Design and evaluation of smart home user interface: effects of age, tasks and intelligence level

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Smart homes are expected to promote productivity and enhance living experience, especially for old adults. To achieve this, the level of user interface intelligence should be designed to meet the needs of users and tasks. The aim of this study was to investigate the impact of user interface intelligence level on user performances for different tasks and different users. Two objectives were pursued. The first was to investigate how the intelligence of the user interface affects user performance when different cognitive tasks are performed. The second was to determine the differences between young and senior users when interacting with smart homes. A two-dimension conceptual model is proposed to describe the impact of these two factors, i.e., user interface intelligence and cognitive tasks, on smart home user performance. A 3-by-3 experiment was designed and three prototypes were developed. Thirty-six young and 36 senior people were recruited as participants. The results showed that different levels of intelligence of user interfaces facilitated user performance with different cognitive tasks. Users completed skill-based tasks using the least time and committing the least errors using the low-intelligence-level interface; when completing rule-based tasks, users exhibited best performance in terms of less error with the high intelligence interface. However, for senior people, because of the decline in cognitive abilities, their performance was not as clearly differentiated as that of younger people when using different smart home interfaces, especially for highly cognitively demanding tasks. Moreover, when senior people completed skill-based tasks, the task load they perceived increased together with the intelligence level of the smart home interface.

Keywords: smart home; intelligence level of user interface; cognitive mode; old adults

1. Introduction

Users of smart home products may be old or young, healthy or disabled, experts or novices in using computers. Therefore, smart home user interfaces should meet the requirements of various users. The smart home is not only an electrical product for people to use but also an environment for people to live in. People spend a lot of time in it every day. ‘The main goal is to make human interactions with the systems effective, safe and enjoyable and entertaining’ (Agah 2001). A number of in-depth researches were conducted on smart homes including infrastructure, hardware and software. Most of these researches focused on smart home enabling technology. ‘Comparatively less attention has been paid to the development of comprehensive, comfortable and self-explanatory user interfaces’ (Borodulkin and Ruser 2002). Hence it is important to study smart home user interfaces.

Increasing the intelligence or smartness level of the user interface is one of the main objectives in the smart home research. But the user interface intelligence is not the ultimate goal. Instead, the focus should be on how to design smart homes that enhance productivity and improve living experience. Is a higher level of intelligence in the user interface better? How do people interact with a smart environment in which more and more tasks are automated? Will such smart technologies facilitate or impede user performance? It is expected that smart home technologies would build seamless interactions between humans and the environment but few studies have been conducted with regard to how smart a smart home should be.

Smart homes have potentials to support independent living of older people, since they can provide a continuously monitoring environment with the ability to automate specific tasks, to alert helpers when needed, to provide a secured environment, and to facilitate the rehabilitation of individuals (Edge et al. 2000). This is especially important in an aging era as today. Societies are ‘getting older’ and this aging of societies is occurring worldwide. Within Asia, North America, and Europe, the current percentage of the population older than age 65 ranges from 6% to 15%. It is estimated that by 2030, those figures will range from 12% to 24% (Fisk et al. 2004). With the
development of aging societies, we need to pay more attention to the design of smart home interfaces for elders. Traditionally, technology associated with aging mainly applied to diseases and disabilities. As a wealthier and more technology-savvy generation is aging, there is a calling for smart technologies extending independence, productivity, and quality of life for senior citizens (Office of Technology Policy of the Commerce Department’s Technology Administration 2005).

Some exploratory studies have been conducted to collect the requirements of proper smart home design enhancing independence and quality of life for elders. In a study of older adults that explored the perceptions and expectations of seniors with regard to ‘smart home’ technology, although a general overall positive attitude towards smart technologies was found, there were also concerns about the user-friendliness of devices (Mann et al. 2007). In another survey among 673 older people, it was also found that smart technologies have been underutilised by the senior generation (Demiris et al. 2004). Martin et al. (2007) conducted a qualitative study investigating care staff perspectives on user interface design and critical core information for information and communication systems embedded in the home of elders with dementia. However, to date, empirical confirmatory studies conducted to understand the difference between young and senior people when interacting with smart homes are sparse. As an effort to address this questions, this study focused on the interaction issues between users and smart home and has two objectives as follows: (1) to investigate how the intelligence level of user interface would affect user performance when different cognitive mode tasks are performed; and (2) to find possible differences between young and senior people when they use the same interfaces of smart homes.

