USER MODELLING FOR OLDER ADULTS' MOBILE INTERACTION BEHAVIOUR: EVALUATION OF USER CHARACTERISTICS, TASK DEMANDS AND INTERFACE DESIGN

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User Modelling for Older Adults' Mobile Interaction Behaviour: Evaluation of User Characteristics, Task Demands and Interface Design

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Certification of Originality

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Qingchuan LI (Name of student)

Abstract

Mobile technologies are emerging as promising tools for older adults to retain a higher level of independence, motivation and well-being. Although older adults are aware of the possible benefits of mobile technologies, they still face significant challenges when interacting with mobile technologies due to their declined perceptual, cognitive and motor capabilities. Moreover, the rapidly evolving mobile user interfaces and interaction design present unprecedented challenges for older adults. Nevertheless, current usability evaluation methods for the elderly-friendly mobile technology design are still depending on the general design guidelines, which mainly deal with some visual and haptic related issues. The interaction processes which require more efforts in cognitive processing are less understood. Given that an understanding of the relationships between user capability, interface demands and task contexts is necessary to access the degree of fit between technology design and elderly users, this research focuses on investigating the effects of these variables on older adults' post-adoption usage and perceptions of mobile technology and modelling older adults' mobile interaction behaviour by quantifying these relationships.

Qualitative and quantitative methods were utilised in the research. First, semi-structured interviews were employed to understand the general situation of older adults' post-adoption usage and perceptions of mobile technologies, examine the possible factors of user characteristics and technology features that could influence their post-adoption behaviour, and identify the major technology features that caused significant usability problems and difficulties during the process. The findings suggest that older adults' post-adoption use of mobile technologies can be influenced by their age, cognitive capability of perceptual speed and technology features of menu design and functionality. Their

post-adoption perceptions were associated with visual perceptions, cognitive capability of spatial ability and technology features of menu design, colour and background, navigation and controls. To focus the research scope, the following studies mainly examined technology features related to mobile navigation behaviour.

Second, usability testing and in-depth interviews were used to investigate whether current mobile user interface design patterns support older adults' navigation behaviour. Activity analysis was applied to detect the possible usability challenges and explore the underlying reasons for these difficulties. From the activity analysis, a list of design guidelines was proposed for elderly-friendly navigation design and two major kinds of mobile navigation behaviour were classified, namely menu-oriented navigation and content-oriented navigation. Accordingly, two experiments were then conducted to quantify the relationships between the influential factors of user characteristics, task demands and interface design for the menu-oriented and content-oriented navigation behaviour respectively. The results emphasise that older adults' menu-oriented navigation behaviour can be predicted by the level of task complexity and user characteristics such as age, education, technology experience and user capabilities in perceptual speed and vision. Older adults' content-oriented navigation was significantly influenced by user capabilities of perceptual speed and task complexity, by the interaction between perceptual speed and navigation design, by the interaction between navigation design, content similarity and task complexity, and by user's technology experience such as duration of use of computers and mobile technologies, and self-efficacy of mobile technologies. It also suggests that a metaphor design may assist older adults' content-oriented navigation behaviour but should be carefully used by considering users' different levels of perceptual speed. Based on the findings, the research develops two user models that address which predictive variables should be modelled and how they should be modelled for older adults' mobile navigation behaviour.

To summarise, the research provides deep insights into older adults' post-adoption usage and perceptions of mobile technologies, which can help to refine technology acceptance theories by emphasising a continued process of adoption. By investigating older adults' usability challenges while navigating mobile user interface, the research proposes a list of guidelines for designers by distinguishing two kinds of navigation behaviour to better fit the realistic design scenarios, which can further compensate the lack of usability standards regarding mobile navigation design. In addition, the development of two predictive user models provides a more effective method for comprehensive analytical usability evaluations on mobile interface design for older adults, with a deeper understanding on the relationship between user capability, interface demands and task contexts. They can help designers to estimate the extent of design inclusion and identify possible design features that may hinder older adults' mobile navigation behaviour in very early design stages, which can considerately reduce resource and time costs.

Publications Arising from the Thesis

Li, Q. & Luximon, Y. 2019. The effects of 3D interface metaphor on older adults' mobile navigation performance and subjective evaluation. *International Journal of Industrial Ergonomics*, 72, 35-44.

