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ORIGINAL PAPER

The role of user age in task performance: examining curvilinear and interaction effects of user age, expertise, and interface design on mistake making

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Abstract The next 30 years are going to be challenging for organizations as they need to transition to a workforce that is rapidly growing older. As the workforce is growing older, the age of organizational technology users is an important aspect to examine in the context of organizational information systems (IS). The corresponding IS literature has largely assumed that age is an impediment or disadvantage when using modern information and communication technologies (ICTs) and has, thus, directed attention to the challenges faced by older technology users in the workforce. However, such research has not examined the potential benefits of an older workforce in terms of a possibly higher task performance under certain workplace conditions, such as employees' subject-area knowledge and the design of

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the ICT interface. Hence, this paper examines age-related differences in the use of organizational ICTs in terms of the propensity that different age groups have toward performance in the form of mistake-making when searching for information. To do so, the paper forms hypotheses that explain how the combination of age, subject-area knowledge, and system interface lead individuals to make mistakes in a technology-enabled context. Drawing on a laboratory experiment using 107 older and younger technology users, we evaluated the three-way interaction of age, subject-area knowledge, and interface design. Our results demonstrate that—under certain conditions—age is not the detriment that it is widely believed to be. The implications of this finding are explored in relation to the "graying of the work-force" that all OECD countries are currently experiencing.

Keywords Age · System design · Expertise · Error · Interface · Novice

JEL Classification L2 · O32 · O39

1 Introduction

Where IS research on age and information communication technologies (ICT) often considers greater age a liability (Lee et al. 2011; Rogers et al. 2005), we believe that factors tied to youth may lead to ICT enabled mistakes. This conclusion counters the conventional wisdom on age and computer use. Previous research demonstrates that mental faculties decline with age, and younger people are more proficient at ICT enabled tasks than older people, especially when using metrics for performance such as speed (Arning and Ziefle 2007; Löckenhoff 2011). Broadly speaking, the IS literature has found support for the younger user being faster and more confident in their use of ICT than older users.

The association of age with lower performance using ICT's poses a challenge for organizations as they strive to cope with an ageing workforce. Organizations are trying to adapt practices to capitalize on the availability of older workers in the 21st century (Taylor 2006). When older workers are retained in the workforce, the pool of skilled labor is increased and the valuable experience of older workers is retained in the economy (Palumbo et al. 2008). However, organizations must take action to counter the challenges older workers face when using ICT's. As they do, these organizations require guidance on how to mitigate problems, and leverage advantages, that may be associated with age. Industry acknowledges the value of experience is and is searching for ways to capitalize on the experience held by older workers (Cohen 2006), and older individuals offer benefits in terms of knowledge and experience (Czaja et al. 2006; Pak et al. 2009). This work is relevant to practitioners by investigating age-related variance in how people use ICT's in the workplace.

Age begets experience, and with experience, older individuals can outperform younger ones in decision making tasks (Tams et al. 2014; Worthy et al. 2011). We suspect that age, familiarity with the topic under investigation (i.e. subject expertise), and interface design can interact to result in variance in the rate of mistakes, caused by shortcutting heuristics during ICT use. To better understand mistake-making, this paper develops a theory-driven behavioral model that explains why, and how, age interacts with subject expertise and interface design. In doing so, it provides direction for future research on age and information technology as well as direction for practitioners seeking to enable more effective online information searches.

This research is situated at the intersection of the HCI, decision making, and age literatures. We focus attention on the number of mistakes an individual makes, and our primary research question is "Do age, experience, and interface combine to influence the number of mistakes individuals make in accomplishing ICT tasks?" This is important, because one of the promises of technology is to increase an individual's productivity, and the number of mistakes an individual makes while accomplishing tasks decreases productivity (Tarafadar et al. 2007). While it is impossible to perform error-free, investigating mistake-making behavior is a worthy endeavor, and a reduction in the amount of time spent correcting errors may save a substantial amount of time in the workplace (Chen et al. 2010). Overall, this research is specifically focused on the domain of a graying workforce. As such, this research makes a number of important contributions (listed in Table 4 in Sect. 6.2) related to the impacts of information systems and technology in the e-business era.

The remainder of this paper unfolds as follows: Sect. 2, the literature review, discusses what is known about mistake-making behavior as well as pertinent sources of such behavior. Section 3 incorporates the IS field's theoretical understanding of youth and ICT use with theoretical observations about mistake-making to articulate testable hypotheses. Sections 4 and 5 describe the experiment and analysis used to test hypotheses. Section 6 concludes this research note with a discussion of limitations and implications for research and practice.

2 Literature review

To better understand the dynamics of an older workforce and ICT use, this work draws upon prior findings in the IS, HCI, and human factors literatures. While old age is typically viewed as a liability when faced with tasks where ICT usage is required (Lee et al. 2011; Rogers et al. 2005), this work argues that the effects of age are not so clearly defined. The assumption that greater age predicates lower performance with ICTs has been increasingly questioned in academic research. Critics contend that the advantages of youth are an artifact of experimental designs, which rely on structured problems such as playing a computer game or physically manipulating interface components as tasks (Mienaltowski 2011). For example, under laboratory conditions, Myerson et al. (2007) observed that younger subjects could identify items as belonging to a common category much faster than older subjects. When performing more realistic, complicated tasks, critics have found that older users are more likely to focus on relevant information than younger user (Johnson and Drungle 2000).

When presented with a "poorly structured, real-world problem", critics argue that, under the right circumstances, older workers possess the potential to outperform younger workers (e.g. Johnson and Drungle 2000; Peters et al. 2007). IS research has examined how ICT design may alter task structure to address performance issues (Courtney 2001; Gorry and Scott Morton 1989). Thus, ICT design and the structure of work tasks may be examined together to address performance issues associated with a graying work force.

Research suggests that different age groups employ distinct cognitive strategies when faced with an unstructured task. Individuals will often use mental heuristics to speed up their decision making, and that these heuristics can lead to suboptimal decisions (Baron and Hershey 1988). Specifically, when solving unstructured problems, older users can perform at higher levels when compared to the young (Mienaltowski 2011). Studies suggest that younger users are more apt to apply shortcutting heuristics where the current task is generalized to match previously encountered tasks, whereas older users utilize more cognitively taxing strategies, and arrive at a solution based upon the unique parameters of the current situation (Klein 2008; Slovic et al. 1977). These age-related differences in problem solving approaches can lead to mistakes (Shanteau 1992), particularly when younger individuals employ short-cutting heuristics to reach decisions (Mienaltowski 2011).