2. Conceptual model and hypotheses

2.1. Conceptual model

A two-dimension conceptual model is proposed in this study. The two dimensions are the intelligence level of the user interface (SLI) and cognitive mode (CM).

The user interface intelligence has three levels: low, medium, or high. At a low-intelligence-level the user interface is device-oriented. Users complete tasks by manipulating each device directly on the user interface. At the medium-intelligence-level the user interface is task-oriented. A task is divided into several actions. The smart home would ask for the user’s confirmation before each action. Furthermore, if there is more than one way to finish the task, users need to choose the preferred method on the user interface. At the high-intelligence level the user interface is also task-oriented. The difference from the medium level is that the completion of tasks is more automated, meaning that the smart home would automatically carry out all actions in a task without any advance confirmation from the users. If there is more than one way to perform the task, the smart home will choose one instead of providing choices for the users. Table 1 describes the intelligence level criteria of the user interface.

According to Rasmussen’s SRK model (Rasmussen et al. 1994), in a task, people’s cognitive mode could be skill-based, rule-based or knowledge-based. At the lowest level, the skill-based mode, human performance is governed by patterns of preprogrammed behaviours represented as analogue structures in a time-space domain in human memory. When a familiar situation is recognised, a certain feedback is made. Neither any conscious analysis of the situation nor any sort of deliberation of alternative solutions is required. At the middle level, rule-based mode, human performance is governed by conditional rules. Behaviours at this level require conscious preparation: first recognition of the need for action, followed by retrieval of past rules or methods, and then composition of new rules through either self-motivation or instruction. The rule-based mode is slower and more cognitively demanding than the skill-based mode. At the highest level, the knowledge-based mode, human performance is governed by a thorough analysis of the situation and a systematic comparison of alternative means for action. Goals are explicitly formulated and alternative plans are compared rationally to maximise efficiency and minimise risks. Alternatives are considered and tested either physically, by trial and error, or

<table>
<thead>
<tr>
<th>Intelligence level of user interface</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manipulation Style</td>
<td>Direct manipulation</td>
<td>Software agent (tasks)</td>
<td>Software agent (tasks)</td>
</tr>
<tr>
<td>Feedback Information</td>
<td>From each devices</td>
<td>From each action consisted in the task</td>
<td>From each task</td>
</tr>
<tr>
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<td>Semi-automatic</td>
<td>Semi-automatic</td>
</tr>
<tr>
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<td>No</td>
<td>Automatic</td>
</tr>
<tr>
<td>Decision-making</td>
<td></td>
<td>Yes</td>
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</tr>
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</table>
conceptually, by means of thought experiments. The knowledge-based mode is even slower and more cognitively demanding than rule-based mode, since it requires accesses to an internal or mental model of the system as well as laborious comparisons of work methods to find the optimal one.

2.2. Hypotheses

2.2.1. Hypothesis 1

User performance will be higher with low-intelligence user interface rather than medium- or high-intelligence user interface for skill-based tasks.

Users perform some activities daily at home, such as turning on lights, opening the curtain, and so on. According to the SRK model, these behaviours fall into the skill-based mode category. Based on past studies, user interfaces that support skill-based behaviour should allow users to act directly on the display and have an information structure mapping the physical world (Rasmussen 1983). Low-intelligence user interface, in other words, a device-oriented user interface, enables a direct manipulation style; hence it is predicted that users will perform better with low-intelligence user interfaces rather than medium- or high-intelligence user interfaces for skill-based tasks.

2.2.2. Hypothesis 2

User performance will be higher with high-intelligence user interface rather than low- or medium-intelligence user interface for rule-based tasks.

In rule-based mode, human performance is governed by conditional rules. Users act by retrieving past patterns or methods in long-term memory. High-intelligence user interfaces provide users with some predefined tasks just like the past patterns and methods in users’ long-term memory to some extent. Thus, for rule-based tasks, users can perform better by choosing a particular predefined task which is compatible with his rules.