Li, Q. & Luximon, Y. 2019. Older adults' use of mobile device: usability challenges while navigating various interfaces. *Behaviour & Information Technology*, 1-25.

Li, Q. & Luximon, Y. 2018. Understanding older adults' post-adoption usage behaviour and perceptions of mobile technology. *International Journal of Design*, 12(3), 93-110.

Li, Q. & Luximon, Y. 2017. A Field Experiment on Capabilities Involved in Mobile Navigation Task. In *International Conference on Human Aspects of IT for the Aged Population*, 68-78. Springer, Cham.

Li, Q. & Luximon, Y. 2017. A Comparative Study between Younger and Older Users on Mobile Interface Navigation. In *The Tenth International Conference on Advances in Computer-Human Interactions*, 128-133. IARIA, Nice.

Li, Q. & Luximon, Y. 2016. Older Adults and Digital Technology: A Study of User Perception and Usage Behaviour. In *Advances in Physical Ergonomics and Human Factors*.155-163. Springer, Cham.

Li, Q. & Luximon, Y. An experimental analysis of user characteristics, interface design and task complexity in mobile navigation for older adults. Prepared to submit to *International Journal of Human-Computer Studies*.

Li, Q. & Luximon, Y. A Comparison of Younger and Older adults' Menu-Oriented Navigation Behaviour. Prepared to submit to *International Journal of Industrial Ergonomics*.

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CHAPTER 1 Introduction

1.1. Research Background

Technology is constantly advancing and changing how humans live and work, but are older adults excluded from this trend? According to the reports of Hong Kong government, Hong Kong has entered an aged society with 16.6% of adults aged over 65 years old in 2016 and is expected to come to a super-aged society by 2026 with a projected ageing rate of 23.0% (Census and Statistics Department, 2017a and 2017b). As 91.4% of older adults reside in domestic households with children (51.2%) or alone (12.7%) (Census and Statistics Department, 2013a), they are eager to remain independent and active. In ageing societies, technologies can provide supports across various domains in life, including social communication, information gathering, learning and entertainment, service delivery and maintaining and monitoring health (Mitzner et al., 2010; Plaza et al. 2011; Hill et al., 2015). The use of technology can empower older adults by enhancing their perceived social inclusion (Karavida et al., 2005), reducing loneliness (Pettigrew and Roberts, 2008) and preventing cognitive decline (Tun and Lachman, 2010), which ultimately facilitates their well-being and supports ageing in place.

Since Apple released the iPhone in 2007, mobile technologies have been implemented as platforms that integrate various functions (West and Mace, 2010). In the research, ‘mobile technologies’ refers to mobile computing devices with touchscreen interfaces that offer more advanced functions than cell phones (which are mainly used for making phone calls, sending messages and taking pictures). In contrast to traditional technologies such as computers, the direct manipulation of touchscreen interfaces is more intuitive for older adults.

Together with its improved mobility, security and functionality, mobile technology has become an important part of older adults' daily lives (Zhou et al., 2012). In Hong Kong, the percentage of smartphone users among persons aged above 65 years old has been increased from 10.2% to 52.1% between 2013 and 2018 (Census and Statistics Department, 2013b and 2018).

Researchers have made tremendous strides in enhancing technology usability for older adults. Guidelines and checklists have been proposed for various usage contexts and technologies from the fields of psychology and human-computer interaction (HCI), including design standards and a number of books and journal papers (Zaphiris et al., 2007; Fisk et al., 2009; Al-Razgan et al., 2012; de Barros et al., 2014; Patsoule and Koutsabasis, 2014; Hoehle et al., 2015; Johnson and Finn, 2017). In effect, mobile technologies avoid some usability issues associated with computers and cell phones such as visual difficulty and disorientation. However, the abundant technological features and rapidly evolving user interfaces inevitably produce other cognitive loads and difficulties for older adults (Cecere et al., 2015), which has been limited studied by the researchers. Furthermore, as their perceptual, cognitive and motor capabilities decline and their attitudes change, older adults are more sensitive to design defects than young adults (van der Wardt et al., 2010; Dommes et al., 2011; Chevalier et al., 2015; Dodd et al., 2017).