Previous research has approached information technology mistake-making as the product of poor interface design (e.g. Weyers et al. 2010) or work-routine factors such as work overload (e.g. Zwaan et al. 2009). However, these views fail to address other pertinent factors such as age and experience. One factor under consideration is the interface of the technology that the individual is using. Great advances in how information can be categorized and portrayed on a screen have been made in the past few years. Advances in user interfaces that can mitigate some of the demonstrated age-related performance decline will be discussed. The second area that is expected to mitigate age-related performance decline is subject area knowledge which is something prior works have not yet addressed. Typically individuals work within a task context, and prior learning should be considered. On the sports field, a crafty veteran with years of experience can often outperform a more athletically gifted younger player. There is no reason to think the same cannot be true when using ICT's. Hence, the knowledge that an individual carries with them should be explicitly considered. In addition to reviewing the age related literature, the literature surrounding user interface design and subject area knowledge is also reviewed to properly ground this study in these three literature streams.

This section begins by reviewing the age-related literature to provide a context for why older age may not necessarily lead to lower performance.

2.1 Age

Cognitive ability changes over individuals' lifespan (Horn and Cattell 1967) and may influence their problem solving and information processing abilities. Information is typically processed using one of two basic methods—affective/experiential processing or deliberative processing (Sloman 1996). Kahneman (2003) subsequently refers to these two modes of processing as "System 1" and "System 2". System 1 represents the fast, experiential, and emotionally based processing that occurs almost constantly, and System 2 represents the deliberative, analytically based processing that typically is only activated when something notable occurs.

There is much to suggest that information processing abilities decline as individuals' age. Older individuals process information more slowly than younger individuals. On tests of motor speed, perceptual speed, reasoning, spatial visualization, and memory, older individuals perform more slowly than younger individuals (Salthouse 1994). However, age differences in decision accuracy are substantially reduced when measures of speed are controlled, and no age effect is seen when measures of decision accuracy are used (Salthouse 1994).

With regard to encoding stimuli into memory, older individuals demonstrate a reduced ability to pair stimuli together. Denney and Larsen (Denney and Larsen 1994) showed different age groups pictures with a word superimposed on the image. Subjects were instructed to remember the picture, the word, or the picture-word combination. As expected the younger subjects outperformed the older individuals as it is well established that younger subjects are better at episodic memory tasks (Denney and Larsen 1994). It is important to remember this finding applies to the encoding of information, and not the retrieval of information.

When searching for information, the ability to accurately parse the incoming information into relevant or irrelevant to the task is paramount. There is some evidence to suggest that older individuals are less proficient at doing this (Hasher and Tasker 1988). Studies show that no age differences exist when encoding and retrieval are tested, however differences do appear when inferences must be formed to understand a passage. These differences are compounded based on how the information is presented. Orally presented information where the individual has no control over the pace of information presentation shows the largest age-related differences (Hasher and Tasker 1988).

Older individuals are less aware of the ongoing cognitive processes that influence their judgment and exhibit more tentativeness and caution in their behavior in unfamiliar situations (Lopatto et al. 1998). In navigating an icon through a matrix, older individuals took more time to maneuver the icon than older individuals. Not only are older individuals more cautious in their problem solving behavior, they are also more over-confident in their rating as to the correctness of their answers to a given problem (Crawford and Stankov 1996). What is open to debate is whether the over confidence in a solution is a result of the cautiousness with which the individual approached the problem.

Finally, age differences are seen in the physical structures of the brain itself. Working memory and general cognition decline with age, and can be partially attributed to prefrontal cortex deterioration. This deterioration often occurs naturally as part of the aging process (Amieva et al. 2003). Regardless of the underlying cause, prior research clearly demonstrates that age related differences in cognitive performance exist. These differences become more important when task effects are considered.

When faced with a complex task, individuals work to quickly eliminate alternatives, even basing decisions on incomplete or limited information (Payne 1976). In situations like this, an exhaustive examination of alternatives is impractical or impossible. Instead the individual would rely on the less cognitively demanding System 1 type thinking to rule out alternatives. Mistakes can occur when an individual relies on System 1 thinking because the search situation appears similar to their existing knowledge base, and hence relies on a mistaken association. Younger individuals might not have the life experiences to identify current situations as being similar to past events, and these individual would have no recourse but to utilize the more cognitively demanding System 2 thinking. Making a decision based on the merits of the current situation should lead to a more accurate decision, but at the cost of increased cognitive processing and increased decision making time. Mistakes occur when an individual relies on System 1 thinking because the search situation appeared similar to knowledge associated with their prior experiences, and the individual relied on that mistaken association.

While many of these differences are part of the normal aging process, it might be possible to mitigate these differences through information systems design. By focusing on the interface design, source designers can directly impact how individuals interact with a system. Systems can be designed in such a way to enhance performance or to minimize the deleterious effects of age. Additionally, older individuals can bring life experiences to the situation that younger individuals do not have. These "life lessons" should also be considered when trying to understand mistake-making behavior. The following sections address this.

2.2 Interface design

Studies suggest that interface design may effectively structure problems, and thus lead to enhanced performance by system users (Schär 1996). For example, when faced with a well-structured problem, individuals perform more effectively with a command line interface. However, when faced with an open problem, individuals perform better with an interactive interface that allows for on screen exploration (Schär 1996). This research implies that by incorporating a logical and optimal path to find information (e.g., a menu-driven hierarchy), a website user may be more apt to apply relevant knowledge when searching for information. Conversely, the fuzzy logic embedded in a Web 2.0 tagging-based interface lends itself to the use of shortcutting heuristics (Browne and Pitts 2004; Browne et al. 2007; Nickles et al. 1995). Understanding drivers of such mistakes is important, because online information sources frequently inform decisions made by users of all ages.

Two basic interface types are considered in this research, the hierarchical and the tagging style interface. The hierarchical interface (see Fig. 2) often appears in conventional Web 1.0 type websites characterized by nested menus and sequential series of steps leading to each page of content. Hierarchical interfaces have the advantage of presenting individuals with an organized content structure, which allows them to "figure out" where their desired content can be found. While hierarchical interfaces were once ubiquitous, with the rise of the concept of Web 2.0, more and more web-based applications are relying on tagging-based interfaces (Sinclair and Cardew-Hall 2008).

Tagging-based interfaces (see Fig. 3) associate content with keywords. Tagging-based interfaces are typically built by users associating new content with keywords, thus creating "tags," through which they navigate an application or website. This kind of interface is popular form of website design, such as corporate intranets, because it allows the user community to organize content through their browsing and tagging activity. Applications with a tagging-based interface offer many ways to arrive at specific content, because many keywords will be associated with each page of content, and these keywords appear as tags in many places in the application.

Hierarchical and tagging-based interfaces map well to System 1 and System 2 processing. System 1 with its quick information processing based on judgment or intuition works well with tagging based interfaces where content is associated by browsing activity and tagging content with keywords for later retrieval. A tagging interface with its user generated links reflects the more variable thinking of users. The tags act as information processing shortcuts that the searching individual relies on for preprocessing thereby enabling System 1 processing.