2.2.3. Hypothesis 3

For young people, user performance will be higher with medium-intelligence user interfaces rather than low- or high-intelligence user interfaces for knowledge-based tasks.

When knowledge-based tasks are performed, human performance is governed by a thorough analysis of the situation and a systematic comparison of alternative means for action. Users would perform better if their expertise evolves. Compared with the low-intelligence level interface, the medium-intelligence user interface can improve participants’ expertise by providing predefined tasks. Compared with the high-intelligence user interface, the medium-intelligence user interface offers the opportunity to choose alternatives. Thus, it is predicted that for young people completing knowledge-based tasks, user performance will be higher with the medium-intelligence user interface rather than the low- or high-intelligence user interface.

Knowledge-based tasks are more complex and cognitively demanding compared with skill-based and rule-based tasks. It is reported by some researchers that significant declines were found in senior people’s working memory (Howard and Howard 1997), divided attention (McDowd and Craik 1988), and intelligence (Birdi et al. 1997) when work becomes complex and cognitively demanding. These significant cognitive declines play more important roles in the performance of knowledge-based tasks than the manipulation on SLI. Thus, it is predicted that, for senior people, the manipulation on SLI will make no significant difference in user performance.

2.2.4. Hypothesis 4

4a For young people, perceived task load will be lower if the intelligence level of the user interface is compatible with the task.

4b For senior people, perceived task load will increase when the intelligence level of user interfaces increases.

For young people, it is predicted in hypotheses 1 – 3 that for different tasks, user performance will be significantly affected by the manipulation on SLI. Thus it is further predicted that perceived task load will be lower if the SLI is compatible with the task.

Focused attention transforms into divided attention when the interface intelligence shifts from low level to medium or high level. More working memory is required as the user interface intelligence level increases. Considering the evident decline in divided attention and working memory in older adults, it is predicted that for senior people, perceived task load will increase when the user interface intelligence increases.

3. Method

3.1. Participants

Two groups, 36 young and 36 senior people, participated in these experiments. To reduce the undesired variations among participants such as education levels, gender, computer-using skill, etc., all of the young people were male undergraduate students from the Department of Industrial Engineering, Tsinghua
University. The senior group consisted of males recruited from an advanced computer training class in Tsinghua community. All participants had little prior knowledge about using smart home products but were experienced with using computers.

There were statistically significant differences in age and computer use frequency between the two groups of participants. The ages of the young participants ranged from 19 to 23 with the mean at 21.0 years and a standard deviation of 0.91 years. The senior participant ages ranged from 59 to 81 with a mean of 70.3 years and standard deviation of 4.21 years. The young participants used computers more frequently than the senior participants. Since both groups had computer experience (5.6 years for young participants and 6.8 for senior participants at average), the practical difference in computer use frequency could be neglected in this study. For Education, Computer Experience, Knowledge about Smart Home and Touch Screen Experience, no statistically significant differences were found between the two groups of participants.

3.2. Experiment design
A 3-by-3 mixed design was used in these experiments. The between group factor was the SLI and the within group factor the CM. There were three levels of SLI: low, medium, and high, and three levels of CM: skill-based, rule-based, and knowledge-based. Thirty-six participants in each age group were randomly nested under the SLI factor. Each participant performed three groups of tasks: skill-based, rule-based, and knowledge-based. The task group sequence was randomised as well.

3.3. Users interface prototypes
Three types of computer-based user interfaces were developed for these experiments using tools from Microsoft Visual Basic 6.0 and Macromedia Flash MX 2004. Visual signals from the CRT and speaker audio signals from the speakers were employed to provide feedback to the users. A touch screen was used in these experiments while the use of keyboard and mouse was forbidden.

3.3.1. Low-intelligence user interface
The low-intelligence user interface was designed device-oriented. Users could manipulate each device directly on the screen. Through the user interface, users were able to examine the status, control with instant feedback and arrange actions in the future for each appliance. Figure 1 shows a screenshot of the low-intelligence-level interface.

