Smart TV for Older Adults: A Comparative Study of the Mega Menu and Tiled Menu

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Abstract. Navigation in a hierarchical menu on the current smart TVs (STVs) contributes to a poor user experience for older adults. Difficulty with navigation is caused by the design of an interface and users' mental models. To explore different design possibilities, two types of menu layouts (i.e., mega menus and tiled menus) with tags were designed in this study. An experiment was conducted to investigate the effect of menu layouts on the user experiences of older adults. A manipulation check of both menu layouts was conducted via eye tracking. To understand users' mental models, a card sorting method with a path diagram was employed. Thirty older adults were recruited in this experiment. The results indicated that a mega menu can reduce the physical effort of pressing keys, whereas a tiled menu achieves higher satisfaction of older adults. However, the mental model similarity between designers and older adults toward mega menus and tiled menus exhibited no significant difference. Older adults with high spatial ability had mental models that were similar to the mental models of designers.

Keywords: Older adults · Smart TV · Navigation · Mega menu Tiled menu

1 Introduction

Navigating current STVs is challenging for older adults. Navigation is central to the STV user experience of older adults. Many factors influence the user experience of navigation; they can be divided into two sources: the design of an interface and human factors.

Regarding the design of an interface, the menu design has a significant impact on the navigation performance [1]. The majority of previous studies have investigated the menu design of smartphones, computers and other devices and proven that a well-designed menu layout can moderate the age-related differences in navigation. However, research on the design of menu layouts on STVs is lacking. Because the input methods between STVs and smartphones or computers differ (remote control vs. fingers or mouse) [2], new menu layouts with effective customization for older adults are essential for improving the user experience of navigation.

Different design possibilities of menu layouts need to be explored to replace the current menu design of STVs. The most common menu design on STVs is the hierarchical menu. Using the hierarchical menu, the problem of disorientation is severe for

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older adults who suffer from a decline in spatial ability [3, 4]. In addition, the ambiguous locations of items in different categories [5, 6] and the deep menu [7] in this menu layout cause problems for older adults due to the shallow mental models of older adults [7] and the effect of their a priori knowledge [8] of cable TV. Thus, two types of menu layouts with tags were designed to simplify navigation on STVs for older adults. The depth of the menu was reduced and tags were added to support the user in efficient navigation.

Regarding human factors, apart from age, spatial ability, vocabulary ability, and a priori knowledge, the mental model has a major role in explaining the internal thought processes of users during menu navigation [9]. Whether and how older adults understand a menu design are important factors in improving the user experience of navigation. To elicit the mental models of older adults, card sorting with a path diagram was proven to be useful [10]; this approach was employed in this study.

Thus, the following research questions were explored in this study:

Between a mega menu and a tiled menu on STVs, which has higher performance and satisfaction for older adults? Do older adults understand how to navigate a mega menu and a tiled menu?

2 Literature Review

With the development of the Internet, the vast amount of digital information has increasingly become overwhelming for older adults who have limited memory resources and decreased capacities [11]. Navigation in this condition of information overload is challenging for older adults. Two types of factors influence the user experience of navigation: the design of an interface and human factors.

Regarding the design of an interface, menu design is an important issue. The most common menu design is the hierarchical menu. The hierarchical menu has been extensively applied to the design of smartphones and websites. Many researchers have coordinated their efforts in improving the design of this menu. Three aspects of designing a hierarchical menu were investigated in previous studies. First, the performance and preference of different types of menu were evaluated. One example is that the net menu structure, tree menu structure and linear menu structure have been investigated to improve the performance of older adults' usage of web pages [3]. Second, the tradeoff of the breadth and depth of the hierarchical menu is another important factor [7]. Older adults experience difficulty when the depth of a menu exceeds three [7], whereas the depth of the majority of current hierarchical menus on STVs exceeds 3. Third, navigation aids were designed to reduce the risk of disorientation in hierarchical menus [4, 12].