Conversely, a hierarchical interface can be viewed as a formalized knowledge system. Both types act as knowledge repositories where encoded knowledge is stored for later retrieval based on current task demands. The hierarchical interface by design assumes an optimal path to the knowledge exists. System 2 thinking with its deliberate consideration of the task requirements closely emulates this style of system design. As such hierarchical interfaces are designed to support deliberative System 2 thinking.

While System 2 thinking can be portrayed as logical, rational, and desirable for decision making, when applied to an information searching situation, organizing information based on System 2 principles can cause undesirable situations. Individuals report that they prefer to organize and find information that is hierarchically stored, however when categorizing information into hierarchies these same individuals report that they have trouble in selecting the single best category for a given piece of information. As a result they experience cognitive dissonance when making these types of decisions, and work to delay making these decisions until it can no longer be avoided (Jones et al. 2005).

While hierarchical interface designs are quite common, they exhibit two fundamental issues. When designing the hierarchical interface, the first issue is generating unambiguous names for the categories to identify the information contained when a particular link is followed. The second issue is real world information often cannot be neatly categorized by a single descriptor, and is more likely to best be represented by overlapping categories (Dumais and Jones 1985). The result of using a hierarchical classification system is it forces information to be organized in a single way despite the likelihood of there being several best ways to classify the information.

When it comes to categorizing information, several competing methods have been proposed. In addition to the hierarchical structure discussed above, Barsalou (1991) describes “goal oriented categories” as a different way to present and organize information. Goal oriented categorization refers to creating ad hoc categories that integrate the information required to accomplish a goal, and when using a multi-threaded linking system would be implemented much like a tagging interface. Alternatively, information can be viewed from content oriented, task oriented, and context oriented perspectives (Ravasio et al. 2004). Tagging interfaces support all three types of categorization whereas hierarchical interfaces only support a single purpose and cannot support context oriented views at all (Uddin and Janecek 2007).

Categorizing information, at its core, is a many-to-many mapping of information to descriptor keywords. A hierarchical interface forces this into a one-to-many mapping of information to keywords. In order to understand why individuals make errors when searching for information, the underlying task that provides the impetus for a search must be discussed. Four objective characteristics can make a task complex (Campbell 1988). These are equifinality (e.g., many potential paths to reach a goal) multiple competing goals, an inability to draw direct causal links between a course of action and outcomes, and choosing one solution that necessarily precludes another. Campbell (1988) says one of the fundamental operators in making a task complex is adding different paths to attain the eventual goal. A tagging interface allows for multiple paths to reach the same outcome whereas the hierarchical interface only provides a single path to the goal.

2.3 Subject area knowledge

Subject area knowledge (SAK) refers to knowledge that users possess that is germane to an information search or other cognitive task. Those individuals with high levels of SAK can also be referred to as experts in a given subject area, while those with low levels of SAK are called novices. A high level of SAK is also indicative of a well-structured domain-related knowledge network, and this network conveys two advantages to the expert that novices do not have. The first being the connections within the knowledge domain are greater for the expert, and the second is the expert's knowledge is better organized than the novice's (Bordage and Zacks 1984; Gonzalvo et al. 1994). Experts typically organize their domain knowledge into closely related hierarchically structured groups.

When faced with a task, experts approach it differently novices (Adelson 1984; Snyder 2000). Experts will spend more time analyzing the task before beginning to directly address it (Chi and Glaser 1988). Experts have the requisite domain knowledge required to effectively restructure the task into something more familiar; therefore their past experiences can be of more use when addressing the task (Devine and Kozlowski 1995). In other words, the experts have the ability to restructure the task at hand to match their domain specific knowledge in order to more effectively utilize that knowledge which is indicative of hierarchical System 2 processing. Once the expert has restructured the task to fit into their hierarchical understanding of the issues, they switch to the more cognitively efficient System 1 processing to address the task (Kavakli and Gero 2002). Under ideal circumstances, it is expected that experts will make fewer mistakes than novices.

However, under some circumstances, expertise can lead to mistake-making behavior (Reason 1984; Wickens and Hollands 2000), and task characteristics have been considered as a possible remedy for this problem (Shanteau 1992). Psychology and human factors research has found a consistent, positive association between extremely high SAK and mistake-making (Shanteau 1992). Marchant et al. (1993) show that expert accountants were less effective at applying recently learned knowledge than novice accountants. Frensch and Sternberg (1989) found that expert chess players were less able to adapt to new rules than novices. In situations that call for creativity and nontraditional approaches to addressing the task, Wiley (1998) found that baseball experts were less able to creatively solve baseball problems than novices, and Kavakli and Gero (2002) found that expert designers were less likely to make accidental discoveries than novices. Collectively, this literature suggests that the decision-making ability of people with very high SAK may be "inaccurate, unreliable, biased, and lack self-insight," (Gaeth and Shanteau 1986), while people who acknowledge that they lack subject-area knowledge have been shown to be less error-prone (Shanteau 1978).

The positive association of SAK with mistake-making behavior seems unlikely at first. Experts may be mistake-prone because they rely on heuristic shortcut thinking. As a result, they may miss critical differences between their current situation and the allegory situation they are referencing for guidance. Specifically, expertise affords a decision-making heuristic called "recognition-primed decision making" (RPD) (Klein 2008), in which an individual is presented with several courses of action and selects the first reasonable one they consider. Under most circumstances, RPD is a beneficial phenomenon because it facilitates rapid behavior by short-cutting the deliberation process. Generally, heuristics are beneficial; they allow for rapid decision-making (Dougherty et al. 2008; Tversky and Kahneman 1973, 1974). The effects of RPD can be negative, however, because individuals generally tend to be overconfident in their estimation of whether they are making a mistake or should consider alternatives, and overconfidence tends to result in their engaging in less deliberation before acting (Wickens and Hollands 2000). Early MIS research suggests that users with a high level of task information search less for alternative choices during ICT use (Zmud 1979), which may lead to mistakes. It can be argued that expert users are likely to make a mistake by overlooking a correct alternative.

When faced with simple or complex tasks (e.g., information searches), an individual draws on different sources of intelligence and rationality. According to Card et al. (1983) rationality principle if an individual has knowledge that a particular action will lead to a goal, then the individual will select that action. This can be generalized to a problem solving situation, and suggests that individuals will choose the least cognitively demanding option available necessary to achieve their goals. According to dual process theories, individuals make decisions either very quickly by intuition using minimal cognitive resources (System 1), or more slowly utilizing cognitive resources and deliberately considering and weighing alternatives (System 2) (Kahneman 2003). The activation of these cognitive routines is relevant to mistake-making with mistakes more likely to occur when individuals employ System 1 thinking (Kahneman 2003). Therefore what leads to System 1 thinking versus System 2 thinking? Three possible factors can play a role in explaining mistakes—age, SAK, and interface, which comprises the crux of the research model.