3.3.2. Medium-intelligence user interface
The medium-intelligence user interface was designed task-oriented. Tasks were decomposed into pre-programmed actions, and the system would finish each action after asking for users’ confirmation. Furthermore, if there were more than one way to finish a task, the user interface of smart home would display a list of choices for the users. Figure 2 shows a screenshot of the medium-intelligence user interface.

3.3.3. High-intelligence user interface
The high-intelligence user interface was also designed as task-oriented. It has an appearance similar to that of the medium-intelligence user interface. Users interacted with the smart home by finishing tasks composed of a series of actions. The high-intelligence...
The user interface was smarter than the medium-intelligence user interface in two aspects. First, the high-intelligence user interface is more automatic than the medium-intelligence user interface. When a user chooses a task on the high-intelligence user interface, the smart home executes all actions automatically without asking for user involvement before each action. Second, the high-intelligence user interface has greater decision-making authority than the medium-intelligence user interface. If there are multiple ways to perform a task, the software agent makes the decision itself.

3.4. Usability

Since the participants' performance may be affected by the usability of the user interface, it is necessary to evaluate the usability of the three interface prototypes. Lin et al. (1997) reported that the Purdue Usability Index had good construct and content validity. Before these experiments were carried out, three usability experts were asked to score the usability of the three interface prototypes. The results showed that the mean score of the low-intelligence user interface was 72.61, medium-intelligence user interface 70.63, and the high-intelligence user interface 69.11. This indicated that the usability scores of the three prototypes were comparable to each other and could be considered at the same level. Hence the variance of participants' performance caused by the user interface usability was not taken into account in this research.

3.5. Experiment procedure

The experiment was conducted in the Human Computer Interaction Lab of Tsinghua University. An HP computer with a 1.66 GHz processor, 512 MB memory and 17" touch screen was used for experimentation. Each participant was required to perform the tasks alone with no other participant present except the experimenter. The computer program automatically timed the participants’ actions.

A brief verbal introduction to the experiment was given to each participant by the experimenter. Then the participant was asked to fill out an informed consent form and a general information questionnaire concerning his personal characteristics.

Before the tasks were started, the experimenter demonstrated to the participant how to use the system. A brief practice session was conducted to help the participant understand the user interface and the tasks to be performed.

Following the practice session each participant was given a sheet with the first group of tasks to be performed. The participants were instructed to perform the tasks as quickly as possible without sacrificing accuracy. After completing the first group of tasks, each participant was asked to complete a questionnaire investigating his perception of the task load using the NASA Task Load Index (TLX, Hart and Staveland 1988). The participant performed the second and the third groups of tasks. The same questionnaire survey was taken after the accomplishment of each group of tasks.

To assess the construct validity of the cognitive mode, the participant was asked to complete a questionnaire regarding their perceptions.

4. Results

4.1. Descriptive statistics of the experimental results

The descriptive statistics of the experiment including means and standard deviations for different conditions are summarised in Table 2. The results the sample t-test from the two age groups on each variable are also summarised in the table.

Data from the user performance (Time and Errors) are compared in Table 2. The senior participants needed more time to accomplish the tasks than young participants in all treatments. Senior participants also committed more errors than the young participants in most treatments. This was ascribed to the aging effect and was consistent with most researches on older adults. There was no significant difference found in the perceived task load between young and senior participants in all treatments excluding the high-intelligence user interface with skill-based and rule-based tasks.

4.2. Construct validity of cognitive mode

The within group factor in the experiment was the CM which consisted of three levels: skill-based, rule-based and knowledge-based. Since the task classifications of tasks were performed subjectively by the experimenter, it is important to determine whether the participants could perceive the classification as skill-based, rule-based, or knowledge-based to ensure the construct validity of the task. Each participant was asked to fill out a questionnaire after performing all three groups of tasks to sort each group of tasks into three cognitive modes. Each correct answer counted for 10 points; each incorrect answer counted for 0 points; thus each participant’s answer was transferred to a total score on the basis of 30.