Although design guidelines can provide relatively inexpensive and quick tools for inspecting usability issues in mobile technologies (Duman and Salzman, 2006), they tend to be quite general. Designers can also face great challenges in applying these high-level principles to low-level user interface details (Duyne et al., 2002) or when trying to comply with style guides required by the mobile industry (von Wangenheim et al., 2016). In addition, the rapid evolution of mobile technologies can make previous guidelines for general technologies problematic in some ways (Zhou et al., 2013, 2012). Little is known about where and to what extent mobile technologies present usability challenges to older adults, how they influence older adults' adoption of mobile technologies, the deeper reasons behind these problems and their association with the age-related changes.

Another strategy for designers to analytically evaluate usability issues when interacting with technologies is through modelling tools that can predict users' interaction behaviour for a given interface or task based on user capability data. Predictive user models have been successfully applied for skilled routine interactive tasks and user interface (UI) exploration behaviour (Jastrzmbski and Charness, 2008; Fu and Pirolli, 2007). Researchers have argued that this method is particularly crucial in the early design process because the predictive model can inform technology designs by detecting probable causes that may lead to poor task performance from a relatively systematic perspective. Nevertheless, the current user models are primarily built on information theories such as the concepts of information scent and label-following, which emphasise the semantic relevance of a user's exploration goal and options shown in the UI. Someone may ask whether these models are sufficient to address all of the potentially relevant variables that influence technology interaction such as user characteristics, task demands and system design. Alternatively, are existing models understandable and useful for designers to evaluate mobile technologies during the design process? There has been little study of how other factors may influence mobile technology interaction, such as rapidly evolving design features, task demands or other contextual factors.

Improved usability is a key solution to overcome older adults' resistance to mobile technology, but it does not necessarily ensure technology acceptance and adoption (Zhou et al., 2012). Although older adults tend to show positive attitudes towards mobile technologies, they are still in the stage of initial adoption and mostly use only elementary and limited functions (Galit Nimrod, 2016). Technology adoption is also influenced by personal and environmental factors such as the perceived ease of use and usefulness of mobile technologies, as well as the facilitating conditions and social influences (Davis et al., 1989; Venkatesh et al., 2003). Only when they perceive greater benefits than difficulties at the initial adoption stage, older adults continue to use mobile technologies or even undertake upgraded adoption, for instance by using more functions and purchasing a new generation (Barnard et al., 2010). Thus, to encourage continued use of mobile technology, before developing usability predictive models it is also crucial to establish the key facilitators and limitations of technology features that can influence older adults' acceptance and adoption of mobile technologies.

1.2. Aims and Objectives

To understand what factors can facilitate or buffer older adults' continued use of mobile technologies in the post-adoption stage, we need an investigation of influential user characteristics particularly the age-related user capabilities and usability challenges posed by current mobile technology features. Furthermore, to compensate for the lack of detail in general design guidelines, designers need model the older adults' mobile interaction behaviour in a more comprehensive way by addressing variables from multiple aspects such as the user, task and technology systems. To meet these aims, the research has the following objectives:

- To investigate older adults' usage and perceptions of mobile technologies and identify the facilitators and hindrances to older adults' continued adoption of mobile technologies, with a specific focus on user characteristics and technology features.

- To identify specific technology features that cause significant usability issues and prevent older adults' adoption of mobile technologies, explore whether and how current UI designs increase or reduce the aforementioned usability issues and characterise these UI designs according to whether they match user capability, task demands and usage contexts.

- To develop user models that quantify the relationships between user characteristics, task demands and interface design. The models should enable better design of mobile user interfaces for older adults by establishing the relationships between these influential factors.

1.3. Scope and Research Questions

In the development of predictive tools for analytical usability evaluation, HCI researchers and practitioners have sought to implement, test and refine various theories and models. Most of these works involve goal-directed computer exploration based on information scent theories, such as the Goals, Operators, Methods, and Selection rules (GOMS), Keystroke-Level Model (KLM), Adaptive Control of Thought-Rational (ACT-R), Comprehension-based Linked Model of Deliberate Search (CoLiDes) and Scent-based Navigation and Information Foraging in the ACT architecture (SNIF-ACT), which are discussed in Section 2.5.2. Nevertheless, the study of user modelling for older adults' mobile interaction behaviour is still in an exploratory phase. The research presented in this thesis is implemented as the first necessary step for the development of predictive user models for older adults' interaction behaviour with mobile technologies, which mainly focused on the empirical evaluation of factors that need to be taken into account for modelling. The results are expected to identify what factors should be modelled and how they should be modelled by addressing variables from multiple perspectives including users, technological systems and tasks, as shown in Figure 1.1.