2.4 Age, Interface design, and subject area knowledge intersect

While the literature has clearly demonstrated age effects, design effects, and subject area knowledge effects (see Table 1), how these relate to one another has not been

Table 1 Review of literature stream findings

2.1 Age
Prior studies have associated age with poor performance using ICT's, particularly when the performance metric is speed and the experimental task is analytical
Youth is associated with higher performance using "System 2" deliberative processing, which is marked by analysis of information
Working memory, which is critical to System 2 deliberation, declines with age. Experience increases with age
"System 1" deliberative processing, marked by the use of heuristics based on experience, saves time but may lead to mistakes caused by over-confidence
Youth is associated with confidence in ICT use, and age is associated with experience that may inform System 1 processing
2.2 Interface design
Hierarchical interfaces apply structure to the task of ICT use by supporting analytical deliberation. Thus, they support System 2 processing
Tagging-based interfaces reduce the task structure of ICT use because they embody fuzzy logic. Thus, they support System 1 processing
2.3 Subject area knowledge
Individuals with very high Subject Area Knowledge tend to restructure work tasks to leverage experience, thus saving time by engaging in System 1 processing
The expert, engaged in System 1 processing, relies on experience rather than analytical ability for performance
The miss-application of heuristics has been demonstrated to cause experts to make mistakes

investigated. It makes intuitive sense that age and subject area knowledge would be related to one another since experience comes with age. This is particularly relevant to a graying workforce where older individuals have the benefit of years of experience. It also makes intuitive sense that interface design and subject area knowledge would be related as well. Properly designed systems can help process information quickly much like experts can do without an available ICT. What is unknown, and what this study addresses is the interplay of all three of these factors. These differences exist in isolation, but can they be combined to offset the detrimental effects of each other? The next section explores this question.

3 Theoretical model

This section draws upon our review of the literature to address the issue of age in the workforce by developing testable hypotheses that connect age, SAK, and interface design with mistake-making. We develop our hypotheses in two steps. The first step explores the nature of the relationship between SAK and mistake-making. The second step builds on the relationship between SAK and mistake-making to hypothesize that SAK interacts with interface design and age in the prediction of mistake-making.

3.1 Subject area knowledge and mistakes

SAK drives how individuals make decisions. Users' SAK refers to knowledge of the domain that is being searched, not to knowledge of how to use IT. For example, consider users with high levels of health SAK searching for medical information. These experts may appropriately identify the information requirements, engage in System 1 information processing, and arrive at a correct solution to the originating problem. In such circumstances, studies suggest that individuals with greater SAK solve problems more quickly than individuals with lesser SAK. Conventional reasoning would argue that experts (those with high SAK in a given area) will make few mistakes and arrive at decisions more quickly than individuals with lower SAK (Hershey et al. 1990).

SAK can lead to wrong decisions when it is misapplied. In the human factors literature, the "strong but wrong" principle suggests that the misapplication of expertise can lead one to have more confidence in the wrong decision (Wickens and Hollands 2000). This is because individuals who believe they are operating in their realm of expertise tend to rely on System 1 thinking and act without deliberation (Ericsson and Simon 1980), which causes the user to proceed with acting (such as clicking on a link to the wrong medical information). The use of RPD would be expected to increase with SAK, so the likelihood of mistakes will increase with the users' SAK, though only to a certain point, where the user actually attains true mastery of health information. In essence, as an individual moves toward high health SAK, they may engage in System 1 thinking too soon when searching for information on a health-related Website. In other words, the individual misapplies their SAK on the subject as a result of engaging RPD.

Another explanation for SAK leading to bad decisions is overconfidence. Consider the case where an individual overrates their SAK; in this scenario the individual misses critical environmental cues as to the true nature of the problem, and mistakenly engage in System 1 when searching for information. When empirically tested, individuals consistently overestimate their predicted task performance even when evidence about their past performance on the same task exists (Moore and Small 2007). So the psychological factors which drive a user to use System 1 processing and possibly make mistakes do not have the up-side which usually benefits experts: that of the ability to recognize serious mistakes before they happen, and to quickly overcome minor ones.

It is expected that novices will make more mistakes than more experienced individuals. Further, it is expected that error rates should decline with increasing experience. However individuals can become overly reliant on their expertise and miss pertinent details. Maslow (1966) refers to this effect as the Law of the Instrument where he states "I suppose it is tempting, if the only tool you have is a hammer, to treat everything as if it were a nail." The implication being that expertise leads to incomplete informational cue processing and subsequent mistakes. This means the shape of the relationship would look like a "U" shaped curve whereby those with the least and most SAK would make more errors, while those with moderate amounts of SAK would make the fewest. These arguments suggest the following hypothesis:

Hypothesis 1: There is a curvilinear relationship between SAK and error rate.

3.2 Subject area knowledge, youth, interface design, and mistakes

Rational choice decision making theories argue that the utility of a choice is maximized when individuals arrive at the same choice under the same set of circumstances (Tversky and Kahneman 1986; Tversky et al. 1988). The knowledge that comes with expertise allows individuals to discern similar scenarios and apply the same selection rules. When empirically tested, an interaction between age and experience is found, such that age-related differences were lessened among experts and wider among novices (Vieluf et al. 2012). Expertise in a given area gives decision makers an advantage in structuring a problem to maximize the potential of making the best decision.

We extend this interaction between age and SAK and hypothesize a three-way interaction of age, interface design and subject-area knowledge shapes IT-enabled mistake-making. The effects of age and SAK compound one another (e.g. Vieluf et al. 2012) and, in concert with interface design, form a three-way interaction that leads to mistake-making behavior. The chain of events which may lead the younger user to make a mistake with ICT is this: While searching for information, the individual sees a link. The link is not to the content that is being sought, but the wording in the link (System 1 thinking) triggers a mental association with the desired content due to lower levels of SAK, hence clicking on this link would be a mistake. The individual who made the mistake is confident in their SAK applies RPD behavior to arrive at the conclusion that they have achieved the threshold of sufficient information to stop searching, and then click on the link (see Fig. 1). This is consistent with expert behavior: people with a great deal of experience in a knowledge domain tend to infer too quickly from scant information, and, thus, move to a decision before carefully considering additional information (Rabin 1998).

