A Field Experiment on Capabilities Involved in Mobile Navigation Task

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Abstract. An increasing usage of mobile technologies has been seen among diverse age groups of users in recent years. The limited screen size and multiple interaction styles inevitably produce much more workload on mobile technologies use; thus it is necessary to investigate the possible capabilities involved in mobile navigation tasks. The particular interests of this study are the cognitive capabilities, namely spatial ability, short-term memory and processing speed and attention, as well as the visual abilities including vision acuity and visual perception of digital screens. Fifteen participants who covered a wide age range attended in this field experiment to complete several navigation tasks with three levels of complexity using an experimental mobile application. The results suggest that the capability of processing speed and attention is more important than the other capabilities for navigation performance and subjective preference. Specifically, the capability of processing speed and attention is significantly correlated with user characteristics, including age, education experience, and technology experience. The results can help designers to address the major capabilities involved in mobile navigation tasks to make relevant allowance to include more possible users, such as elderly people.

Keywords: Mobile technology · Navigation task · Capability · User characteristics · Aging

1 Introduction

An increasing usage of mobile technologies has been seen in recent years, especially among the older adults who aged 65 years old and above [1]. Mobile technologies can provide improved mobility, better security and advanced functions that benefit users from diverse age groups; thus it becomes more convenient for users to manage social relationships, monitor health status as well as learn and search online information [2, 3]. However, the features of contemporary mobile technology make it inevitably produce much more workload on technology use. In the same time, the declines in capabilities with aging could also slow down the human information processing cycle from information perception to response execution. For instance, the small multi-touch screens normally come with hidden buttons or menus, complicated information structures, as well as changeable interaction modes, which proposes more mental requirements for the mobile

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navigation tasks, especially for older adults. Thus it is necessary to investigate possible capacities involved in technology use and examine relevant limitations to maintain a proper workload when design mobile technologies, in particular considering the process of aging.

Designers should be aware of the typical changes with aging in terms of cognitive functions and visual facilities, such as attention, memory, processing speed, and visuo-spatial functioning [4]. For instance, the declines of cognitive capabilities may harm the process of paying attention to multiple resources, encoding of new information and retrieval of information from memory. The declines in visual abilities buffer the process of executing technology tasks, such as information seeking [5, 6]. Studies demonstrate that most of the cognitive capabilities have started to decline as early as mid-fifties, and then present a very fast decrease since the seventies [7]. In this way, with aging, people are experiencing more difficulties in ignoring the irrelevant information, dividing attention to different resources, recalling and recognizing the information when doing technology tasks. Particularly, spatial ability is reported to be an important determinant in technology usage especially menu navigation [8–10]. Users with higher spatial ability are expected to have better mental model to understand the underlying website structures to search the information efficiently [5, 11, 12].

While considerable studies have been conducted to investigate the effects of individual characteristics on computerized web-navigation that utilizing larger screens and mouse controlling, there is a distinct lack of research into the situation when navigating and browsing by advanced mobile technologies. The issue of user experience exists at different levels, from the user interface design to various task demands. Much of the current studies are concentrated on the menu and interface design [13, 14] as well as web browsing styles [15]. However, considering of wider range of possible users and increased task demands, it is also essential to examine how user capability make an impact on mobile navigation tasks. This study aims to explore the effects of cognitive and visual abilities on users' task performance and subjective preference in mobile navigation tasks. Three kinds of cognition capabilities were emphasized, namely short-term memory, spatial ability, and processing speed and attention. Vision acuity and visual perception of digital screens were measured by test performance and self-reports. The results give some insights into the possible capabilities that involved in mobile interface navigation with different levels of task complexity.

2 Methods

In order to investigate the role of related capabilities in mobile navigation tasks, a field experiment was utilized to measure user's mobile navigation performance and collect their subject preference among fifteen participants. Since this study aimed to include a wider age range of users, participants were recruited from different age brackets from 20s to 80s. In this situation, the field experiment allows for flexible arrangement considering of older adults' security and mobility issues. All the experimental environments were separated from the outside and kept quiet and tiny; the disturbing factors were controlled in an acceptable range.