In addition, user modelling for a whole process of mobile technology interaction is a very complicated process, which requires large amounts of data even for one parameter estimation (Rogers and Fisk, 2010). Thus, the current research is limited to the investigation of one specific mobile interaction behaviour, which is determined by the most significant technology features that hinder older adults' usage and perceptions in their post-adoption behaviour and further limit their future adoption of mobile technologies. In addition, although motor capabilities are vital in modelling users' performance (Jastrzembski and Charness, 2008), the research mainly emphasises the roles of cognitive and perceptual capabilities. Studies have primarily dealt with usability issues related to visual and haptic issues, but many vital interaction aspects that demand more cognitive and perceptual processing have been less thoroughly explored (Petrovčič et al. 2017). In effect, the cognitive and perceptual capabilities are much more complex to quantify, which increases the difficulty of including them in user models.

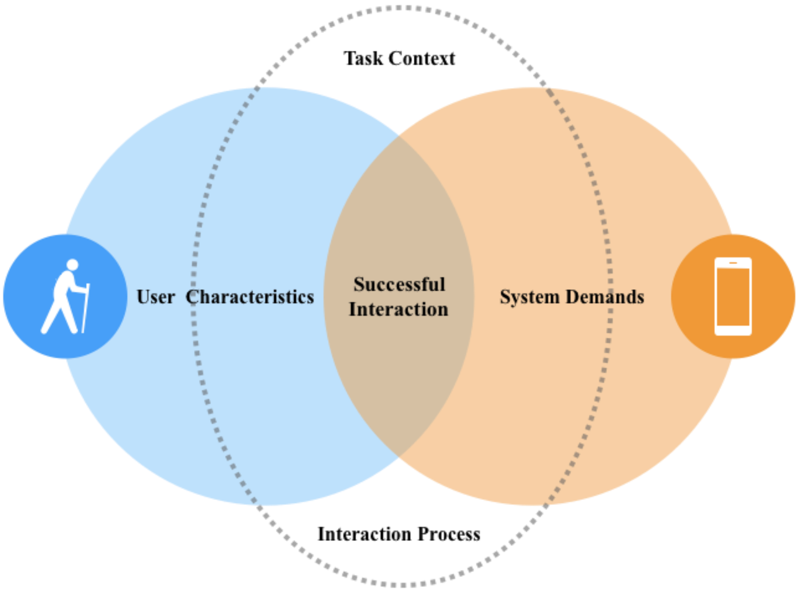


Figure 1.1 Research scope of the study

The research expects to answer the following research questions:

Q1. How do older adults use and perceive mobile technologies after their initial adoption?

Q2. What are the possible factors that influence older adults' usage and perceptions in their post-adoption behaviour and affect older adults' further adoption of mobile technologies, with a specific focus on user characteristics and technology features?

Q3. Which technology feature causes the most frequently reported usability problem and affects older adults' usage and perceptions of mobile technologies?

Q4. In terms of the aforementioned technology feature, do current UI designs support the specific mobile interaction behaviour for older adults? In other words, what characteristics of current UI designs may result in usability problems, and which characteristics would lessen the usability problems?

Q5. What variables should be modelled and how they should be modelled to develop user models for older adults' interaction with this specific mobile technology feature identified in Q3, from the perspectives of users, technological systems and tasks?

1.4. Significance and Value

The research is highlighted in the context that an increasing number of older adults are adopting advanced technologies, but most only use elementary features and limited functions. Zhou et al. (2012) suggested that unlike computers, the adoption of mobile technologies lies in the continued use of functions and applications. Thus, the investigation into older adults' post-adoption behaviour helps to refine the theory of technology acceptance from a more holistic point of view. By exploring how older adults use and perceive mobile technology after their initial adoption, we can reveal the undesirable and hard-to-use technology features and identify critical user characteristics that limit future technology adaptation. Rather than just applying all the relevant guidelines, designers can be better informed about older adults' usage and perceptions of critical technology features, which is particularly vital for encouraging further technology acceptance and usage, as well as improving user experience and satisfaction over a whole life cycle (Wyatt, 2003).