The high mean score (mean = 26.4 for young participants, mean = 23.3 for senior participants, and mean = 24.9 for combined data) of the questionnaire indicates that the participants had a good understanding of the skill, rule, or knowledge and could perceive the groups of tasks as skill-based, rule-based, or knowledge-based. The internal consistency was 0.71 which was calculated using Cronbach’s Alpha calculation (Crobach 1990).
4.3. Hypotheses testing

ANOVA of Time, Errors, and TLX scores response variables were used to test the hypotheses. Since the data Errors violated the ANOVA assumptions even after transformation, the nonparametric Kruskal-Wallis tests (Kruskal and Wallis 1952) were performed on the tests Errors of the different SLI levels.

4.3.1. Hypothesis 1

The intention of this hypothesis is to examine how intelligence level of user interface might influence the users’ performance when the users accomplished skill-based tasks. It was hypothesised that the users’ performance would be better on low-intelligence level interface rather than medium- or high-intelligence level user interface.

An examination of the planned Performance Time comparison results in Table 3 indicates that the SLI effect was highly significant for both the young and senior groups ($F_{(2,33)} = 34.17$, $p < 0.01$ for young group and $F_{(2,33)} = 13.38$, $p < 0.01$ for senior group). Duncan’s multiple range test results show that the Performance Time with low-intelligence user interface was significantly shorter than with medium- or high-intelligence user interface.

Table 3 reveals that the Errors on different SLI levels were significantly different from each other for both the young and senior groups ($H = 6.57, p = 0.04$ for young group and $H = 8.61, p = 0.01$ for senior group). The lowest rank sum (best performance) appeared at the low level of SLI, that is, users made fewest errors when they performed skill-based tasks with a low-intelligence user interface.

In summary, Hypothesis 1 was supported. Both young and senior groups exhibited the best performance (Performance Time and Errors) when SLI was set to the low level.

4.3.2. Hypothesis 2

The intention of this hypothesis is to examine how different interface intelligence levels might influence user performance when the users accomplish rule-based tasks. It was hypothesised that users’ performance would be better on the high-intelligence interface rather than low- or medium-intelligence user interface.

An examination of the Performance Time planned comparison results in Table 4 indicates that SLI effect was...
was not significant for both young and senior group \((F_{(2,33)} = 0.57, \ p = 0.57\) for young group and \(F_{(2,33)} = 0.74, \ p = 0.49\) for senior group).

Summarised results in Table 4 reveal that the Errors on different SLI level were significantly different from each other for both young and senior groups \((H = 9.90, \ p = 0.01\) for young group and \(H = 21.90, \ p = 0.00\) for senior group). The lowest rank sum (best performance) appeared at the high level of SLI, that is, users made fewest errors when they performed rule-based tasks with a low-intelligence user interface.

In summary, hypothesis 2 was partially supported. A high-intelligence user interface helped reduce the errors significantly for both young and senior participants accomplishing rule-based tasks.

### 4.3.3. Hypothesis 3

The intention of this hypothesis is to examine how different interface-intelligence levels might influence users’ performance when they accomplish knowledge-based tasks. It was hypothesised that for young people users’ performance would be better on medium-intelligence level interface rather than low- or high-intelligence user interface. However, for senior people, the manipulation on the user interface, regardless of intelligence level, would make no significant difference in user performance.

An examination of the Performance Time planned comparison results in Table 5 indicates that the SLI had a significant effect on the Performance Time for young participants \((F_{(2,33)} = 4.70, \ p = 0.02\) while for senior people no significant difference was found in Performance Time \((F_{(2,33)} = 0.63, \ p = 0.5391\). However, Duncan’s multiple range test results indicate that Performance Time on medium-intelligence user interface was not significantly shorter than Performance Time on low- or high-intelligence interface for young participants.

Summarised results in Table 5 reveal that marginally significant difference was found in the Errors on different SLI level for young participants \((H = 4.72, \ p = 0.09\) while no significant difference was found for senior groups \((H = 1.84, \ p = 0.40)\).

In summary, hypothesis 3 was not supported. But senior participants’ performance was in accordance with our prediction. No significant difference was found in senior people’s performance (Performance Time and Errors) on low-, medium- or high-intelligence user interfaces.

