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The effects of 3D interface metaphor on older adults' mobile navigation performance and subjective evaluation

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Abstract: Navigating vast information spaces through mobile interfaces has become a common activity in older adults' everyday lives. Studies suggested that interface metaphors could be used to facilitate users' metal model development and information processing when using mobile technologies. However, we know little about how metaphors affect older adults' mobile navigation behavior, and which user characteristics matter during this perceptual and cognitive process. To investigate this, a card interface with the 3D metaphor and a list interface without the 3D metaphors were compared among twenty-two participants when performing four navigation tasks. User characteristics including demographic factors, technology experience, and user capabilities were examined. The participants' navigation performance and subjective evaluations were measured as the dependent variables. From the results, we recommend the list interface without the 3D metaphor as a beneficial choice for older adults. It performed better in navigation performance, although the differences are not statistically significant. Moreover, navigation performance using the card interface with the 3D metaphor was significantly associated with participants' perceptual speed, thus this interface may be more sensitive to capability declines. Valuable insights into the older adults' mobile navigation performance and preferences are discussed and important implications for the design of mobile navigation user interfaces are proposed based on the results.

Relevance to industry: The experimental results propose a more beneficial way to present contents on a mobile user interfaces for older adults and provide valuable insights for the designers and industry to help them understand the older adults' usage and perceptions towards the application of 3D metaphors when navigating with mobile interfaces.

Keywords: Mobile navigation, Older adults, 3D interface metaphor, User characteristics, Perceptual speed

1. Introduction

Mobile technologies are becoming an indispensable part of older adults' everyday lives. The percentage of smartphone users among persons aged 65 and older has considerably increased from 15.1% to 52.1% between 2013 and 2018 in Hong Kong (Census and Statistics Department, 2018). However, older adults face various capability declines with aging, such as vision, hearing, motor skills, and cognitive capabilities that may affect their use of mobile technologies (Zhou et al., 2017; Vines et al., 2015; Chin and Fu, 2012). For example, older adults with declined spatial ability may suffer from menu disorientation because they have difficulties understanding the spatial relations of menu items within the hierarchical navigation (Gao et al., 2015; Mi et al., 2014; Wagner et al., 2014; Kim et al., 2007; Ziefle et al., 2007). Furthermore, the intense evolution of mobile interfaces inevitably produces greater mental loads and unprecedented usability challenges for older adults, but the effects of these interfaces on older adults' technology usage are still unknown (Li and Luximon, 2018; Zhou et al., 2012). Thus, there is a necessity to evaluate the effectiveness of different interface designs by considering older adults' specific user characteristics and understanding their perceptual and cognitive processes.

For the use of mobile technologies, navigating through the applications is an essential way to retrieve information and accomplish tasks (Puerta Melguizo et al., 2012). Nevertheless, instead of displaying all the information in a full page, mobile interfaces have more contents hidden within each other that can only be revealed with specific gestures, such as a tap, click, or swipe (Punchoojit and Hongwarittorrn, 2017). This significantly increases older adults' cognitive loads and decreases levels of satisfaction and usage intention. For instance, older adults reported great difficulty browsing broad menus, sliding between different interfaces, switching between various functions, and returning to previous interfaces when using mobile technologies (Li and Luximon, 2018). One possible way to solve these problems is to facilitate older adults' perception and cognition within navigation through interface metaphors (Zhou et al., 2017; Yang et al., 2010). By referring to some physical objects around the users and utilizing the knowledge they already have in relevant domains, interface metaphors can help users to access and interact with the displays in a more understandable manner

(Blackwell, 2006). For example, the three-dimensional (3D) interface metaphor has been widely applied in the information visualization and menu design of computers, televisions, and mobile technologies by being compared to cards, books, carousels and so on (Kim et al., 2011; Rice and Alm, 2008; Cockburn and McKenzie, 2001).

Overall, 3D menu design has been recommended because it provides a more natural and intuitive method of interaction, makes full use of the screen space, and represents clearer spatial relations between information patches (Molina et al., 2003). It has been highly rated in terms of satisfaction and fun because it is natural and realistic, especially for those who are not familiar with technology (Cockbum and McKenzie, 2001). Nevertheless, the positive effects of the 3D menu design are questionable. On the one hand, it is much harder to build up 3D metaphors for designers and developers because of their complex mechanisms (Vidakis et al., 2012). On the other hand, failures in performance improvement were frequently reported in the designs (Kim et al., 2011; Blackwell, 2006; Ware, 2004; Cockbum and McKenzie, 2001). In addition, the emergence of touch-screen mobile devices has largely changed the way of interface interactions and information retrieval. Little is known about how 3D interface metaphors influence users' information navigation behavior when using touch-screen mobile technologies. Furthermore, the use of metaphor may be more challenging for older adults than younger adults due to the age-related differences (Zhou et al., 2017). It is unknown how the 3D interface metaphor works for older adults and which age-related specifications may influence their understanding of metaphor use.

2. Related Works

2.1 3D Interface Metaphor for Navigation Design

Studies suggested that interface metaphors can help in conceptualizing and delivering meanings by reminding users of their previous experience, which can accelerate the process of information understanding, processing and responding when interacting with new interfaces (Lakoff and Johnson, 1980; Nepon and Cate, 1996). Nevertheless, there still exists a debate on the effectiveness of interface metaphors for novice users. Although some researchers reported that the interface metaphor can help novice users to construct mental models when learning new interfaces, the metaphor may also increase users' cognitive load at the same time (Lee, 2007). Possible reasons lie at that novice users could not understand the externally provided information cues of the metaphor effectively due to their decreasing information processing abilities (Fix et al., 1993; Hsu, 2005). Specifically, in another study of Hsu (2006), they found that the interface metaphor cannot help with the development of simple knowledge such as unrelated concepts, but it can assist users to learn integrative knowledge such as understanding the relationships between concepts.