Furthermore, the research contributes to the advancement of analytical usability evaluation methods for mobile interface navigation design among older adults. First, by characterising current interface designs in detail according to whether or not they support or limit older adults' mobile navigation behaviour, the findings of the work provide insights into how mobile navigation patterns should be designed in accordance with age-related characteristics, task contexts and personal preferences. A list of design guidelines for mobile interface navigation design can be proposed accordingly. These guidelines are crucial for designers and practitioners because most of the previous design guidelines are quite general and disconnected from the current mobile industry. Second, by quantifying the relationships between users, technological systems and task contexts, relevant predictive user models can be developed, which can compensate for traditional user modelling tools that depend on the theories of information scent. In addition, these models can serve as valid predictive tools for designers to establish the relationships between these influential factors and to evaluate mobile technology at a very early design stage, which will largely reduce the time and resource cost required in empirical methods (Gyi et al., 2004).

1.5. Framework of the Research

The research framework is shown in Figure 1.2. Chapter 1 introduces the research background and motivations. The research objectives are proposed and the scope and research questions are identified. The significance and value of the study are discussed.

Chapter 2 provides a review of the literature on older adults and technology use. It starts by defining the relevant terms and existing knowledge about older adults, mobile technology, human information processing and cognitive ageing. It then discusses theoretical models of how older adults accept and adopt technologies in their lives, addressing possible influential factors. Subsequently, it reviews navigation behaviour with computers, features phones and mobile technologies. Finally, it compares the current design solutions for older adults, including various design guidelines, principles and concepts, as well as user modelling. The research rationale is further identified.

Chapter 3 describes the research methodology for this study. A mixed methodology was employed. Qualitative research provides an in-depth understanding of the current situation and quantitative research generalises the quantified relationships between the interested variables and develops relevant user models for designers.

Chapter 4 outlines the first study of the research – the semi-structured interviews, which are held to investigate older adults' usage and perceptions of mobile technologies in their post-adoption behaviour and examine influencing factors such as user characteristics and technology features. It also focuses on the research topic by pinpointing mobile navigation as a major technology feature that limits older adults' acceptance and adoption of mobile technologies. This chapter addresses objective 1 and informs the research questions Q1- Q3.

Chapter 5 outlines the second study in the research, an experimental usability investigation, which analyses how current interface designs facilitate or limit older adults' mobile navigation behaviour and characterises the older adults' mobile navigation behaviour into two streams: menu-oriented and content-oriented navigation. This study addresses objective 2 and informs research question Q4.

Chapters 6 and 7 outline the third and fourth studies, the experiments, which investigate the possible factors that influence older adults' menu-oriented and content-oriented navigation behaviour respectively, focusing on user characteristics, task demands and interface designs. The integrated results of experiments can assist in user model development by addressing what variables should be modelled and how they should be modelled for older adults' mobile navigation behaviour. These two studies address objective 3 and inform research question Q5.

Chapter 8 discusses the findings of each study and develops user models to predict older adults' mobile navigation behaviour. This chapter also discusses the limitations and further studies of the research. Chapter 9 concludes the research by returning to the research questions outlined in this thesis and addressing its primary contributions to the field and industry.