2.1 Participants

Fifteen participants were recruited from the community center and university in Hong Kong. Participants were selected without any cognitive and visual impairments. Of all the participants, experience of using advanced mobile technologies was reported, such as smartphones, tables or smart watches. Participant's demographic information was collected, including age, gender and education level. In addition, prior technology experience was evaluated because of the high importance reported in previous studies [16, 17]. It is also notable that the experience with previous generations of technology may also matter when interacting with new technologies, especially for older adults [18]. Thus, the technology experience was measured by computer experience and mobile technology experience. Specifically, mobile technology experience was evaluated by technology exposure (e.g. duration of use, intensity of use, diversity of use) and technology competence.

2.2 Capability Measurement

Before the experiment, three particular cognitive capabilities in terms of working memory, spatial ability, as well as attention and processing speed, were measured by a modified Mini-Cog™ test [19] and symbol digit modalities test [20] respectively. The Mini-Cog™ test was composed of a word recall test (WRT) and clock drawing test (CDT). The spatial digit modalities test (SDMT) was administered to measure participants' attention and processing speed. Additionally, visual abilities were evaluated in terms of visual acuity and self-reported visual perception of digital screens.

Word Recall Test (WRT). The word recall test was used to evaluate the participants' short-term memory. In this test, participants were required to remember 5 unrelated words and then complete the following clock drawing test (CDT). After finishing the CDT test, they were instructed to tell the 5 previously stated words. The number of correctly recalled words was recorded as the test performance. Thus, the result scale was from 0 to 5.

Clock Drawing Test (CDT). The clock drawing test was employed to evaluate participants' spatial ability [21]. Provided with a circle on a paper, participants were first verbally instructed to draw the number to display the clock face, and then were asked to draw the hands of clock to read the time of 09:20. Each point was given to the participants if they correctly instructed the numbers on the circle or drew the hand of the clock to indicate correct time. Thus, the result scale was from 0 to 2.

Spatial Digit Modalities Test (SDMT). The spatial digit modalities test was administered by asking participants to correctly match 9 pairs of symbols and numbers (e.g., "(" and "1", "#" and "2", ">" and "3", …, "&" and "9"). They were asked to complete as many as paired symbols and numbers in 90 s. The number of correctly matched pairs was recorded as user performance. Result scale is from 0 to 90.

Vision Acuity (VA). This study used Tumbling E chart that calibrated and showed by a 2048 × 1536 display screen. Participants were asked to read the chart from 1.9 meters' distance with corrections. Starting from the biggest row, each participant was tested three letters in each row. The vision acuity results were calculated and noted as the minimum visual angel of each participant.

Self-reported Visual Perception (SVP). The participants were asked about their ability of reading and recognizing the characteristics on a 2048 × 1536 display screen, such as "is it easy for you to read or recognize the characteristics on this screen". The responses were marked as 1–5 from very difficult, difficult, neutral, easy and very easy.

2.3 Experimental Design

In order to reduce the influence of experience with specific mobile applications, a new iOS mobile application was designed and built using Unity. To facilitate user's real experience of using mobile technologies, this application was simulated to remind participants to take specific medicine in time. Participants were instructed to navigate between a menu navigation page and four sub-pages to complete serval tasks. Totally, three levels of task complexity were designed to simulate the real situations that the users would face in different kinds of tasks.

Specifically, this study concerned the task complexity according to the cognitive workload and requirements of the task. It was defined by how many information sources the participants need to remember or integrate when doing the mobile navigation tasks. For instance, the task complexity of level 1 didn't require participants to remember or integrate information at all; whereas, the task complexity of level 2 required for some memory load when completing tasks. When coming to the task complexity of level 3, users needed to remember some information as well as search for the relevant information to integrate useful resources and make decisions.

Participants' navigation performance was measured by their completion time, correctness rate, and the number of return steps and incorrect clicks. Following each task, the participants were asked to evaluate their subjective preference. They need to evaluate in terms of ease-of-use from very difficult to very easy (ranking 1–5), the disorientation from very disoriented to not disorientated at all (ranking 1–5), the effort needed from many efforts needed to few efforts needed (ranking 1–5), and overall satisfaction from very dissatisfied to very satisfied (ranking 1–5).

2.4 Procedure

Participants were provided with a brief experimental instruction and instructed to fill the consent form upon arriving. Then they were required to answer some questions and complete several tests according to the questionnaire. The first part of questions was concerned participants' age, gender, education level and technology experience. Following that, several paper-based assessments of short-term memory, spatial ability, and processing speed and attention were administered. The Tumbling E chart was then

used to measure participants' vision acuity and a digital display was showed to ask about their visual perception of reading and recognizing texts.