3D interface metaphor has been widely employed for the navigation design of computer systems such as information visualization and menus design. The effectiveness of 3D interface metaphor has been extensively evaluated among young users. Sebrechts and his colleagues (1999) analyzed the task efficiency of three kinds of visualization (3D, 2D, and text versions) for information searching on desktops. Results indicated that 3D interface that displaying the documents on the surface of a sphere was the worst in terms of response time, although their performance was largely improved after practice (Sebrechts et al., 1999). Later, Cockburn and Mckenzie (2001) compared the differences in task efficiency and subjective evaluations between 2D and 3D information visualizations in terms of storing and retrieving web page thumbnail images with different levels of data densities. They didn't find any statistical differences between the 3D and 2D interfaces, and the latter even performed better in terms of task completion time, but the participants showed significantly higher evaluations for the 3D interface design.

For mobile devices, the 3D menu design is also emerging as a prominent method of representing navigation hierarchies. Osman, Ismail, and Wahab (2009) found that for younger adults, the 2D vertical list outperformed the 3D fisheye list in terms of mobile navigation task execution time; however, the latter performed better regarding the dimensions of comprehension and acceptance. In addition, a study by Kim, Proctor, and Salvendy (2011) compared the performance and satisfaction of three types of 3D menus—revolving stage, 3D carousel, and collapsible cylindrical trees—in locating target products. It was reported that users performed faster and perceived higher levels of satisfaction, use of space, and fun when using the revolving stage menu. In addition, they further compared the 3D revolving stage menu and the 2D overview menu using the same tasks. They found that, overall, the 2D menus yielded faster performance than 3D menus with low memory loads, but the 3D menus were preferred by most participants (Kim et al., 2011).

The advantages of 3D interface metaphor may also work for older adults. Rice and Alm (2008) developed four navigational tools for digital television (carousel interface, flipper interface, transparency interface, and standard digital television interface) after collecting extensive requirements from older adults. The results showed that older adults favored the carousel interface because of its fluidity of movement and clear guides for the spatial placement of each navigation item. The 3D flipper format was also reported to be a powerful navigational tool by showing the sequence of menu items like sheets of paper. Traditional list menus performed the worst, resulting in more difficulties with interaction and understanding. Summarily, although there is a debate on the benefits of 3D metaphor design on performance efficiency, new opportunities still exist in applying 3D interface designs for better understanding and acceptance of technological systems for older adults. Moreover, different from previous technologies, mobile devices with touch screens allow for direct manipulation of 3D objects, which may produce further benefits of 3D interface metaphors.

2.2 Characteristics Related to Mobile Navigation

With the aim of making the technology accessible and usable for a wider range of users such as aging population, it is essential to characterizing the users' demographic background, user capabilities and prior technology experience in design process (Langdon et al., 2010). For instance, researchers suggest that the match between the design attributions and users' sensory, cognitive and motor capabilities is important to assure a successful human-computer interaction (Persad et al., 2007). Specifically, the influences of age-related cognitive declines on older adults' information searching and navigating of mobile technologies have been noted in a number of previous studies (Kamin and Lang, 2015; Dommes et al., 2011; Drag and Bieliauskas, 2010). For example, spatial ability, which plays a crucial role in users' understanding of the relationships between pages and locating the page that is currently being viewed, is believed to be the most significant capability in web navigation performance (Puerta Melguizo et al., 2012; Juvina and van Oostendorp, 2006; Pak et al., 2006; Ziefle and

Bay, 2006; Chen, 2001). Additionally, the importance of memory and attention for complex information seeking task performance, such as reasoning, working memory, and perceptual speed, has also been recognized in previous works (Laberge and Scialfa, 2005). A study by Juvina and van Oostendorp (2006) did not report the effects of working memory on web navigation task performance to be the same as spatial abilities, but working memory was found to be the best predictor for user disorientation.

Other variables of user characteristics are also found to moderate the cognitive aging process and further influence older adults' use of mobile technologies. For example, it was proposed that education levels are significantly associated with age-related capability declines, where higher education levels may result in lower rates of cognitive decline over time (Li and Luximon, 2017; Biswas, 2015; Wagner et al., 2014; Habib et al., 2007). Furthermore, designers should also establish the users' prior technology experience in order to develop technologies that are easy to learn and use (Fish et al., 2009). Several components have been reported to effectively predict the degree of technology usability for older adults including previous generations of technology use (Docampo Rama, 2001), technology exposure, and competence (Hurtienne et al., 2013; Langdon et al., 2007). Specifically, the exposure is usually measured by three aspects of mobile technology usage, including duration of use, intensity of use, and diversity of use. Thus, older adults with richer technology experience may perform better in mobile navigation tasks.

However, with the development of touch-screen mobile technologies, information hierarchies are becoming flatter and broader than desktops, which have considerably lessened disorientation issues caused by declined spatial ability (Zhou et al., 2012; Boulos et al., 2011; Hoehle et al., 2011). At the same time, another challenge introduced by mobile technology is the demand of visual attention (Li and Luximon, 2017; Punchoojit and Hongwarittorrn, 2017; Yang et al., 2012). Users need to quickly shift their attention between different pages and across mobile applications via interacting with the interfaces with gestures such as scrolling, tapping, and swiping. Previous research could not provide a deep understanding of how older adults' specific user characteristics, such as cognitive capabilities, education, and technology experience, can influence their navigation behavior with mobile technologies.