However, the problem of disorientation of hierarchical menus is severe for older adults [3, 4]. Two possible methods can reduce the risk of disorientation in navigation. First, reduce the depth of the menu. A mega menu is recommended for site navigation by Nielsen and Li [13] because a mega menu has the advantage of revealing a lower-level menu without a deep menu. Tiling a menu to full use enables the large screen of a STV to reduce the depth of the menu. Second, add tags to rapidly retrieve information. Tags are becoming more popular due to the advantages of personal, contextual and dynamic characteristics [14], which are similar to natural language [15]. Multiple tags about the keywords of the content can be employed to effectively reach a target.

Regarding human factors, users' age, education, experience in using technological products and their perceptual, cognitive and motor abilities impact their navigation performance. Among these factors, the mental model is important because it is formed by users to understand navigation [9]. The most extensively applied method to elicit users' mental models of hierarchical menus is card sorting. Based on card sorting, the directional relationship of elements with path diagrams is added to further understand users' mental models [10].

However, studies of the menu design of STVs to address the problem of disorientation are lacking. Regarding the menu design of STVs for older adults, a previous study researched navigation layouts [16]; however, these navigation layouts were designed in terms of navigation metaphors based on hierarchical menus, which could not solve the problem of disorientation. This study aimed to design an appropriate menu layout for STVs to improve the experience of navigation by older adults.

3 Methodology

3.1 Variables

An experiment was conducted to investigate user performance and satisfaction with mega menus and tiled menus. Thus, the independent variable was the menu layout (between-subject); it had two levels, namely, mega menu and tiled menu.

The dependent variables were performance and satisfaction. Performance had five measures: the completion rate, task completion time, number of keystrokes, number of errors in card sorting and mental model similarity. The first three measures were automatically recorded by a Morae Recorder. The last two measures were calculated by the card sorting method with path diagrams according to the achievements of Xie et al. [10], which were employed to elicit older adults' mental models. Satisfaction was measured by a one-question questionnaire [17] on a seven-point Likert scale.

Users' areas of interest (AOI) and fixation counts were analyzed by the Gazetech mini ET1000 Eyetracker to check the manipulation of the menu design.

The covariates included age, sex, education, usage of TV types (cable TV and smart TV), spatial and vocabulary ability [18]. The spatial abilities of the participants were measured with the highest scores of the KJ-I spatial location memory span tester. The vocabulary abilities were tested by the vocabulary part of the Chinese version of the Wechsler Adult Intelligence Scale (WAIS) [19]. On this scale, participants were required to explain 40 words. Scores of zero, one and two were given according to the quality of the participants' answers; thus, the highest total score was 80. The test ended when five consecutive scores of zero were obtained.

3.2 Participants

A total of 30 participants (22 females and 8 males) were recruited in this experiment. All participants were residents at the senior center in the Shapingba district in

Chongqing, China. To ensure that they were capable of locating the targets, all participants were literate. The average score of vocal capacity was 74.4 (SD = 10.72). To ensure that the eye tracker can accurately track their eye movements, participants without serious eye disease (such as cataracts, high myopia, and high astigmatism) were eligible for this experiment. The average age of the participants was 66.4 years old (SD = 4.9, ages ranged from 60 to 75).

3.3 Experimental System Design

Two experimental systems were designed to present the mega menu (in Fig. 1a) and tiled menu (in Fig. 1b). Both menu layouts had four areas: area 1 (i.e., chosen tags, which displayed the current tags chosen by the participants), area 2 (i.e., top-level menu, which displayed the navigation bars of the tags), area 3 (i.e., available tags,

a. Mega menu

b. Tiled menu

Fig. 1. Screenshot of menu layouts to present the information structure based on multiple tags. (Note: the green rectangular boxes represent the interface framework, and the blue labels represent the translation of the eight top-level menu items.) (Color figure online)

which displayed all tags in each panel), and area 4 (i.e., search results, which displayed the search programs according to the chosen tags).

A mega menu is an expandable menu with stack panels. The stack panels are useful because they conserve screen space, which enables the submenu to remain visible without leaving the current pages [13]. Conversely, the stack panels cause problems in moving focus and switching the panels when using a remote control. In addition, finding the tags in the hidden areas may create difficulties for older adults.