Finally, participants were provided with a smartphone with a 1080 × 1920 digital screen. Experimenters instructed them to use the application first and participants could try and use the application freely. Then, participants were required to complete three trials by themselves. With no questions or doubts, the experiment began. For each participant, 9 tasks were assigned to them in the randomized order. The background system recorded all the click data automatically.

3 Results

3.1 Participants Description

In order to analyze the mobile navigation behavior among a wide age range of users, we recruited fifteen participants aged from 24 and 81 years old. They averagely aged at 47.73 years old, with an average education experience of 15.47 years. The participants reported that they had the experience of using computer for 11.10 years averagely and have been adopted mobile technologies for about 5.19 years in average. They normally use the mobile technologies for 22.03 hours per week. High diversity of use was reflected by the number of functions that used by these participants. On average, they used 4.80 functions or applications, mainly for maintaining social relationships (100%), some basic functions (93.33%), managing healthcare status (73.33%), information searching (73.33%) and entertainment (46.67%). When asked how confident they feel when using mobile technologies, the majority participants reported they had a medium technology competence level of 3.53.

3.2 Analysis of Capability Assessments

Three categories of cognitive capabilities were measured, namely short-term memory, spatial ability, and processing speed and attention. Visual ability was assessed by the participants' vision acuity and self-reported visual perception. The details of assessment results are shown in Table 1. Basically, most of the participants indicated a normal level of short-term memory and spatial ability in the Mini-Cog™ test, with no significant declines or impairment reported. The results of SDMT test varied a lot between different participant, which may be because the total scores had wider range. For visual abilities, no significant difficulties were reported from the participants with corrections when reading on the digital screens.

Table 1. Capability assessment results (n = 15)

	Cognitive capability			Visual ability	
	WRT	CDT	SDMT	VA	SVP
Mean	4.93	1.93	46.07	1.12	4.73
Standard deviation	0.26	0.26	19.23	0.48	0.59

To further analyze the relationship between participants' capabilities and their demographic factors, as well as the technology experience, the Spearman Test was employed. Results showed that the SDMT results indicated a significant correlation with participants' age ($p = 0.000$), education experience ($p = 0.001$), computer experience ($p = 0.020$), duration of use with mobile technologies ($p = 0.003$), intensity of use with mobile technologies ($p = 0.028$), and competence of use with mobile technologies ($p = 0.031$). The visual abilities were also found some significant relationships with demographic factors and technology experience. Specifically, the minimum visual angel was found to be positively correlated with age ($p = 0.003$) and negatively correlated with duration of use with mobile technologies ($p = 0.001$). The self-reported visual perceptions were found to be negatively related with age ($p = 0.034$), and positively related with education experience ($p = 0.036$) and duration of use with mobile technologies ($p = 0.031$). However, there is no correlation found in the other two capability assessment results. The details of relevant correlations are shown in the following Fig. 1.

3.3 Capabilities Involved in Navigation Tasks

The descriptive data of navigation performance of participants are shown in Table 2. For navigation performance, participants outperformed when the level of task complexity was lower (level 1 and level 2). They needed nearly half of the completion time, had higher correctness rate, and less return steps and incorrect clicks. However, for subjective preference, no significant differences were reported between different levels of task complexity.

In order to investigate the capabilities involved in mobile navigation tasks, the relations between capabilities and navigation performance as well as subjective preferences were analyzed by the spearman test. The results showed that, for task complexity of level 1, there were significant correlations between the SDMT results and completion time ($p = 0.000$), as well as the correctness rate ($p = 0.007$). For the task complexity of level 2, significant relationship was found between SDMT results and completion time ($p = 0.000$). The similar relationships were also found when the task complexity was level 3. Specifically, significant correlations were found between the SDMT results and completion time ($p = 0.000$), as well as correctness rate ($p = 0.000$). Details are further shown in Figs. 2 and 3.

The correlation between capabilities and subjective preferences were also analyzed by the spearman test. The results are as follows. For task complexity of level 1, there is a significantly positive correlation between SDMT results and effort used ($p = 0.037$), and a significantly negative correlation between SDMT results and satisfaction ($p = 0.008$). The significantly negative correlation was also found between SDMT results and satisfaction ($p = 0.026$), when the task complexity was at level 3.