2.3 Present Study

To examine the effects of 3D interface metaphor on older adults' mobile navigation behavior, this study compares two navigation design patterns, a 2D list interface and a 3D card interface (Tidwell, 2010). The 2D list pattern presents a vertical stack of information without 3D metaphors. Each list is comprised of section names and article headlines. Sometimes, the list is accompanied by a brief summary of the information (Yu and Kong, 2016). The 3D card pattern is a newer interface design pattern that works well across desktop and mobile platforms (Laubheimer, 2016). It is a 3D metaphor design of stacking cards taken from the physical world, which can help to facilitate users' mental models through previous experience (Zhou et al., 2017). Specifically, cards have been found to be effective at grouping heterogeneous content and providing additional preview details for each patch of information.

In sum, this study aims to investigate how older adults navigate the interfaces with and without 3D metaphors and address the possible factors of user characteristics that influence their navigation performance and subjective evaluation. Two main questions are formulated as follows: (1) Will the application of 3D interface metaphor improve older adults' navigation performance and subjective evaluations with mobile technologies? (2) What factors of user characteristics, if any, influence older adults' navigation performance and subjective evaluations during the process? In the following sections, we elaborate on the experimental design, including participant recruitment, user characteristics investigation, interface and task design, measures, and data analysis. Then, the results are discussed in detail, followed by the conclusion.

3. Methodology

3.1 Participants

Participants were recruited from three local community elder centers by leaflet and verbal advertisement. 22 Hong Kong Chinese older adults over 60 years old who had previous experience with smartphones, tablets, and relevant applications participated in this study. All participants reported that they could read Chinese characters and were in good physical condition without any cognitive impairment. As compensation for participating in the experiment, participants received a supermarket coupon for 100 Hong Kong dollars.

3.2 Experimental Design

3.2.1 Capability Measurement

Participants' cognitive capabilities were evaluated according to short-term memory, spatial ability, and perceptual speed, and visual ability was determined by a self-reporting evaluation.

First, the short-term memory and spatial ability were measured by the auditory number span test (ANST) and card rotation test (CRT), respectively, as selected from the Kit of Factor referenced cognitive tests (Ekstrom et al., 1976). The ANST was used to measure participants' ability to store and retrieve a number of distinct elements in their short-term memory. In the test, the experimenter called out a series of digits at a speed of one digit per second. Participants were asked to verbally repeat these numbers in the exact order in which they were called. For each digit series, the participants were given a second chance if they failed the first try. The lengths of the digit series were increased until the participants failed both their first and second tries. The test scores were the highest number of digits the participants repeated correctly in the exact order.

Subsequently, the participants were instructed to complete the CRT to evaluate the participants' ability to perceive spatial patterns and maintain orientation in respect to objects in space. In the test, participants were given a drawing of a card that was cut into an irregular shape. On the right side of this card were eight drawings of the same shape, some of which were rotated or flipped. Participants needed to indicate whether the drawings had been flipped. This test consisted of two parts. For each part, participants were asked to finish the test as quickly as possible without sacrificing accuracy in three minutes. The score was the number of items answered correctly minus the number answered incorrectly.

Next, the symbol digit modalities test (SDMT) was employed to evaluate participants' perceptual speeds (Benedict et al., 2012). In this test, participants were provided with a coding scheme in which nine abstract symbols were paired with nine digital numbers. During the test, participants were given a task sheet with the abstract symbols randomly arranged.

They were required to fill in as many of the paired numbers as they could, according to the coding scheme sheet. The score was calculated based on the number of correctly matched symbols finished by the participants.

Finally, a self-reporting evaluation was used to examine participants' visual ability in reading text on digital displays (VA). A tablet interface was employed to ask the participants to verbally evaluate their visual abilities, which involved various sizes of text, pictures, and icons. Participants rated their perceived difficulties on a 5-point Likert scale (extremely difficult, very difficult, moderately difficult, a little difficult, and not difficult at all).

3.2.2 Interface

A simulated iBook store was implemented for this experiment. This mobile application is developed by the programming language of C# on a Samsung smartphone (Galaxy C7 Pro) with a resolution of 1080×1920 pixels. Participants could browse through various categories and search detailed contents of each book including their names, authors, publication time, content introduction, and author biography. 144 pieces of book material were created in 12 book categories, with each category including 12 books. Materials used in the iBook store were Hong Kong Chinese publications collected from Google books (https://play.google.com/store/books) and the Sanmin iBook store (http://www.sanmin.com.tw/Home/Index.html). They were then partly revised and simplified by two local language experts to eliminate the possible influences of different levels of language understanding. Additionally, with the aim of maintaining a consistent cognitive load across various books, the book names were rewritten without any information cues directly related to task instruction, the word count of the book introductions was limited to 210, and the word count of the author biographies was limited to 125. For each task, the iBook store randomly selected 12 books including one target book and 11 confounding books from the different categories without repetition.

The iBook store interfaces consisted of four main pages (see Fig. 1): (1) a task instruction page with a start button where participants were instructed to find a book that matches the keywords in the task; (2) a home page with 12 books presented in the format of either a list or card, where participants could tap the list or card to enter the detailed content page. Specifically, the card content could also be selected in the home page by tapping the button “adding to favorite”; (3) a detailed content page showing the book category, name, content introduction, and author biography, where participants could select the book by tapping the button “adding to favorite” at the top-right corner of the interface; (4) an ending page showing participants whether or not they have selected the correct book. Additionally, if the participants forgot the task instructions, they could click the return button at the top-left corner of the home page. However, the users were informed that this would be recorded and may influence their navigation performance.

Fig. 1. The iBook store interfaces: (a) task instruction; (b) home page (card); (c) home page (list); (d) detailed content page; (e) completing.