Although the tiled menu is an alternative layout of the mega menu, problems also occurred. In this menu, the tags were tiled, and eight tag groups were horizontally arranged. Without using the stack panels, the flat menu may be suitable for older adults who have shallow mental models because the focus could be easily moved in the grid layout. However, the hidden parts of the menu also existed. Targets in the hidden parts could not be located if the participants ignored the cue from the top-level menu and context. In addition, substantial effort in pressing the keys was needed for navigation when the target was located far from the current location.

The content and operation rules of the two prototypes were consistent. For the content, eight types of tags (my record, channel, playtime, type, content, actor, role and emcee) were selected from a pilot study prior to this experiment. Each type of tag was gathered into a panel. To satisfy the interface design requirements, four of the panels (channel, actor, role and emcee) needed to be scrolled down to find a target to accommodate the large number of tags in real cases. Tags with text and pictures were involved in this experiment.

For the operation rules, to choose a tag, the focus should be moved to the target tag and then the "enter" key should be pressed. To delete a chosen tag, the focus should be moved to the wrongly chosen tag and the enter key should be pressed. To close a window (such as the stack panel of the available tags in the mega menu and the panel of results in the tiled menu), the "back" key should be pressed.

3.4 Card Sorting Material

The cards used to draw the path diagram were selected from the tasks performed by the participants. Three levels of cards were involved: first, the cards of the top-level menu items; second, the cards of the tags involved in the target program; and third, the cards of the target program (as shown in Fig. 2). A total of 11 cards were employed in both menu layouts. The tags with only text and with both text and a picture (e.g., tags about human faces or posters) were selected for the participants to sort. Participants were allowed to draw the segments with one or two arrows. One arrow indicated that he could move from node A to node B, and two arrows indicated that node A and node B could reach each other.

3.5 Equipment

The KJ-I spatial location memory span tester was used to test spatial ability. The tester had 25 (5 * 5) buttons with LED. 2–7 buttons randomly lit up in proper order, which the participants were required to remember. Then, the participants were required to press the buttons to turn off the lights in the same order as the buttons were lit. This step

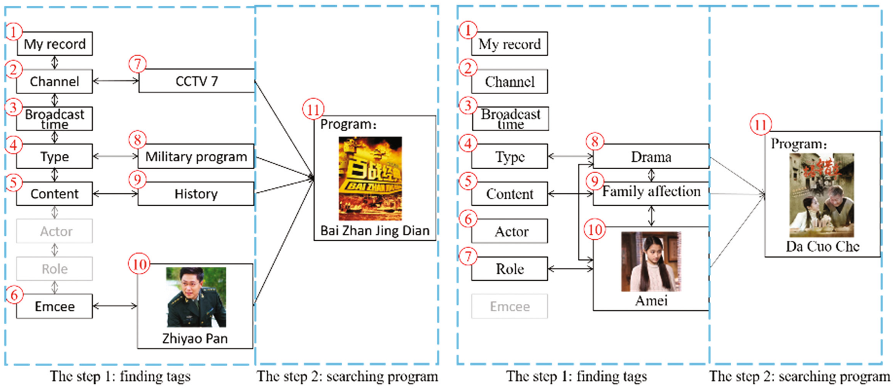

Fig. 2. Presentation of card sorting and path diagram from a designer's mental model (from left to right: mega menu, tiled menu). Notes: red numbers in the circle represent the codes of the cards. The transparent cards and arrows were excluded because they were unrelated. (Color figure online)

was repeated, and the number of buttons with light increased. The highest scores were recorded to measure the spatial ability. A 32-inch LG 4 K display was connected to a notebook to present the prototypes to the participants. Each participant sat in a chair that was located 2 m from the display in sufficient light; if the display was unclear, the chair was moved 1 m closer to the display. iMotions software was run on the notebook to record the number of the task completion time and the eye tracking data. A universal remote control (2.4 G wireless) was connected to the notebook, on which only six keys (directional, return and "OK" keys) were used for navigation.