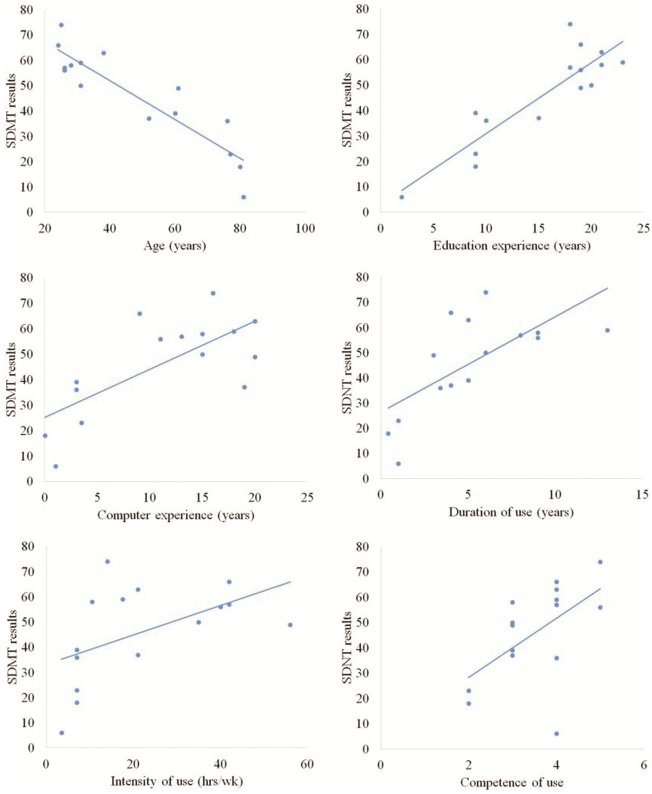

Fig. 1. Correlations between SDMT results and demographic factors and technology experience

Table 2. Descriptive data of navigation performance and subjective preference (n = 15)

Task complexity		Mean (Standard deviation)		
		Level 1	Level 2	Level 3
Navigation performance	Completion time	31.24 (21.30)	30.80 (19.03)	62.49 (37.86)
	Correctness rate	93.89 (9.16)	93.89 (13.16)	85.56 (18.49)
	Return steps	0.29 (0.47)	0.24 (0.39)	1.44 (1.24)
	Incorrect clicks	0.07 (0.14)	0.02 (0.09)	0.18 (0.28)
Subjective preference	Ease-of-use	3.87 (0.80)	4.02 (0.62)	4.36 (0.77)
	Disorientation	3.98 (0.97)	4.11 (0.65)	4.29 (0.73)
	Effort	3.58 (1.03)	3.75 (0.95)	4.02 (0.81)
	Satisfaction	3.58 (0.94)	3.76 (1.08)	3.73 (0.83)