### 4.3.4. Hypothesis 4

The intention of this hypothesis is to examine how different interface intelligence levels might influence perceived task load when the users accomplish different kinds of tasks. It was hypothesised that for
young people perceived task load would be lower if the user interface intelligence level was compatible with the cognitive mode. However, for senior people, perceived task load would increase when the user interface intelligence level increased. Planned comparisons of mean TLX scores were used to test this hypothesis.

Results in Table 6 indicate that there was no significant difference found in TLX scores between three interface intelligence levels for young participants when different kinds of tasks were performed ($F_{(2,33)} = 1.28, \ p = 0.29$ for skill-based tasks, $F_{(2,33)} = 0.72, \ p = 0.49$ for rule-based tasks, and $F_{(2,33)} = 0.02, \ p = 0.98$ for knowledge-based tasks). For senior participants, the testing result shows that a significant difference was found in TLX scores between three user interface intelligence levels when skill-based tasks were performed ($F_{(2,33)} = 3.98, \ p = 0.03$). However, when rule-based tasks and knowledge-based tasks were performed, no significant difference was found in TLX scores between the three user interface intelligence levels ($F_{(2,33)} = 0.25, \ p = 0.78$ for rule-based tasks and $F_{(2,33)} = 1.03, \ p = 0.37$ for knowledge-based tasks).

Duncan’s multiple range test results indicate that for senior participants, TLX scores on low-intelligence level interface were significantly lower than for the high-intelligence user interface ($p = 0.01$ and 25% less).

In summary, hypothesis 4a was not supported, while hypothesis 4b was partially supported. When completing skill-based tasks, the user interface intelligence increases task load perceived by senior participants.

Upon closer investigation of the results, some further indications were found, as shown in Figure 3. For young participants, the lowest TLX scores for completing skill-based tasks were associated with low-intelligence user interface (17% less than with medium- and high-intelligence user interfaces); when completing rule-based tasks, users using high-intelligence interface were found perceiving the lowest level of perceived task load (TLX score 14% lower than with low-intelligence level and 15% lower than medium-intelligence user interface). These differences, thought not statistically significant, imply a possibility that supporting skill-based tasks with low-intelligence interfaces and supporting rule-based tasks with high-intelligence interfaces may be more effective. For senior people, with the increase in user interface intelligence level, there was a clear increasing tendency of means of perceived task load with all three types of cognitive tasks. Concerning skill-based tasks, the mean TLX scores with medium-intelligence user interface had a 17% increment, and the mean TLX scores with high-intelligence user interface had a 33% increment; concerning knowledge-based tasks, the increments were 9% and 20% respectively. For rule-based tasks, there was a clear increment of perceived task load.

Table 5. Testing result of hypothesis 3.

<table>
<thead>
<tr>
<th>Cognitive mode</th>
<th>Age group</th>
<th>Var.</th>
<th></th>
<th></th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>$F_{(2,33)}$</td>
<td>$p$</td>
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<tr>
<td>Knowledge-based</td>
<td>Young</td>
<td>Time (sec)</td>
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<td>65.63</td>
<td>253.3</td>
<td>67.75</td>
<td>304.4</td>
<td>84.22</td>
<td>4.70</td>
<td>0.02†</td>
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<tr>
<td></td>
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<td>Errors</td>
<td>1.8</td>
<td>1.59</td>
<td>1.0</td>
<td>1.86</td>
<td>2.4</td>
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<td>$H^* = 4.72$</td>
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<tr>
<td></td>
<td>Senior</td>
<td>Time (sec)</td>
<td>374.0</td>
<td>125.86</td>
<td>432.6</td>
<td>179.26</td>
<td>437.3</td>
<td>156.75</td>
<td>0.63</td>
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<tr>
<td></td>
<td></td>
<td>Errors</td>
<td>3.1</td>
<td>1.38</td>
<td>2.6</td>
<td>1.93</td>
<td>4.2</td>
<td>3.21</td>
<td>$H^* = 1.84$</td>
<td>0.40</td>
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*Kruskal-Wallis test: $H(2, N = 36)$.
†Significant at $\alpha = 0.05$.