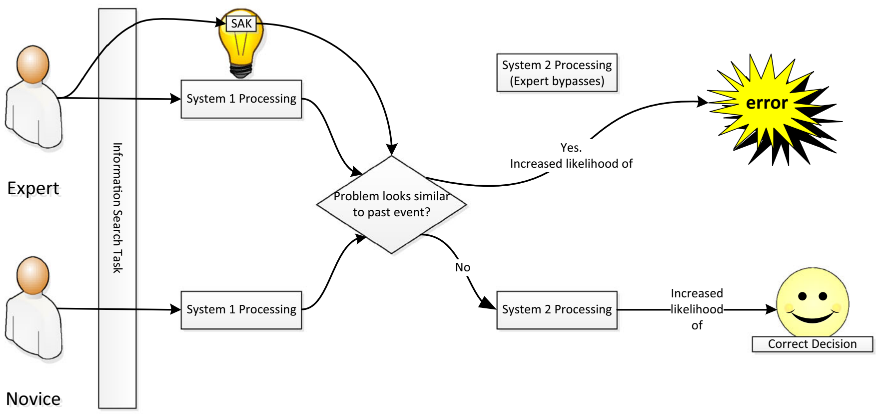

Fig. 1 The influence of SAK and RPD on the information search task

The presence of a tagging-based interface converts the search activity from a structured task to a poorly-structured task (Browne et al. 2007). Poorly-structured tasks, through their prompting of System 1 thinking (Browne et al. 2007), place the younger user at a disadvantage, because System 1 processing relies more on more-developed SAK, which is found in greater abundance in older individuals (Mienaltowski 2011; Strough et al. 2011). When they believe they possess greater subject area knowledge, as well, younger users will be primed to use System 1 thinking (Klein 2008).

By contrast, on the hierarchical interface, the younger users will be able to engage in a deconstructive search strategy (System 2 thinking) that conveys the advantage of deeper cognitive processing (Browne et al. 2007). They will be able to work out navigation by using the structure of the hierarchical menus; this is a deliberate behavior and thus less vulnerable to being hijacked by heuristic RPD patterns which may lead to mistakes. This organization of navigable links results in the search task being a highly-structured task. Many interfaces, however, cannot provide this affordance, due to constantly changing content. These are commonly found in Web sites which are built from user content, such as forums, blogs, wikis, and many other "Web 2.0" applications (Sinclair and Cardew-Hall 2008). Thus:

> Hypothesis 2: The interaction of age, subject-area knowledge, and interface type is a significant predictor of error rate, in that the perceived knowledge area familiarity of younger users only, and only when using a tagging-based interface, will be positively associated with mistake-making behavior.

This hypothesis directly addresses the motivation of this study. Organizations and governments are presented with the challenge of a graying workforce in an age of ubiquitous ICT use; yet and the preponderance of research and guidance on age and ICT use is focused on the disadvantages of older workers. Hypothesis 2 proposes an advantage that comes with experience and would thus be associated with older workers, and that advantage is that older workers would be less likely, under the proper circumstances, to make mistakes while using ICT's.

4 Methods

When a user is using an ICT to reach a decision, they are likely operating in a knowledge domain of some activity, i.e., their task (Lamb and Kling 2003). This is addressed in the following sections where details about the study participants, the measures used, the experimental interface, the experimental task, and the study procedures are provided.

4.1 Participants

Subjects for the experiment were recruited from two locations in Southeastern United States. Younger subjects were recruited on a large college campus and either received course credit or compensation at 7 dollars an hour. Older subjects were recruited from an independent living facility via newspaper advertisements and were compensated at 7 dollars an hour.

In addition to basic demographic information, subjects also self-reported the number of prescriptions medications they were currently taking as an indirect measure of prior health related knowledge (Pak et al. 2009).

A total of 60 subjects (33 females, 27 males) were in the younger group. These subjects ranged in age from 19 to 23 ($\bar{X}$ = 19.83 sd = 1.84). A total of 48 subjects (28 females, 20 males) were in the older group. These subjects ranged in age from 60 to 80 ($\bar{X}$ = 68.52, sd = 5.27). Across the whole sample, 61 were female, and 47 were male. When asked about their frequency of computer use, 50 subjects in your younger group (83 %) reported using the internet 10 h or more per week while 35 of the older subjects (73 %) reported using the internet 10 or more hours per week. Fifty two subjects were in the tagging experimental condition, and fifty six subjects were in the taxonomy experimental condition.

4.2 Measures

Being an experiment, many of the variables under consideration are dichotomous. Interface type is a binary variable, with the types being hierarchical and tagging-based. Age is also a binary variable, operationalized as either younger than 26 or older than 60. Since cognitive abilities change at different rates for different individuals, age effects could be masked if it was treated as a continuous variable. Furthermore, the span of approximately 30 years between young and old participants allows us to isolate age-related impacts effectively.

Two continuous variables are also included in the research model. Error rate, the dependent variable, is our measure of mistake-making behavior, operationalized as the number of times that subjects clicked on a link that did not take them to the content they were seeking. The other continuous variable, subject area knowledge, is the Short Test of Functional Health Literacy in Adults (STOFHLA). The STOFHLA is a well-established and valid test of general health literacy (Baker et al. 1999; Chesser et al. 2014; Gazmararian et al. 1999).

4.3 Experimental interfaces

To ensure that the two different interfaces had equivalent information all information was extracted from the National Institutes of Health website NIHSeniorHealth.gov (NIH 2009). One hundred twenty two webpages were captured which provided the information available to experimental subjects. Once the information was extracted the process of organizing it into a hierarchical and tagging system was begun.

To create the hierarchical system, undergraduate students participated in a card sorting exercise where they placed the 122 cards into hierarchical structures that made sense to them. After the cards were grouped, they named each group. After several card-sorting sessions, the results were merged in order to create the hierarchical structure. This structure was comprised of 10 top-level categories (bone and joint, cardiovascular diseases, depression, diabetes, dry mouth, hearing and vision, lung diseases, medications, skin cancer, and talking to your doctor). This same methodology for creating hierarchical interfaces has been used in previous research (Pak and Price 2008; Pak et al. 2009).

The tagging system was created from the hierarchical system. For example the hierarchical system had a page on gout treatment organized along the following path: Bone and Joint > Arthritis > Gout > Treatment. In the tagging system it received the following keywords: "Bone and Joint", "Arthritis", "Gout", "Treatment." The overriding goal for developing the tagging system was to keep the naming conventions constant across both conditions. This ensures that one condition does not have access to more or better information.

To further standardize the experience between conditions, fonts, text size and color, and background colors were identical between the conditions. However two differences were apparent. The first is the hierarchical condition (see Fig. 2) is visually longer than the tagging condition (see Fig. 3). Furthermore pages were only accessible in the hierarchical condition if a subject took the right path to the information (i.e. the only way to get to gout treatment is down the Bone and Joint > Arthritis > Gout > Treatment path). In the tagging condition choosing any label associated with a page could access pages.

Hierarchical organization is the typical method used in organizing content online or in a file structure on a computer—folders within subfolders each following some sort of logical grouping. In other words the hierarchical method is the result of having to organize content into filing cabinets and is reminiscent of Web 1.0 thinking. Tagging organization, on the other hand, content is "tagged" with keywords and users click on the relevant keywords and content matching that keyword is displayed. This method is similar to the way content is organized on websites such as Flickr, Facebook, or Tumblr. This type of organizational methodology is one of the hallmarks of Web 2.0 and the social web (Parameswaran 2007; Zammuto et al. 2007).

