computers and the Internet more often (Carpenter & Buday, 2007). A second limitation is the experimental website. It was designed for the purpose of the experiment and may not be representative of actual websites. For example, the navigation of the site was limited to links in the navigation system and the site was simple in that it excluded some aspects of navigation (such as breadcrumbs and search functionality) to facilitate the MMA exercise. Further, the MMA was assessed after fairly limited exposure to the website. Although the website was designed to be simple enough for this

to be sufficient, the study does not consider how a mental model develops over time. Lastly, this study was conducted in Canada and may not be generalizable to other geographic locations, particularly where attitudes toward aging and exposure to technology vary significantly.

Although this study resulted in a number of practical and theoretical contributions, it also had some unexpected findings that generate curiosity for future research. In particular, the inconsistent relationship between MMA and disorientation should be explored further in future work. Other dimensions of subjective age-related changes (e.g. expectations and perspectives) may influence this inconsistent relationship. Finally, it would be interesting to investigate how well the model developed here holds for other types of websites, other cultures, as well as in other information and communication technology mediums such as mobile phones or tablets.

Appendix A. Graphical example of tree distance calculation

Processing each participant's tree involved the following steps:

1. Label the pages of the participant's hierarchy with the appropriate page letters. These letters are derived from the correct hierarchy, which has been labeled (from top to bottom, left to right) with letters from a–z and aa–mm. A sample labeled participant tree is illustrated in Fig. A1.1.
2. Redraw the participant's hierarchy taking order into consideration (since the algorithm processes ordered trees, this will prevent penalizing for order when that was not required of the participants). Essentially, this means that the hierarchies were redrawn with the sibling pages in the correct order in cases that they were not, and in a more consistent format. Fig. A1.2 illustrates the sample tree from Fig. A1.1 once redrawn.
3. Create groups of correct pages in the participant's hierarchy, label each group with the lowest letter of the grouped pages; create the corresponding group on the correct hierarchy. This grouping is what eliminates the problem discovered in the pilot analysis, since each group (rather than each page) will be counted as a move toward the correct hierarchy. Fig. A1.2 illustrates how the sample participant tree from Fig. A1.1 looked
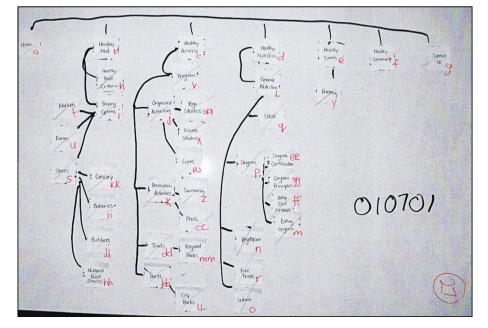

Fig. A1.1. Sample labeled participant tree.

after being redrawn as an ordered tree and having the pages grouped. Fig. A1.3 illustrates how the same groupings were made on the correct tree.

4. Create the character strings for the resulting participant and correct hierarchies for entry into the tree distance algorithm. These character strings summarize the parent–child relationships in each tree and are in the form "from_node-to_node;". The resulting character strings for the sample participant are shown in Fig. A1.4.

5. Run the algorithm, which will result in a tree distance number. The lower the number, the more accurate the participant's tree (mental model).

Appendix B. Exploring different conceptualizations of age

The demographic questionnaire completed by the participants collected chronological, functional, and subjective age since these are the conceptualizations that may relate to usability factors. Subjective Age was collected by asking the participant how old they feel, and Functional Age was collected by asking the participant about their health status, as described in Kooij et al. (2008). Since there was no difference between the health status reported by the older and younger groups, this conceptualization was not used in further analysis.

A variety of post hoc exploratory analyses were, however, performed using the chronological and subjective conceptualizations of age. First, a PLS analysis was conducted where the Age construct was operationalized as a formative combination of chronological age and subjective age, as opposed to only chronological age as in the main research model. The results of the analysis were essentially the same, indicating that chronological age is an appropriate proxy for age in this context. Similarly, when only subjective age was used to form Age, the magnitude and direction of relationships emanating from Age did not change.
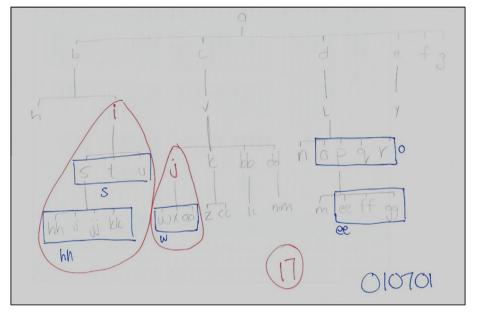

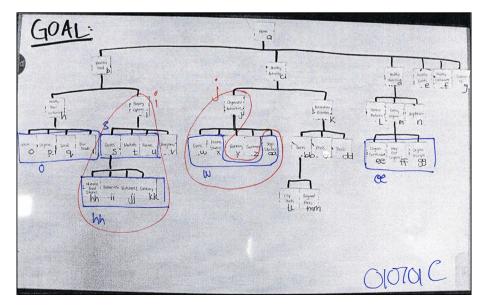**Fig. A1.2.** Sample participant tree with groupings.

Fig. A1.3. Correct hierarchy with groupings.

correct:	a-b;a-c;a-d;a-e;a-f;a-g;b-h;b-i;c-j;c-k;d-l;d-m;d-n;h-o;i-v;j-y;j-z;k-bb;k-cc;k-dd;m-ee;bb-ll;bb-mm												
participant:	a-b;a-c;a-d;a-e;a-f;a-g;b-h;b-i;d-l;e-y;c-j;c-k;c-bb;c-dd;l-n;l-o;k-z;k-cc;bb-ll;dd-mm;o-m;o-ee												
distance:	17												

Fig. A1.4. Participant and correct character strings.

Table A2.1

Correlations between conceptualizations and constructs (* $p < 0.05$).

Construct	Correlation with age conceptualization		
	Chronological	Subjective	Functional
Hours/week	−0.537**	−0.560**	0.045
Familiarity	0.241*	0.147	0.207*
Spatial ability	−0.615**	−0.561**	0.008
MMA	−0.432**	−0.387**	0.103
Performance	−0.633**	−0.494**	−0.085
Disorientation	−0.212*	−0.208*	−0.037
Satisfaction	0.138	0.058	0.118

In order to further explore the impact of different conceptualizations of age, correlations were run between each of the age conceptualizations collected and each of the model constructs. Although some of the correlations are insignificant, as shown in Table A2.1, their directionality and relative magnitudes may provide some indications for future exploration of the constructs. While the objective outcomes (spatial ability, MMA, and performance) all correlate more strongly with chronological age than the other age conceptualizations, the correlations with other constructs are less clear. Hours of Internet use per week correlated more strongly with subjective age, implying that older adults that feel younger may behave younger in terms of their Internet use. Disorientation correlates fairly equally with the chronological and subjective conceptualizations and satisfaction does not correlate significantly with any of the conceptualizations. This may imply that chronological age is a strong predictor of utilitarian outcomes, whereas other conceptualizations could add insight to the more complex study of hedonic outcomes. Older adults' subjective age had greater variance from their actual age than that of younger adults, thus these conceptualizations may have greater importance when studying older adults.

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