Two types of navigation design were used in this study. For 2D vertical lists, the home page was designed as content lists stacked in a linear presentation, as shown in Fig. 2. Each list contained the category title, book name, authors, and publication time. The lists could be scrolled up and down, with four entire lists and one half-presented list shown in one screen maximally. For the 3D flipper cards, the home page was designed with content cards stacked one by one, as shown in Fig. 3. Each card contained a category title, book name, authors, publication time, and half of the book introduction. The cards could be flipped up and down. Only one card was presented on the screen at a time, with all the previous cards stacked behind it and one preview card shown below it; the nearest previous card and the preview card displayed their category titles.

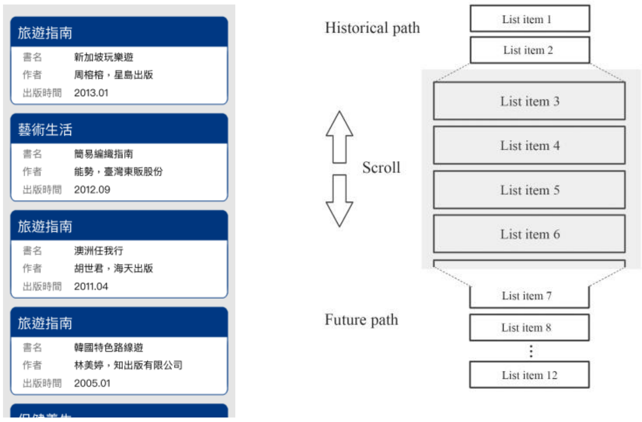

Fig. 2. The 2D list interface design

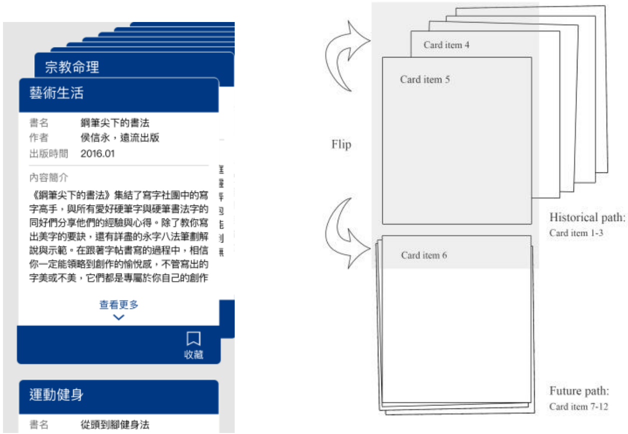

Fig. 3. The 3D card interface design

3.2.3 Task.

In the experiment, the participants were asked to find one target book that matched the topic described explicitly in the task instruction (examples shown in Table 1). The keyword was highlighted in red and could be found in the content introduction of each book. Based on the specific task instruction, participants could select the book by adding it to the favorites list. If they chose the wrong book, the interface would prompt them to try again. The task was completed only when the correct book was selected. The participants completed two information-searching tasks for each interface. All tasks were randomly generated from the task pool shown in Table 1.

Table 1 Overview of task descriptions, translated by authors.

No.	Task Description

1	You are an elder who is aged over 60 years old and hope to do some simple exercises, such as practicing a front bend. Please find a book related to the forward bending exercise and add it to your favorites.
2	Your friend wants to return to work and start a business after retirement. In order to help him master the rules of entrepreneurship, please find a book introducing the elderly entrepreneurial experience and add it to your favorites.
3	You are planning a long-distance railway journey from Hong Kong. Please find a book that suits your journey and add it to your favorites.
4	One of your family members has recently been working on a slimming program and wants to make foods that are better for slimming. Please find a book related to weight-loss diets and add it to your favorites.
5	Your elderly friend just started using the computer. He hopes to learn some practical computer and web knowledge. Please pick out a book that suits him and add it to your favorites.

3.2.4 Navigation Performance and Subjective Evaluation.

The entire experimental process was video and audio recorded. Every interactive click was automatically recorded by the system. The dependent variables were participants' navigation performance in terms of completion time and correctness rate, as well as subjective evaluations for tasks and interfaces. Specifically, task completion time was counted in seconds from when participants clicked the start button until they clicked the "adding to favorite" button for the target book. Correctness rate was measured by the percentage of correct answers chosen for each task.

After each task, participants were asked to evaluate their perceived difficulty with each task. In addition, for each interface design, participants' subjective evaluation were measured using interview questions covering several aspects of user perceptions including perceived ease of use, perceived usefulness, effort spent, disorientation, satisfaction, and behavioral intention to use, as shown in Table 2. These questions were verbally answered based on a 5-point Likert scale (1=completely disagree, 2=disagree, 3=neutral, 4=agree, and 5=completely agree).

Table 2 Questions on subjective evaluations.

Object	Category	Item	Questions
Task	Perceived	PF	This task is easy for me to complete.

	difficulty		
Interface	Ease of use	PEOU1	In this version of the interface, it is easy for me to complete the tasks.
		PEOU2	The interaction with this interface is clear and understandable.
	Perceived usefulness	PU1	The interface can help me in completing my tasks.
		PU2	I believe this interface could improve my information searching performance.
	Effort	EF	I do not need a lot of effort to fulfill these tasks.
	Disorientation	DO1	I do not feel lost or disoriented.
		DO2	I know my current position in the interface.
	Satisfaction	ST	I feel very satisfied with the overall experience.
	Behavioral intention to use	BITU	I intend to continue to use this kind of interface if there are opportunities in the future.

3.3 Procedure

Before the experiment, participants were asked about their demographic information, including age, gender, education, duration of using computers, duration of using mobile technologies, intensity of using mobile technologies (specifically, the frequency of using mobile technologies per week), diversity of using mobile applications (specifically, the adoption of advanced mobile applications other than the fundamental functions such as calling, sending a text message, taking photos, calculation and setting alarm), and self-rated competence of using mobile technologies. Participants were then instructed to complete the capability tests.