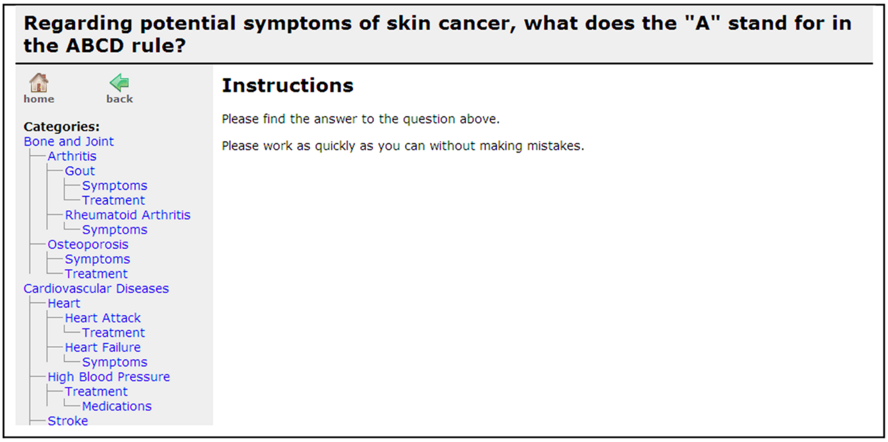

Fig. 2 Hierarchical interface screen shot

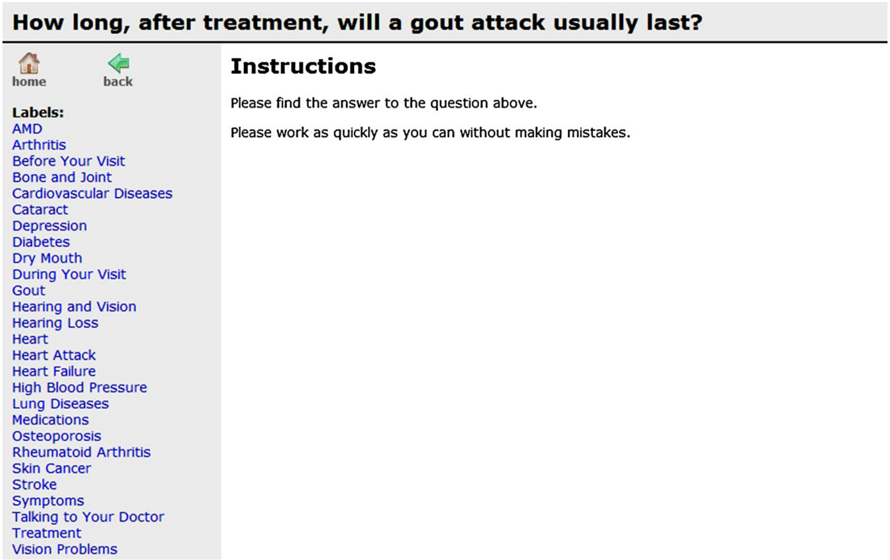

Fig. 3 Tagging interface screen shot

4.4 Experimental task

Participants were tasked with answering 25 health related questions. To answer the questions, subjects had to find the information on the website provided. Half the subjects answered questions using the hierarchical interface, and the other half used the tagging interface. As an example, a health-related question is, "What is considered normal blood pressure?" Once a subject found the answer on a specific webpage, they clicked the answer and the application presented feedback as to whether the answer was correct. The web application was programmed in PHP and ran on a WAMP (Windows XP, Apache 2.2.6, MySQL 5.0.45, PHP 5.2.5) server. All client machines were connected on a wired network hence server response and page load times were not an issue. The application recorded the name of each visited page, the length of time spent on each page, and the number of times the back button was pressed.

4.5 Study design and procedure

The study was a 2 (age group: young, old) X 2 (interface: hierarchical, tagging) factorial with age as a grouping variable and interface as a between subjects group variable. Subjects were randomly assigned into an interface condition. Additionally SAK was included as a covariate in the analyses. Sessions were assigned to each interface condition and each session was comprised of three or four subjects; therefore all subjects within a session were assigned to the same interface type (hierarchical or tagging). The dependent variable was number of errors made.

Upon entering the lab, subjects completed relevant paperwork (e.g. consent forms, demographics, and abilities tests) and then went to the computers to begin the experiment. Each session of subjects saw two sample tasks where the experimenter guided them through the system answering any questions and clarifying aspects of the interface. After the practice session, subjects were told to complete the search tasks as quickly and accurately as possible. Subjects were left to work at their own pace, but these instructions were reiterated after each question. Upon completion of the 25 questions, subjects were compensated and they left the lab.

5 Results

The experimental data are analyzed in this section. All research hypotheses were tested using SAS version 9.1.3 with Service Pack 4. Analyses were conducted utilizing the general linear model (GLM) which form the foundation for various statistical tests with ANOVA, ANCOVA, and regression analysis being examples of the most commonly used GLM analyses (Maxwell and Delaney 2004).

5.1 SAK and error rate

Hypothesis 1 states that SAK will display a curvilinear relationship with error rate. This relationship is expected because experts will incorrectly apply time saving heuristics thereby missing key differentiating indicators that the moderately experienced will not miss.

Polynomial regression was used to test the hypothesis. To conduct the analysis, a quadratic term for SAK was created. Error rate was then regressed on both the linear and quadratic term for SAK. If Hypothesis 1 is correct, then the quadratic term will be positive meaning that the predicted error rates are higher for both novices and experts and lower for those individuals with moderate levels of SAK.

The results of the hypothesis test were significant [$F_{(2,\ 104)} = 3.82$, MSE = 401.08, $p = 0.03$] indicating that there is a relationship between SAK and error rate (see Table 2). Investigating the individual regression parameter, Hypothesis 1 is supported; the quadratic term displays a significant, positive relationship with error rate. As can be seen in Fig. 4, error rates are predicted to be lowest for moderate levels of SAK, with the highest error rates being predicted for those individuals with both the lowest and highest levels of SAK. The implications of this finding are discussed in Sect. 6.2.