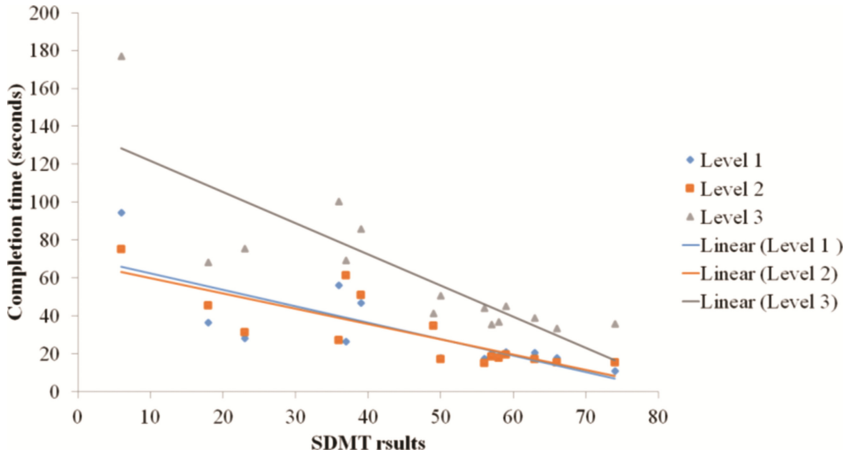

Fig. 2. Relationship between SDMT results and completion time

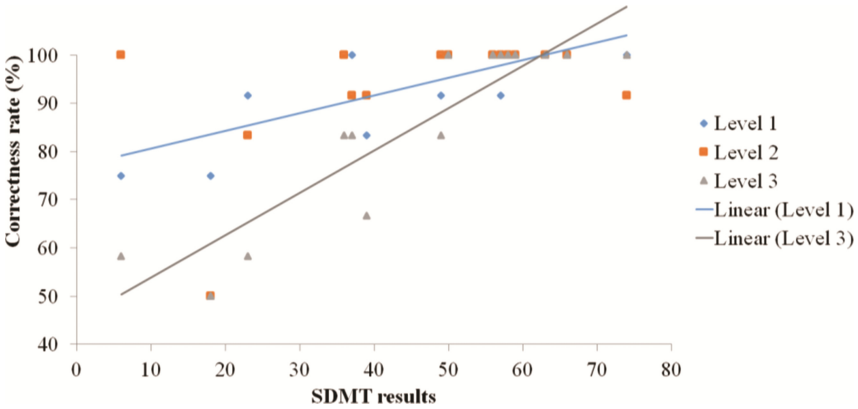

Fig. 3. Relationship between SDMT results and correctness rate

4 Discussion

Mobile navigating in a small touch-screen is a complex process. Thus, knowing different users' capabilities and limitations can help in reducing workload in mobile technology usage. This study is highlighted in the situation that a wider age range of users are adopting mobile technologies in the modern society [22]. The present results provide a number of interesting insights about mobile navigation behavior among participants with a wide age range.

Results indicate that age, education experience, and technology experience have significant correlations with SDMT results. The results supplemented previous studies that showed age and education are important for cognitive capabilities [5, 23]. With aging, users suffer from declined processing speed and attention; while longer education

experience may compensate relevant loss. In addition, current results also emphasize the role of technology experience. Specifically, both of the duration of use of mobile technologies and the computer experience were found to be significantly correlated with SDMT results. Nevertheless, further studies should be planned because these correlations could be interactive. For instance, it may imply that users with declined processing speed and attention tend to use less technologies; conversely, longer use of technologies may help to slowdown the declines in processing speed and attention.

The results also show that the capability of processing speed and attention is important for users' mobile navigation behavior in terms of objective performance and subjective preference. Significant correlations were reported between completion time and SDMT results at all the levels of task complexities, as well as correctness rate and SDMT results at the level 1 and level 3 of task complexity. This result is interesting because most of the previous studies mainly considered spatial ability and working memory as critical factors in computerized web-navigation [24]. Few studies have investigated the role of processing speed and attention.

The possible reason may lie at two aspects. First, it may be because of the difference between computerized web-navigation and mobile interface navigation. For computerized web-navigation, the information structures are usually quite complex with flat or hierarchical layers. Thus, users need to build the correct mental model to search for useful information, which emphasizes the importance of spatial ability [24]. However, the interaction style of direct manipulation makes it easier to jump between each pages when using mobile technologies. Users can get access with more information with shorter time. Therefore, it is more crucial to divide the attention to different resources and process more information at one time, which needs higher level of processing speed and attention. Second, it may be due to the limitations of method of Mini-Cog™ test. The test was only sensitive for some significant declines or damage of cognition; thus the sensitivity is not high enough for the participants in present study. Further research should be conducted by improving the difficulties of tests or utilizing various performance tests for spatial ability and short-memory to provide greater validity [25].

5 Conclusion

The field experiment outlined in this article found that the capability of processing speed and attention is important for mobile interface navigation. Users with higher processing speed and attention is more likely to find the information and complete the navigation task efficiently and effectively. The capability in terms of processing speed and attention is related to users' age, education experience, and technology experience with mobile technologies and computers. By investigating the capabilities involved in mobile interface navigation, designers could better understand a wider range of users' capability and limitation with different age, education experience and technology experience. In this way, it allows for including more possible users, such as elderly people.

The current results generate curiosity for some directions for future studies. First, more participants should be included to add the validity of participant's data. More age groups should be settled to further analyze the effects of individual characteristics on

the mobile navigation behavior. Second, it would be interesting to explore the reason of how the processing speed and attention influence user's navigation behavior on small screens of mobile technologies. It is also important to investigate how to design the interface to compensate this capability lost. Third, other performance tests of spatial ability and short-term memory should be utilized to further analyze their possible effects on mobile navigation behavior.

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