Then, participants were introduced to the experiment in detail. The task requirement was first explained, and the 12 book categories were introduced by the researchers to ensure that the participants were familiar with the materials used in the test. Participants were then shown the two types of navigation design on the screen and instructed how to begin and end the task, as well as how to navigate between pages by scrolling, flipping, clicking, and returning. Participants were informed that they could take their time to read the task instructions and that there would be no benefit to guessing the answers because the correctness rate would be substantially affected.

After the introduction, participants were given three trial tasks to familiarize themselves with the tasks and interfaces and to ask questions. In the experiment, there were four tasks for each participant to complete. After each task, participants evaluated their perceived difficulty using the 5-point Likert scales. When finished with each interface, the participants were instructed to report their subjective evaluations on perceived ease of use, perceived usefulness, effort, disorientation, satisfaction, and behavioral intention to use via a 5-point Likert scale.

3.4 Data Analysis

Completion time and correction rate were recorded for navigation performance analysis, and participants' perceived difficulty with each task, perceived ease of use, usefulness, effort, disorientation, satisfaction, and behavioral intention to use each interface were collected for subjective evaluations. An alpha level of 0.05 was used for statistical analysis. A descriptive data analysis was conducted for the factors of user characteristics. The Spearman correlation analysis was used to analyze the possible relationships between user characteristics, navigation performance and subjective evaluation. A multiple regression analysis was further performed to ascertain factors of user characteristics associated with participants' navigation performance and subjective perceptions for the 2D list and 3D card interfaces. In addition, paired t-tests were employed to analyze the differences in completion time between 2D and 3D interfaces because the data on completion times were normally distributed after being log-transformed according to the Shapiro-Wilk test. Simultaneously, the Wilcoxon signed-rank test was employed to analyze the differences between the 2D list and 3D card interfaces in terms of navigation performance of correctness rate and subjective evaluations.

4. Results

4.1 User Characteristics

In total, 22 older adults (8 males and 14 females) participated in the experiment, with an average age of 69.7 years (age range: 62 to 82 years old, SD=6.02 years). Participants reported a range of education levels from below the primary school (0 years) to the university level and above (17 years), with an average education of 8.36 years (SD= 4.66).

Participants' experiences with previous generations of technology and current advanced mobile technology were recorded. In this study, 63.6% of participants reported having experience using a computer, with an average duration of 6.16 years (SD=7.97). All participants had experience using smartphones, and 63.6% had experience with tablets. The average duration of using these mobile technologies was 4.84 years (SD=2.48). Participants reported using smartphones or tablets 2.36 hours per day on average and reported using an average of 6.95 advanced mobile applications (SD=2.10). In addition, participants' self-assessed technology competence was measured using 5-point Likert scales. This showed that the half of participants (50.0%) believed they were at a middle level in using mobile technologies, followed by those who thought they were at a relatively poor level (27.3%), those who believed they were at a relatively good level (18.2%), and those who thought they were at a very poor level (4.5%).

In terms of capability measurements, we collected the participants' scores on three performance tests, the ANST, CRT, SDMT, as well as the VA. The results showed that the participants varied greatly in terms of cognitive capabilities, especially for spatial ability, cognitive inhibition, and perceptual speed. Detailed statistics on the descriptive data are presented in Table 3.

Table 3 Descriptive statistics on user characteristics.

		N	Minimum	Maximum	Mean	SD
Demographic factors	Age (years)	22	62	82	69.7	6.02
	Education (years)	22	0	17	8.36	4.66
Technology experience	Duration of using computers (years)	22	0	25	6.16	7.97
	Duration of using mobile technologies (years)	22	1	10	4.84	2.48
	Intensity of using mobile technologies (hours/week)	22	3.50	45.50	16.53	10.71
	Diversity of using mobile applications	22	2	11	6.95	2.10
	Self-rated competence of using mobile technologies*	22	1	4	2.82	0.80
User capabilities	ANST	22	5	10	7.73	1.45
	CRT	22	11	84	38	22.36
	SCWT	20	-4.93	14.38	4.38	5.44
	SDMT	22	7	55	32.14	11.73
	VA*	22	3	5	3.95	0.77

Note: *1-extremely difficult; 2- very difficult; 3- moderately difficult; 4- a little difficult; and 5-not difficult at all.

4.2 Relationship between User Characteristics, Navigation Performance and Subjective Evaluation

4.2.1 Correlations between user characteristics, task performance and subjective evaluation.

To identify possible factors of user characteristics that predict navigation performances and subjective evaluations, a correlation analysis and a multiple regression analysis were employed in this study. Firstly, the correlation analysis was conducted between factors of user characteristics and the dependent variables. Table 4 depicts the significant correlations. For the 2D list interface, it was found that participants' completion time was significantly and negatively related to their diversity of using mobile applications (p=0.023), and the perceived difficulties towards the tasks were significantly and positively related to their self-rated competence of using the mobile technologies (p=0.046). As for the 3D card interface, a significantly positive correlation was reported between participants' age (p=0.037) and completion time, and significantly negative correlations were found between perceptual speed (SDMT) (p=0.003), visual ability (VA) (p=0.022), and completion time. It also showed a significantly negative correlation between participants' duration of using mobile technologies and their perceived difficulty with the tasks (p=0.012).

Table 4 Significant correlations between user characteristics, navigation performance, and subjective evaluations of perceived difficulties with tasks (n=22).

	2D list interface		3D card interface	
	Completion time	Perceived difficulties	Completion time	Perceived difficulties
Age			0.315*	
Duration of using mobile technologies				-0.375*
Diversity of using mobile applications	-0.341*			
Self-rated competence of using mobile technologies		0.302*		
SDMT			-0.441**	
VA			-0.346*	

Note: *p < 0.05; **p < 0.01.