5.2 SAK, youth, interface interaction

Hypothesis 2 states that SAK, age, and interface will interact; specifically younger users with high SAK using a tagging interface will have higher error rates. To test

Table 2 Polynomial regression results

Predictor	DV: error rate ($N = 107$)			
	β	Std. error	T	p
Subject area knowledge	−14.69	5.57	−2.64	0.009
Subject area knowledge × subject area knowledge	1.87	0.68	2.76	0.007

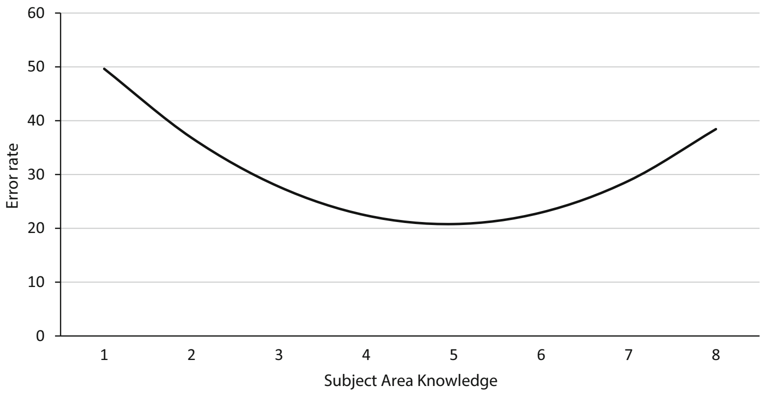

Fig. 4 Predicted values for curvilinear effect of SAK

this hypothesis, an ANCOVA was conducted. Prior to presenting the results for Hypothesis 2, a brief discussion on the assumptions of ANCOVA is warranted.

The primary assumption of the ANCOVA design is that a linear relationship exists between the dependent variable of interest and the covariate (Stevens 2002). The result of Hypothesis 1 demonstrates that a curvilinear relationship exists between error rate and SAK. The preferred remedy for this situation is to transform the data in such a way that the data are linear (Stevens 2002). Therefore prior to testing Hypothesis 2, a square root transformation was applied to the SAK variable.

After transforming SAK, Hypothesis 2 was formally tested. The overall model was significant [$F_{(7,\ 100)} = 2.35$, MSE = 513.28, $p = 0.03$, $\eta^2 = 0.14$] indicating that subsequent effect tests were not due to chance. Hypothesis 2 predicted an interaction between SAK, interface type, and age. This interaction test was significant [$F_{(1,\ 100)} = 8.12$, MSE = 513.28, $p = 0.01$, partial $\eta^2 = 0.06$] thus Hypothesis 2 was supported (see Table 3).

In order to better understand the effects of the three way interaction, the data were subdivided into four groups based on age and interface type. Once divided, four polynomial regressions were conducted. In each regression analysis, error rates were regressed on both the linear and quadratic SAK terms. The results of these analyses are shown in Table 3. One thing to note about the results in Table 3 is that these results apply to the interaction test. While many of the regression parameters are not different than zero, they are significantly different from each other.

Next the predicted regression lines for each condition were plotted relative to each other. As can be seen in Fig. 5, the different conditions resulted in quite different prediction curves. For younger users, those using a tagging interface are predicted to make more errors as their SAK increases. However, when using a taxonomic interface, those individuals are expected to see a reduction in errors as their SAK increases. Older users conform to the expectation that those with the lowest and highest levels of SAK will make more errors than users with moderate levels of SAK. However the effects of SAK are more pronounced for the tagging

Table 3 Regression results by experimental condition

Predictors (Youth, tagging) $R^2 = 0.19$	DV: error rate ($N = 29$)			
	β	Std. error	T	p
Subject area knowledge	−0.07	10.83	−0.01	0.99
Subject area knowledge × subject area knowledge	−0.65	1.28	0.50	0.62
Predictor (Youth, taxonomy) $R^2 = 0.05$	DV: error rate ($N = 31$)			
	β	Std. error	T	p
Subject area knowledge	−6.89	9.65	−0.71	0.48
Subject area knowledge × subject area knowledge	0.53	1.27	0.42	0.67
Predictor (Aged, tagging) $R^2 = 0.43$	DV: error rate ($N = 23$)			
	β	Std. error	T	p
Subject area knowledge	−36.62	9.63	−3.80	0.001
Subject area knowledge × subject area knowledge	3.97	1.12	3.55	0.002
Predictor (Aged, taxonomy) $R^2 = 0.09$	DV: error rate ($N = 24$)			
	β	Std. error	T	p
Subject area knowledge	−18.81	13.50	−1.39	0.17
Subject area knowledge × subject area knowledge	2.34	1.65	1.41	0.17

condition relative to the taxonomic condition. The implications of these findings are discussed further in Sect. 6.2.

6 Discussion

Prior to discussing the implications of this work, limitations must be noted. In the following section, these limitations are addressed, and then the implications are discussed.

In a study on errors, approximately 10 % of the time an individual spent on a task was spent making corrections (Chen et al. 2010). This finding, extrapolated over the course of a working year equates to approximately 5.2 weeks an individual spends correcting mistakes.

7 Limitations

This experiment was carried out using online medical information as the subject area for the experimental task. While the underlying psychological factors of subject-area knowledge are consistent across knowledge domains (Feltovich et al. 2006; Mitchell et al. 2000), additional studies may be warranted to support the

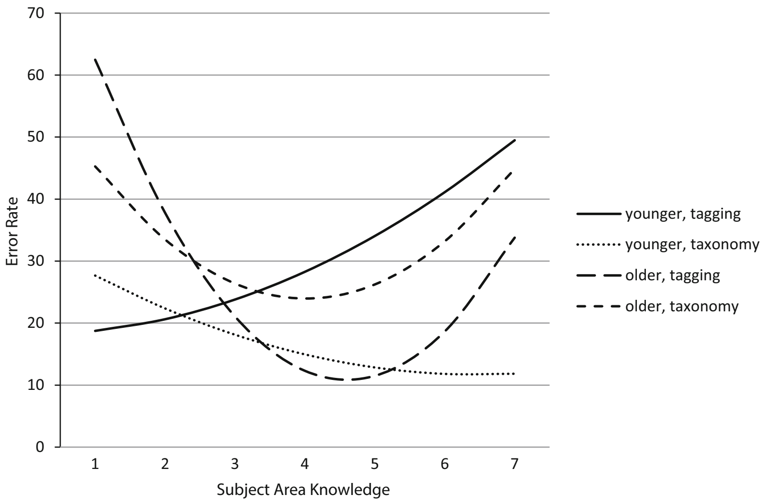

Fig. 5 Predicted values for error rate by age group and interface type

inference that the results of this experiment can predict mistake-making behavior in other contexts.

In addition, it is easy to confuse our dependent variable with indicators of performance, such as speed. Experts can be expected to demonstrate superior performance as typically measured in psychological studies (Greeno and Simon 1988). This study is only concerned with mistake-making behavior as a dependent variable. It may be that the mistakes made by experts are less severe than those made by novices and that experts recover more quickly from mistakes (Shanteau 1992), thus resulting in better overall performance by most measures.