3.6 Procedure

The experiment required approximately 60 min. First, an informed consent and a background information questionnaire were given to the participants. Spatial and vocabulary abilities were tested. Second, necessary training about the system was conducted. Before the participants were asked to complete two tasks, an eye tracker calibration process was conducted. The task in each trial was to find an appointed video until the end page was attained. Each participant was encouraged to individually complete the experiment. The order of the tasks was counterbalanced. Third, an interview about their preferences was conducted. "How do you like using this menu layout?" "What problems do you think there are when you complete the task?" The participants indicated their final ratings on the one-question questionnaire. Fourth, the participants were asked to complete the card sorting and path diagram task.

4 Results

4.1 Descriptive Statistics

Basic background information was analyzed. All participants reported a habit of watching TV for an average period of three hours (SD = 1.7) each day. Information about education and TV usage experience of older adults is listed in Table 1. The participants reported that they either had Chongqing TV or a smart TV in their home. Chongqing cable TV primarily offers basic broadcasting services and pay-for services, such as video-on-demand. On smart TVs, the apps used to watch broadcasts and videos on demand are available. A total of 83.3% of older adults had technology usage experience in smart phones, iPads or computers and had used technology products an average of 5.8 years (SD = 6.8) and 2.4 h (SD = 2.9) each day.

Table 1. Demographic information

Variable	Category	Num.	%
Education	Primary school and below	4	13.3
	Middle school	13	43.3
	High school	9	3
	Bachelor's degree	4	13.3
TV usage experience	Chongqing cable TV	19	63.3
	Only use broadcast service of cable TV	14	73.7
	Using video-on-demand service of cable TV	5	26.3
	Smart TV	11	36.7
	Only using broadcast service of smart TV	4	36.4
	Using video-on-demand service of smart TV	7	63.6

4.2 Manipulation Check

The data from the eye tracker were analyzed. The scenes of two minutes of step 1 (finding tags) after the participants entered the main page were cut to analyze the Heatmap and fixation count. Due to the attention switch between the display and the remote control (or other disturbances), the average sampling rate of the eye tracker was 55.5% (SD = 19.1%, ranged from 6% to 85%).

The Heatmap and fixation count of the four areas were computed to detect whether participants had paid attention to the four parts of the interface, which was similar to the design of the prototypes (as shown in Fig. 1).

Regarding the mega menu (as shown in Fig. 3), two sides of the findings were summarized according to the various degree of attention to the four areas. Area 2 and area 3 attracted significant attention from older adults, which indicated that older adults had noticed the manipulation of the menu design. Note that older adults were concerned with area 2, which only had eight menu items. This finding indicates that participants were either interested in the top-level menu or they did not understand the top-level menu and spent time thinking about how to navigate the top-level.

Fig. 3. Heatmap (left) and fixation count (right) of the mega menu. (Note that the numbers (1–4) represent the coding of the four areas in the black rectangular boxes.)

Area 1 and area 4 attracted minimal attention from older adults. For area 1, the participants tended to select the tags following a process as they learned to complete the tasks. However, they encountered problems in understanding the chosen tags on the top of the display or they considered the chosen tags to be useless. For area 4, they may not have understood the elevated view with higher Z values (namely, the hidden parts under the translucent panel) of the interface.

Regarding the tiled menu (as shown in Fig. 4), two sides of the findings were summarized. Area 3 received the majority of the attention from older adults, which indicated the tendency of older adults to randomly search area 3 (available tags). In this condition, the content of the tags became one of the cues of navigation. Thus, the more distinct the logic of the content in the tiled menu, the better was the understanding of older adults.

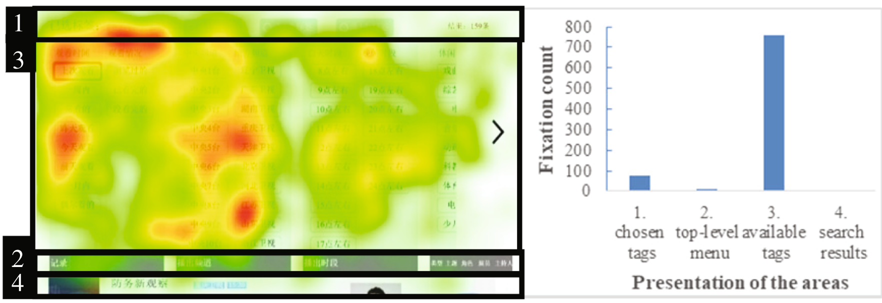

Fig. 4. Heatmap (left) and fixation count (right) of the tiled menu. (Note that the numbers (1–4) represent the coding of the four areas in the black rectangular boxes.)