Relationships between the participants' evaluations of the interfaces and user characteristics were also analyzed, and significant correlations are shown in Table 5. The results showed that participants' short-term memory (ANST) was significantly and positively correlated with their perceived usefulness (p=0.044) and effort spent (p=0.012) regarding the 2D list interface. In the same time, the participants' perceptual speed (SDMT) also reported significantly positive correlations with participants' evaluations of 2D list interface in terms of effort spent (p=0.030) and two aspects of disorientation (p=0.005; p=0.015). Additionally, there was a significantly negative correlation between age and one aspect of evaluation on 2D list interface' disorientation (p=0.036) and a significantly positive correlation between education and another aspect of evaluation on 2D list interface' disorientation (p=0.042).

Participants' evaluations of the 3D card interface also showed various significant correlations with their user characteristics (see Table 5). Firstly, the two aspects of perceived ease of use of the interfaces were significantly and positively related with the participants' duration of using computers (p=0.045) and the duration of using mobile technologies (p=0.019) respectively. Instead of relating to short-term memory, participants' perceived usefulness of the 3D card interface was significantly and positively correlated with their perceptual speed (SDMT) (p=0.009). Similar to the list interface, the participants' perceived disorientation with the 3D card interface was significantly and positively related with their education (p=0.033) and perceptual speed (SDMT) (p=0.001). It was also positively correlated with participants' duration of using computers (p=0.005) and self-rated competence level (p=0.004). Moreover, participants' behavioral intention to use the card interface was found to be significantly and negatively related to their self-rated competence levels (p=0.044).

Table 5 Significant correlations between user characteristics and subjective evaluations on interfaces (n=22).

		PEOU1	PEOU2	PU2	EF1	DO1	DO2	BITU1
	Age						-0.439*	
2D list	Education					0.437*		
interface	ANST			0.433*	0.527*			
	SDMT				0.464*	0.578**	0.513**	
3D card	Education					0.456*		

interface	Duration of using computers	0.431*				0.576**		
	Duration of using mobile technologies		0.497*					
	Self-rated competence of using mobile technologies						0.583**	-0.434*
	SDMT			0.546**		0.678**		

Note: **p* < 0.05; ***p* < 0.01; PEOU refers to ease of use, PU refers to perceived usefulness, EF refers to effort, DO refers to disorientation, ST refers to satisfaction, BITU refers to behavioral intention to use.

4.2.2 User characteristics associated with navigation performance and subjective evaluation.

A multiple regression analysis with a stepwise inclusion specification was performed to explore the predictive contribution of the user characteristics for navigation behavior depending on different interface designs. Before the analysis, the tolerance value and variance inflation factor (VIF) of the dependent variables were calculated to access the multicollinearity of predictors. It showed that the multicollinearity is not a problem because all tolerance values were greater than 0.01, together with VIFs less than 5.

For the 3D card interface, one multiple regression equation was developed for the navigation performance of completion time. The regression models that indicated significant associations are shown in Table 6. In total, the proposed user characteristics explained 21.2% of the variance regarding completion time. Specifically, participants with higher levels of perceptual speed (SDMT) performed faster when navigating the 3D card interface (β= -0.460, p=0.002). However, no regression model was developed for the navigation performance using the 2D list interface. Additionally, it was found that the perceived difficulty of tasks using the 2D list interface was significantly associated with the variable of self-rated competence, resulting in a model with R^2=0.121. In other words, participants who thought they were more familiar with mobile technologies tended to perceive navigation tasks using the 2D list interface as easier to complete (β= 0.348, p=0.021).

In terms of the subjective evaluations of the interfaces, three regression models were developed for the 2D list interface and five regression models were developed for the 3D card interface. Table 7 presents the final regression models that reported the significant associations. It was shown that for the 2D list interface, capability of short-term memory was the only significant factor predicting participants' perceived effort spent, resulting in a model with R^2=0.208. Specifically, participants with higher levels of short-term memory (ANST) (β= 0.457, p=0.033) perceived navigation using the list interface as more effortless. In the same time, the capability of perceptual speed was significantly associated with participants' disorientation when navigating the list interface, resulting in two models with R^2=0.398 and R^2=0.187. Specifically, participants with higher levels of perceptual speed (SDMT) tended not to feel lost or disorientated (β= 0.631, p=0.002) and knew their current position in the interface clearly (β= 0.432, p=0.045).

As for the 3D card interface, it was found that the duration of experience using mobile technologies was reported as significantly and positively associated with participants' perceived ease of use in terms of understandability (β= 0.449, p=0.036), resulting in a model with R^2=0.202. The capability of perceptual speed also reported significant associations with participants' perceived usefulness and perceived disorientation, resulting in three regression models with R^2=0.232 and R^2=0.404 respectively. Particularly, participants with higher levels of perceptual speed (SDMT) tended to think the interface improved their navigation performances (β=0.482, p=0.023) and experienced fewer disorientations (β=0.636, p=0.001). In addition, the level of self-rated competence also showed a significant and positive association with participants' perceived disorientation in knowing their current position in the interfaces (β= 0.565, p=0.006), resulting in a model with R^2=0.320. Moreover, self-rated competence was the significant predictor of participants' behavioral intention to use the 3D card interface, resulting in a regression model with R^2=0.192. Nevertheless, it showed that participants who thought they were more familiar with the mobile technologies tended to avoid using the 3D card interface in the future (β=-0.438, p=0.041).

Table 6 Standardized coefficients Beta of hierarchical regression for navigation performance and subjective evaluations of perceived difficulties with tasks (n=22).

	Dependent variables	
	List	Card
Independent variables	Perceived difficulties	Completion time
Age		
Self-rated competence of using mobile technologies	0.348*	
SDMT		-0.460**
R^2	0.121	0.212

Note: *$p < 0.05$; **$p < 0.01$.