Finally we were unable to conduct an interesting post hoc analysis due to power issues. It would be interesting to determine among experts, those with the highest subject area knowledge, if error rates were impacted due to age and interface design. When we attempted to analyze that question, there was not enough power to make that determination. Future research should investigate this interesting idea.

7.1 Implications

The broad implication of this work is that research on an ageing workforce may provide value by considering the possible benefits of age in addition to the well-documented advantages of youth in ICT use. Prior works (e.g. Pak et al. 2009) have proposed that the experience that comes with age may be a source of advantage for older workers (Tams et al. 2014). In this spirit, this research contributes to a range of research streams and should serve as a foundation for future investigation designed to provide useful guidance to organizations as they cope with a graying workforce. This paper contributes to the age and ICT use literature in several ways (see Table 4 for an overview). First, it contributes to a growing understanding about task performance in ICT use. In an information intensive environment, measuring task

Table 4 Review and summary of study contributions

Findings of this study	Source theory and research	State of knowledge *before* this study	State of knowledge *after* this study	Practical implications	Research stream this contributes to:	References
Advanced age is not necessarily detrimental to ICT use	Age and Cognition	As individuals age, their ability to use ICTs error-free diminished	The interface an individual uses can mitigate errors, particularly for older individuals	Systems designers need to design interfaces in such a way as to mitigate the probability a user can make an error	Age and HCI	Lee et al. (2011); Mienaltowski (2011); Myerson et al. (2007); Rogers et al. (2005)
System design can impact mistake-making depending on the age of the user	System 1/System 2 Processing; Human Factors Engineering	Younger individuals are purported to have greater fluid intelligence, and thereby make fewer mistakes—though other research has shown older individuals perform well on tasks that require fluid intelligence	Interface design can help users tap into their fluid intelligence	Interface design can help reduce the amount of mistakes individuals make when searching	HCI	Dumais and Jones (1985); Jones et al. (2005)
Subject area knowledge can be detrimental to performance	System 1/System 2 Processing; Human Factors Engineering	The more knowledgeable an individual is about a given area, the fewer mistakes she will make due to that knowledge	Knowledge can lead to overconfidence or misreading a situation, thereby leading to more errors	Experts need to be aware that subject area knowledge does not make them immune to making mistakes	Age and task performance	Adelson (1984); Bordage and Zacks (1984); Gonzalvo et al. (1994); Maslow (1966); Shanteau (1992)
Mistake-making is a useful performance-related dependent variable to examine in the context of age and ICT use	Human Factors Engineering	Past dependent variables in age research, such as computer self-efficacy and anxiety, subsume age is a disadvantage, and these dependent variables fall short of explaining use-related performance aspects	Mistake-making offers a useful measure of performance in system use. It can describe improved ICT performance for the domain of a graying workforce	Organizations can address mistake-making more directly than psychological factors such as computer self-efficacy and anxiety	Task performance	Huysmans (1970); Karavidas et al. (2005)

performance via mistake-making is appropriate. Arguments on public policy have been waged with evidence rooted in spreadsheets that contain errors, among the most famous of which is the Reinhart and Rogoff (2010) error that mistakenly analyzed an incomplete dataset. Thus, there is a need that factors that mitigate mistake-making be explored, and this study takes important first steps in this regard. Second, this research takes a novel approach to age and ICT use by abandoning the tradition of focusing, in a value-laden and negative way, on the challenges faced by older users. Instead, methods of system design are investigated to alleviate age related performance decline. Additionally, by providing an experimental task that was designed to allow subjects to transition between System 1 and System 2 processing, more generalizable results were obtained. This study demonstrates that tasks do not exist within a vacuum, but instead individuals rely on their accumulated knowledge to help address the strategy used to accomplish a task.

In addition, this paper presents a resolution to the apparent contradiction in existing aging literature. While younger people are known to have greater fluid intelligence (Birren and Schaie 2006), in at least some laboratory tests of problem-solving, older subjects have performed unexpectedly well (Artistico et al. 2010). Existing literature has suggested that the resolution lies in the nature of the experimental task and has called for experimental tasks with greater ecological validity (Mienaltowski 2011). Our paper presents empirical evidence, as well as a theoretical explanation of how the performance of older research subjects is contingent on the selection of fuzzy, real-world, experimental tasks. In addition, our results point to an effective treatment: interface design can allow younger users to capitalize on their fluid intelligence to perform well and avoid mistakes. Thus, we not only caution industry by pointing out that their most knowledgeable young employees may be mistake-prone; we also provide direction regarding a practical treatment for this problem.

One reason behind the negative focus of the preponderance of age/IT research might be the limited range of choices of dependent variables. Computer self-efficacy (CSE) and computer anxiety have been found lacking in older users (Karavidas et al. 2005), and negative attitudes toward computers have been identified as a disadvantage of age (Huysmans 1970). This study is among the first to consider the benefits of being older. By expanding the pool of dependent variables to include positive phenomena that are associated with older users, future studies may take on an optimistic tone regarding older ICT users. Thus, a collateral contribution of this paper is that it demonstrates a novel application of age-related theory, one that pinpoints a benefit of age, in contrast to the bulk of age-related IS literature, which treats age as a challenge to be overcome.

Additionally, this research has implications for system designers. In selecting a type of interface to implement, designers should consider the type of user likely to use the site. Ideally, information will be presented in such a way that users can rely on System 1 processing and draw upon their fluid intelligence. This is in contrast to traditional design philosophies which focus on the source of the information instead. Crowd sourced or user contributed content is particularly suited for a tagging style interface because it is relatively easy to implement tags versus formally designing and building a hierarchical structure.

Finally, it is important to note that the knowledge domain that is the focus of this study is not information systems; it is whatever information the user is utilizing the information system to manipulate. Subjects' subject-area knowledge of medical information, when combined with a challenging interface, caused heuristic behavior carried out over an information technology. The ability to recognize serious information technology mistakes (such as clicking on a link in a phishing email, for example) or to overcome them quickly should not be a factor of a user's non-IT domain knowledge. For example, a high level of knowledge about the subject of a phishing email may actually reduce the user's deliberation of the email and reduce the probability of threat detection. Hence, subject-area knowledge will not always protect users from information technology use mistakes, but instead it may help cause those mistakes.

8 Conclusion

This study brings together the literature surrounding aging, expertise, and interface design to create a theory-based understanding of mistake-making with information technology. Youth, subject-area knowledge and information technology are demonstrated to, under some circumstances, lead to problems. It also demonstrates that design features can mitigate those problems. Further research can continue to integrate human factors engineering with social aspects of ICT use, such as youth and other individual differences, to find and treat new issues within a diverse population of workers.

In addition, this paper acts as a call for researchers to broaden their range of dependent variables to include those which cast older users in a positive light. The focus of this paper is on the younger user, but the contrast with older users reveals an advantage that older users have. Further research would serve industry well by identifying additional advantages that come with age.

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