Table 6. Testing result of hypothesis 4.

<table>
<thead>
<tr>
<th>Cognitive mode</th>
<th>Age group</th>
<th>Var.</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>$F_{(2,33)}$</td>
<td>$p$</td>
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<tr>
<td>Skill-based</td>
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<td>Task load</td>
<td>40.0</td>
<td>14.44</td>
<td>48.6</td>
<td>18.69</td>
<td>48.6</td>
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<td>Task load</td>
<td>48.1</td>
<td>20.76</td>
<td>52.6</td>
<td>17.31</td>
<td>57.9</td>
<td>9.97</td>
<td>3.98</td>
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<td>Young</td>
<td>Task load</td>
<td>47.8</td>
<td>15.31</td>
<td>48.6</td>
<td>21.33</td>
<td>41.1</td>
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<td>50.3</td>
<td>20.06</td>
<td>53.9</td>
<td>14.33</td>
<td>54.3</td>
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<td>17.99</td>
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<td>Senior</td>
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<td>48.1</td>
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<td>52.6</td>
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<td>1.03</td>
<td>0.37</td>
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(7% and 8%) with medium and high level of interface intelligence, but the increment of perceived task load from medium to high level of interface intelligence was still positive but quite small. These increments show the tendency that perceived task load may increase along with the increase in user interface intelligence level for senior people, which is more explicitly shown in Figure 3.

5. Discussion

For young participants, the manipulation of SLI significantly affected the performance time when they accomplished skill-based tasks. Time cost in accomplishing skill-based tasks on a low-intelligence user interface is less than on a medium- or high-intelligence user interface. The manipulation of SLI significantly affected the number of errors for skill-based and rule-based tasks and marginally significantly affected for knowledge-based task. For young participants, when accomplishing skill-based tasks, fewest errors were committed on a low-intelligence level interface; when accomplishing rule-based tasks, they committed fewest errors on a high-intelligence user interface.

These experimental results supported hypothesis 1 and partially supported hypothesis 2. The implication for smart home interface design is that providing an appropriate user interface intelligence level, compatible with the cognitive mode will help young people perform better (less time and fewer errors). A low-intelligence user interface is compatible with user’s cognitive mode for skill-based tasks, and a medium-intelligence user interface is compatible with user’s cognitive mode for knowledge-based tasks.

Skill-based tasks are the most familiar tasks for people. When accomplishing skill-based tasks, people act in a highly skilled style and conscious analysis is not required. In the low-intelligence level user interface, information is represented in the way consistent with the real world, which does not require further coding and processing information from the user. The user interface can provide instant feedback as well. Moreover, skilled and experienced users can work extremely rapidly to carry out a wide range of tasks on direct manipulation interface, even defining new functions and features (Shneiderman 1983). These user interface characteristics support the cognitive model for skill-based tasks. Thus when accomplishing skill-based tasks with a low-intelligence interface, users need least time and commit fewest errors.

When performing rule-based tasks, users first recognise the need for action, then retrieve past rules or method from long-term memory, and then respond upon the environment. In the high-intelligence user interface, there are some predefined tasks which to some extent serve as past rules in users’ long-term memory. Users’ task selection process is like the retrieval of past rules from long-term memory. Once a task is selected, the smart home accomplishes all the actions automatically without any further feedback from the user. These interface characteristics well-support the cognitive model for rule-based tasks. Thus, when accomplishing rule-based tasks with a high-intelligence user interface, users commit fewest errors. The experimental data of the young participants show that the performance time with the high-intelligence interface is not the least. This may be ascribed to the fact that users are not familiar enough with the user interface. It took more time to find a matched task in the user interface than to retrieve past rules from the long-term memory.

When performing knowledge-based tasks, user performance is governed by a thorough analysis of the situation and systematic comparison of alternative combination of actions. The medium-intelligence interface could provide users with predefined tasks which to some extent serve as past rules in users’ long-term
memory and help decrease cognitive demand, and more interactions which support users' comparisons of alternative means and decision-making. These user interface characteristics are expected to support the cognitive model for knowledge-based tasks. However, no significant evidence was found in the experiment. This may be ascribed to the time-consuming and cognitively demanding characteristics of knowledge-based tasks. Most time is spent on analyzing rather than operation. Thus performance time was not significantly different between the three interfaces. Moreover, users may not be familiar enough with the user interfaces.