Areas 1, 2 and 4 were almost ignored. For area 1, the results were identical to the results of the mega menu. For area 2, the manipulation of the design of the top-level menu was ineffective. One possible reason may be that its font was too small or its location was incorrect. For area 4, the participants experienced problems understanding the hidden content, and use of the remaining small part of the elements as a cue was ineffective for older adults.

4.3 Effect of Menu Layout

The influence of menu layouts for older adults was tested. First, the descriptive statistics were analyzed. Second, the data were analyzed using one-way ANOVA and the paired t-tests method. The within-subject variable was the menu style. All six covariates were included in the first one-way ANOVA model. Prior to the analysis, the intercorrelation of dependent variables was examined. No significant correlations between three measures of performance were indicated. To satisfy the normality assumption, the data of the task completion time and number of keystrokes were transformed by the box-cox method with the same optimal parameters ($\lambda = 0.2$). The covariates without significant correlations with dependent variables were removed from the model. Last, the remaining covariates without significantly different slopes in the ANOVA model were removed. Conversely, covariates with different slopes were reported in the model. All results of the homogeneity of variance were satisfied. If the effect of the independent variables was significant, paired t-tests were conducted. Mean squared errors derived from the ANOVA were used to compute the t-statistic.

The general performance was investigated according to two types of menu layout in terms of the task completion rate, task completion time and number of keystrokes. First, the task completion rates were compared. The average completion rate for all tasks was 68.3%. For the mega menu, 64.3% of the tasks were completed. For the tiled menu, a higher (71.9%) task completion rate was obtained.

However, the difference in the task completion rate between the mega menu and the tiled menu was not significant for older adults based on the one-way ANOVA. One possible reason was that both menu layouts had significant problems, which caused failure. For the mega menu, the problems of switching between hidden panels and switching between the area of tags and the area of the search result lists were damaged for older adults according to their behavior when completing tasks. For the tiled menu, the difficult interactions of switching the panels decreased, whereas new problems appeared. The hidden panels of the search result list and the hidden panels of the tags in the left, right or down sides were problematic for older adults. Some parts of the panel were visible in the display, which were cues that enabled them to understand the hidden panels.

Second, the task completion times were compared. For the mega menu, older adults required an average of 289.7 s (SD = 109.9) to complete a task. For the tiled menu, an average of 290.8 s (SD = 164.1) was needed. However, no significant difference in completion time was observed between the mega menu and the tiled menu. Note that the standard deviations were significant, which may cause different interpretations of the results.

Third, the number of keystrokes was compared. For the mega menu, older adults required an average of 56.6 (SD = 29.2) keystrokes to complete a task. For the tiled menu, older adults required a higher number of keystrokes (mean = 94.7, SD = 55.3).

A significant difference between the mega menu and the tiled menu in terms of the number of keystrokes ($F = 9.04$, $p = 0.005$) was observed, as shown in Fig. 5. Compared with the tiled menu, use of the mega menu contributed to 50.4% fewer keystrokes ($T = -3.01$, $p = 0.006$). Note that a larger number of keystrokes never caused a higher task completion time in the tiled menu. Rather than spending time pressing keys, the participants shared their efforts and resources on other aspects of the tasks when using the mega menu. Compared with the tiled menu, a possible explanation may be that older adults needed to think about the location of the target, how to switch the stack panels, or which keys should be pressed.