Table 7 Standardized coefficients Beta of hierarchical regression for subjective evaluations toward interfaces (n=22).

		Dependent variables					
	Independent variables	PEOU2	PU2	EF1	DO1	DO2	BITU1
List	Age						
	Education						
	ANST			0.457*			
	SDMT				0.631**	0.432*	
	R^2			0.208	0.398	0.187	
Card	Education						
	Duration of using computers						
	Duration of using mobile technologies	0.449*					
	Diversity of using mobile applications						
	Self-rated competence of using mobile technologies					0.565**	-0.438*
	SDMT		0.482*		0.636**		
	R^2	0.202	0.232		0.404		0.320

Note: *$p < 0.05$; **$p < 0.01$; PEOU refers to ease of use, PU refers to perceived usefulness, EF refers to effort, DO refers to disorientation, ST refers to satisfaction, BITU refers to behavioral intention to use.

4.3 Comparisons of 2D and 3D Interfaces in Navigation Performance and Subjective Evaluation

4.3.1 Navigation Performance.

Navigation performances were measured by the average completion time and correctness rate of tasks using the 2D list and 3D card interfaces. The descriptive data are shown in Table 8. Overall, the results indicated that the 2D list design outperformed the 3D card design in terms of completion time (65.43s vs. 82.02s). However, the paired-samples t-test detected that there were no statistically significant differences between the use of 2D and 3D interfaces in terms of completion time. At the same time, participants achieved similar high levels of correctness rate in the tasks when using both interfaces. No significant differences were detected between the 2D and 3D interfaces in correctness rate according to the Wilcoxon signed-ranked tests.

Table 8 Participants' performance of completion time and correctness rate, as well as subjective evaluation of perceived difficulty with tasks (n=22).

Interface	Completion time (s)				Correctness rate	Perceived difficulty
	Minimum	Maximum	Mean (SD)	Mean log (SD)	Mean (SD)	Mean (SD)
2D List	9	289	65.43 (28.49)	1.72 (0.16)	0.9432 (0.1072)	4.20 (0.57)
3D Card	14	386	82.02 (49.53)	1.80 (0.25)	0.9432 (0.1072)	4.02 (0.76)

4.3.2 Subjective Evaluation

Participants' perceived difficulty with each task was collected using 5-point Likert scales. Overall, participants perceived the tasks using the 2D list interface as easier than the 3D card interface (4.20 vs. 4.02), as show in Table 8. However, the analysis of the Wilcoxon signed-ranked tests with a Bonferroni correction showed that there was no statistically significant difference between the participants' perceived difficulty with the interfaces.

As for participants' subjective evaluations of the interface designs, descriptive statistics are reported in Fig. 4. The results showed that the 2D list interface outperformed the 3D card interface in subjective evaluations for several aspects, including perceived ease of use, perceived usefulness, and overall satisfaction. For participants' disorientation, the list and card interfaces achieved similar levels of subjective evaluation. Regarding effort spent and behavioral intention to use, the card interface was preferred by participants. However, the analysis of the Wilcoxon signed test did not reveal any statistically significant differences in terms of subjective evaluations with the different interface designs.

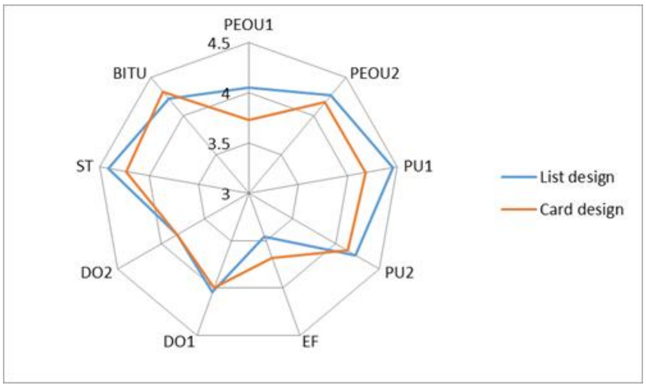

Fig. 4. Scores of subjective evaluations for interface design.

Note: PEOU refers to ease of use, PU refers to perceived usefulness, EF refers to effort, DO refers to disorientation, ST refers to satisfaction, BITU refers to behavioral intention to use.

5. Discussion

To summarize the results, the 2D list interface outperformed the 3D card interface for older adults in terms of navigation completion time, although these differences were not statistically significant. Correctness rate, however, was achie

ved at the same level for both interfaces with rather high performances. This is probably because this experiment tried to control the speed-accuracy trade-off by telling the participants not to risk errors to improve completion time. Overall, the results are consistent with other studies conducted with young adults finding that 2D interfaces improved navigation performance more than 3D interfaces (Kim et al., 2011; Rice and Alm, 2008; Cockburn and McKenzie, 2001). Nevertheless, the previous studies only provided possible explanations instead of investigating the underlying reasons for the results. For example, Cockburn and McKenzie (2001) thought it was due to the lack of visual guidance from the current card to the preview or history cards, and Kim et al. (2011) explained that it was because 3D interfaces are difficult to manipulate and cannot perform as well when the menu is broader. Based on this study, we believe that the reasons mainly lie in the demands of certain cognitive capabilities required by 3D interface metaphors.