For senior participants, the manipulation on different user interfaces significantly affected the performance time when they accomplished skill-based tasks. Time for accomplishing skill-based tasks on a low-intelligence user interface is less than on a medium- or high-intelligence user interface. No significant difference was found in performance time when they accomplished rule- or knowledge-based tasks. Changing the SLI significantly affected the number of errors for skill- and rule-based tasks. When accomplishing skill-based tasks, senior participants committed the fewest errors on a low-intelligence user interface. When accomplishing rule-based tasks, they made fewest errors on a high-intelligence user interface. No significant difference was found in errors when the elders accomplished knowledge-based tasks.

Several limitations of this study should be considered where the validity of the findings is concerned. First, senior participants of the experiments were recruited from a senior school mainly opened to retired faculty members of Tsinghua University. These people, except for their high education level, have on average used computers for about 7 years, which is very uncommon for people at their age. While the research framework and the methodology of the current study requires certain technical background and such a sampling bias is nearly inevitable, future studies observing needs and behaviours of computer-naive senior people are needed to benefit the majority of the current senior population. Second, all participants were males experienced with computers. This may be different from the real-world scenario, in which people who interact with a home environment are more likely to be women. Third, this study controlled the level of computer experience (i.e., frequency of computer use, how many years they have been using computers) to ensure the comparability between the senior group and the young group. The underlying assumption is that computer experience is the same as computer expertise. But this assumption is not firmly held, as Chadwick-Dias et al. argued (2004). In their study of senior web users, they found that even when web experience is controlled, older adults still demonstrated less web expertise than younger adults, and how they learned the web – or their cumulative time spent in collaborative learning environments – may contribute to this phenomenon.

6. Conclusion

Based on the above discussions, for different cognitive mode tasks, users would perform differently on interfaces with different intelligence levels. This means that when completing skill-based tasks, users would have best performance (less time and fewer errors) on low-intelligence level interface. When completing rule-based tasks, users would have best performance on high-intelligence user interface and (see Figure 4). However, for senior people, due to the decline of the cognitive abilities, their performance would not differentiate as clearly as that of the young people while using different user interfaces of smart home,

Figure 4. Relationship between cognitive mode and intelligence level of user interface.
especially for high cognitive demanded tasks. Moreover, perceived task load has a tendency to increase together with the intelligence level of user interface. Since home is one of the most familiar environments for people and most tasks in home are skill-based or rule-based, the implications from experimental result are meaningful in the smart home interface design for both young and senior people.

A major limitation of this study is the biased sample selection, which may limit the scope for generalisation. Care should be exercised when generalising the findings of this study to a broader population, especially to senior people with little or no computer literacy. However, results of the current study still offer meaningful insights on the characteristics of smart home users, and can help predict behaviour of people with increasing levels of computer literacy. Such a development is very likely to take place in the near future, even with the senior generation. As in the United States, so-called Baby Boomers (people born between 1946 and 1964) are growing older. Since they are themselves largely responsible for the successful development and widespread use of technology, they can be expected to continue to be technology savvy consumers as they grow older (Office of Technology Policy of the Commerce Department’s Technology Administration, 2005).

Based on our findings, we propose the following guidelines for smart home interface designers:

- Classify domestic tasks into three categories, namely skill-based, rule-based, and knowledge-based, according to the SRK model before designing the smart home interface.
- Both device-oriented and task-oriented interfaces are needed in the smart home. Designers should combine these two kinds of interface into one to provide users with multiple choices.
- For skill-based tasks, a low-intelligence level user interface with direct control style is highly recommended.
- For rule-based tasks, a task-oriented high-intelligence user interface is recommended.
- If the user interface intelligence level is high, a test of mental workload is needed to ensure that the senior users’ cognitive abilities are not exceeded.

References