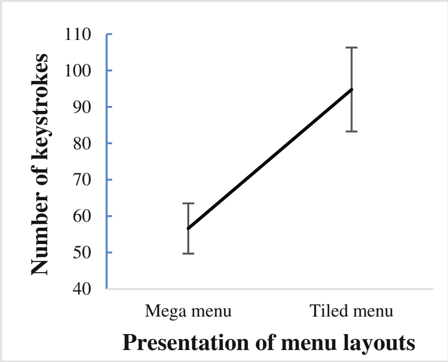

Fig. 5. Influence of menu layouts on number of keystrokes (error bars = 95% c.i.).

Satisfaction was investigated according to the mega menu and tiled menu. The average score of the mega menu was 4.5 (SD = 1.2), whereas the average score of the tiled menu was 5.5 (SD = 1.3). The total satisfaction score was seven. In the ANOVA model, the difference between the mega menu and the tiled menu with regard to satisfaction was significant ($F = 7.40$, $p = 0.011$), as shown in Fig. 6. The tiled menu gained higher satisfaction (19.8%) than the mega menu ($T = 2.721$, $p = 0.013$).

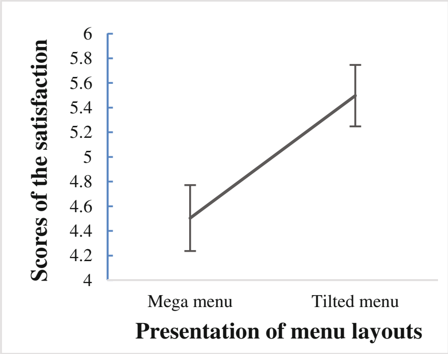

Fig. 6. Influence of menu layouts on satisfaction (error bars = 95% c.i.).

4.4 Mental Model

The results of the card sorting and path diagram were tested. One example for one of the participants is shown in Fig. 7.

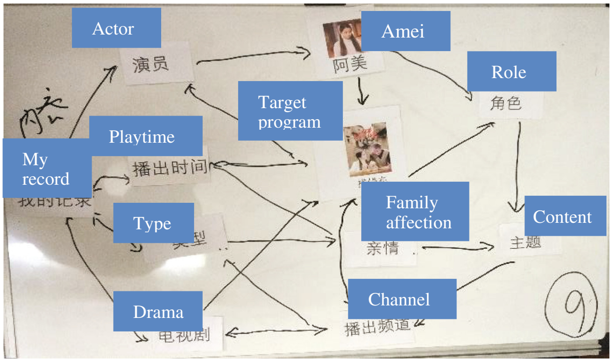

Fig. 7. Example of card sorting and path diagram.

The number of errors was calculated by the number of the uncorrected segments (e.g., the segments drawn by the participants differed from the segments drawn by the designer). For the mega menu, the average number of errors was 13.5 (SD = 2.9), and the total number of segments was 20. Thus, the error rate of the mega menu was 67.6%. For the tiled menu, the average number of errors was 10.3 (SD = 2.0), and the total number of segments was 15. Thus, the error rate of the tiled menu was 68.6%. Therefore, no distinct difference in the error rate between the mega menu and the tiled menu was observed.

To understand the mental model of older adults, the error rates of step 1 (finding tags) and step 2 (searching program) for both the mega menu and the tiled menu were analyzed with a paired t-test. The results indicated a significant difference ($t = 6.050$, $p = 0.000$) in the error rate between step 1 and step 2. The error rate of step 1 was 47.4% higher than the error rate of step 2. Thus, older adults understood how to use related tags to search the target program. However, they were unable to provide a clear classification of the tags.

The mental model similarity was calculated according to the previous study [10]. The directional similarity of older adults was low (mean = 0.23, SD = 0.11). The average directional similarity for the mega menu was 0.25 (SD = 0.11), whereas the average similarity for the tiled menu was 0.21 (SD = 0.11). Before conducting the ANOVA method, the data were transformed by the box-cox method with an optimal parameter ($\lambda = 0.5$) to satisfy the normality assumption. However, no significant difference ($F = 2.018$, $p = 0.167$) between the mega menu and the tiled menu was observed with regard to the mental model similarity. There were two possible reasons. First, the participants did not detect a large difference between the two menu layouts. Second, the individual differences were too large to detect the difference.