Although there was no significant difference reported between these two interfaces, the range of completion time when navigating the 3D card interface (9s to 289s) was more varying than that when navigating the 2D list interface (14s to 386s). The higher variance in completion time when navigating 3D card interface may be explained by the influence of users' perceptual speed. Specifically, the results of current study indicate that the older adults' navigation performance with the 3D card interface were predicted by their capability level of perceptual speed; whereas, there was no predictive variable of user capabilities or technology experience found for the older adults' navigation performance with the 2D list interface. Thus, in other words, the use of 3D interface metaphor may require higher level of user capability in terms of perceptual speed. This result is also consistent with some previous studies that reported the deficit of perceptual speed was closely related to decline visual scanning ability, which would adversely affect the users' information-seeking performance (Sharit et al., 2006). In addition, another possible explanation is that the flipping gesture of the 3D card interface may be difficult to understand and requires more precise interaction techniques for older adults, which may also be a disadvantage of 3D interface metaphors.

There is a long history emphasizing the effects of spatial ability in web navigation (Wagner et al., 2014). One of the major benefits of using 3D interface metaphors is improved use of space and clear representation of the spatial relations of navigation items. However, with the mobile applications becoming flat and broad, disorientation caused by the hierarchically deep menus was considerably lessened. Together with previous studies (Li and Luximon, 2017), we further confirmed that spatial ability was no longer a major consideration in terms of mobile navigation performance. On the contrary, the 2D list interface without 3D metaphors, which could better facilitate a linear method of visual exploration, may be beneficial for older adults' navigation behavior and results in fewer usability issues (Castilla et al., 2016). In addition, we did not find any effects of short-term memory on navigation performance, which may be because the information-searching tasks used in the current study were simple and required a smaller memory load.

Although previous research has reported that users preferred 3D interface metaphors in terms of fun (Kim et al., 2011; Rice and Alm, 2008), we did not find any statistically significant differences in the participants' subjective evaluation for the 2D or 3D interfaces in this study. Supplementary to previous research, this study also investigated user characteristics that could predict users' subjective evaluations of 2D and 3D interfaces, as shown in Table 7. Overall, participants thought the 2D interface was easier to use and reported higher levels of usefulness and satisfaction. Participants with higher levels of self-rated competence using mobile technologies perceived the tasks using the 2D list interface as easier to complete. In addition, the results showed that the older adults with lower level of short-term memory could perceive a higher level effort needed and the older adults who had lower level of perceptual speed tended to easily feel disorientated when navigating with the 2D list interface (Juvina and vaa Oostendorp, 2006).

Nevertheless, the card interface with 3D metaphor was overall preferred in terms of perceived effort and behavioral intention to use when comparing to the 2D list interface. Factors of technology experience and user capabilities were proven to have a significant influence on participants' evaluation of the 3D card interface (see Table 7). Participants with longer durations of using mobile technologies tended to find the 3D card interface easier to use. Simultaneous, higher levels of self-rated competence predicted fewer feelings of disorientation. This may be because most participants were not familiar with the 3D card interface. A richer technology experience could help them to quickly build a mental model when using the new interface (Blackwell, 2006). Additionally, the capability of perceptual speed was also important for participants' evaluations of the 3D card interface, specifically on perceived usefulness and disorientation. Older adults who had higher level of perceptual speed were easier to perceive the 3D card interface as usefulness and oriented. However, it is surprising that participants with higher self-rated competence indicated that they tended to abandon the use of the 3D card interface in the future, which deserves to be studied in further research.

To date, researchers have made some efforts on developing a model of analytical inclusive design evaluation (Langdon et al., 2010). Specifically, it aims to addresses the capability-demands relationships to quantify how many users can use a specific interface by evaluating whether the design demands has exceeded the target users' capability range. Nevertheless, these studies are still in a phase of initial exploration on framework proposing. Overall, the results of this study can provide some experimental evidences for the analytical inclusive model building in the context of mobile interface navigation. By quantifying the relationships between the interface design and user capabilities and technology experience, it confirmed that different interface design, such as with and without 3D interface metaphors, were predicted by various user capabilities and technology experience. Nevertheless, this study is an initial attempt in identifying the predictive factors for the analytical model development and further studies are still needed to investigate the capability-demand relationships established by more kinds of interface design and within more kinds of interaction contexts.

This study should also be considered in terms of limitations and future directions. First, the task employed here was a simple information-searching task. It is unknown whether different levels of task complexity, such as additional memory load, would influence the mobile navigation performance and subjective evaluation of the user interfaces with different levels of metaphors (Kim et al., 2011). As reported by the study of Jeong, Jung and Im (2016), the stack menus can easily induce visual fatigue especially when the information density was high. Second, each of the book materials used in this study came from different categories. The results may differ if the contents are at different similarities or at different densities. For example, a mobile shopping application may have more than one product item under the same category, and the information displayed for each product list or card may be abstract or concrete. Thus, future studies could further investigate the possible effects of the 3D interface metaphors under more complicated conditions such as manipulating different types of tasks and contents.

6. Conclusion

There has been a growth of interest in the application of 3D interface metaphors in designing elderly-friendly mobile technologies. Nevertheless, it was unknown how the use of metaphor would influence older adults' mobile navigation behavior, especially considering age-related differences. Thus, we investigated the influences of 3D interface metaphor by comparing two types of mobile user interfaces: the 2D list interface and 3D card interface. To further understand the possible factors that may influence older adults' cognitive processes when navigating these interfaces, we also investigated various user characteristics including demographic factors, technology experience, and user capabilities.

Overall, we recommend it is better to avoid the use 3D interface metaphors, especially when the older adults need to perform information searching with lower memory loads and when the contents come from diverse categories. The 3D card interface should be implemented with caution because the navigation performance using 3D interface metaphor was significantly associated with users' capability of perceptual speed. Thus, navigating with this interface requires a higher level of perceptual speed. In addition, older adults felt that the 2D list interface was easier and more useful than the 3D card interface. Nevertheless, they thought the 3D card interface required less effort and thus showed more intention to use the 3D card interface in the future when comparing to the 2D list interface. Future work is needed to investigate the relevant effects of 3D interface metaphors concerning other factors such as task complexity and content similarity.

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