4.5 Effect of Covariates

The six demographic covariates (age, sex, education, vocabulary ability, spatial ability, and usage of TV types) were analyzed, as shown in Table 2. For spatial ability, the average score of the spatial ability tester was 4.0 (SD = .0.5), and the maximum number of digits that participants remembered ranged from 4 to 6 (Mean = 5.3, SD = 0.5).

Table 2. Effects of covariates

Dependent variable	Covariates	Effect
Task completion rate	Usage of TV types	$F(1,57) = 9.804$, $p = 0.003$**
Task completion time	Age	$F(1,37) = 12.609$, $p = 0.001$**
	Education	$F(1,37) = 11.484$, $p = 0.002$**
Mental model similarity	Spatial ability	$F(1,27) = 10.064$, $p = 0.004$**
Satisfaction	Education	$F(1,27) = 14.728$, $p = 0.001$**

Note. ** Significant at the .01 level. * Significant at the .05 level.

The correlation coefficients of these covariates were analyzed. First, regarding the usage of TV types, the types of TV in the participants' home exhibited a significant correlation with the task completion rate ($r = 0.369$, $p = 0.004$). The results indicated that participants who had experience using smart TVs achieved higher task completion rates.

Second, the task completion time was linearly dependent on age ($r = -0.310$, $p = 0.020$) and education ($r = 0.125$, $p = 0.360$). The tendencies for the results were the same as the empirical evidence, that is, old age and low educational attainment were attributed to poor performance.

Third, mental model similarity was linearly dependent on spatial ability ($r = 0.489$, $p = 0.006$). The results indicated that older adults who had high spatial ability had a high mental model similarity.

5 Discussion

An appropriate menu layout on STVs is desired to improve older adults' experience with navigation. To achieve this goal, a mega menu and a tiled menu with tags were designed and evaluated in this study. The results revealed that the more frequently used menu layouts between the mega menu and the tiled menu depended on the demands of practitioners of STVs.

First, if practitioners expect to reduce users' physical efforts (e.g., pressing a large number of keys), a mega menu is recommended. To attain the same goal with a tiled menu with the same task completion time, 50.4% fewer keystrokes are required when using the mega menu.

However, the mega menu has a problem that must be solved prior to its use. The majority of older adults were confused about how to shift focus among the split areas or in the elevated view with higher Z values. For example, the focus located in the stack panels could be moved after closing the panel by pressing the "back" key. However, the participants could not remember this fact.

Second, if practitioners expect to achieve higher satisfaction despite the physical effort, a tiled menu is recommended. Because the tiled menu gained higher satisfaction, it was preferred to the mega menu. Two reasons explain why the tiled menu was preferred even though a larger number of keystrokes was required. First, without the elevated view with higher Z values, moving the focus in the left, right and down directions was easier in the tiled menu than the mega menu. Second, the target tags could be randomly located in the area of the available tags even if the participants did not navigate the top-level menu.

However, the tiled menu also has two problems that need to be solved prior to its use. First, more effective navigation aids to help older adults learn their location when they scroll the panels is desired due to their neglect of the top-level menu. Second, appropriate locations of the area of search results need to be changed rather than hidden at the bottom of the display.

6 Conclusion

This study aimed to improve older adults' experience with navigating STVs from two perspectives: the menu design of STVs and the mental models of users. Regarding menu design, a mega menu and tiled menu were designed, implemented, and tested in an experiment. Regarding mental models, older participants' mental models were elicited via card sorting with a path diagram. The results are not clear-cut, and different menu layouts should be considered on a case-by-case basis.

To reduce the physical effort of users, the mega menu was a better choice than the tiled menu for older adults based on 50.4% fewer keystrokes. To achieve higher satisfaction for older adults, the tiled menu was a better choice than the mega menu in terms of the adding percentage of higher satisfaction scores.

However, older adults in this study did not perform tasks more efficiently or exhibit better understanding between the mega menu and the tiled menu. This calls for future research on which aspects of performance are critical and what makes them feel good when using STVs.

Older adults who had experience using STVs had a higher task completion rate than older adults without experience using STVs. In addition, the mental model similarity between older adults and designers was higher for older adults with higher spatial ability.

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