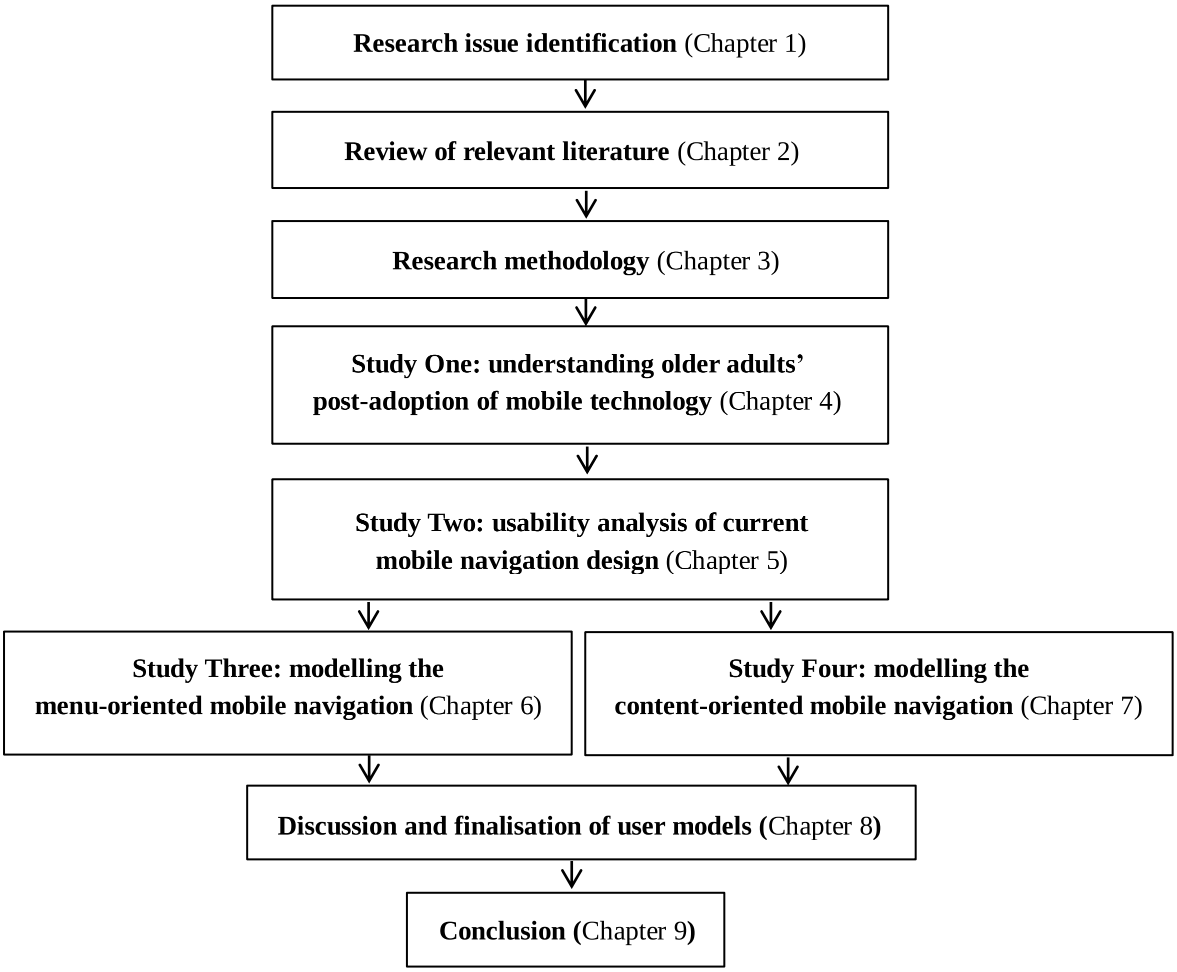


Figure 1.2. Framework of the research

CHAPTER 2 Literature Review

This chapter begins by defining the terms ‘older adults’ and ‘mobile technology’ and examining the literature on human information processing and cognitive ageing. Then, it reviews theories of technology diffusion and technology acceptance and discusses possible influential factors for older adults’ adoption of mobile technologies, including attitudes and perceptions, user characteristics and technology features. Concurrently, empirical evidence of how older adults navigate various technologies is reviewed, and the possible influential factors of user, task and interface design are addressed. In addition, the design guidelines and tools of user modelling that are frequently employed in elderly-friendly technology evaluation are reviewed and discussed in terms of their advantages and limitations. Following the above reviews, the research rationale is formulated.

2.1. Discussion of Terms

2.1.1. Older Adults

Specifying the user population is a critical step for designers because this decision affects the design process and user evaluation. Based on psychological research, individuals aged 60–65 and above are considered older adults (Nichol et al., 2003). Nevertheless, the definition of older adults has not always been so straightforward. For instance, research focusing on workforce-related product and application design includes individuals aged 55 and above as older adults, as most cognitive capabilities begin to decline as early as the mid-50s and decrease more rapidly in the 70s (Drag and Bieliauskas, 2010). This group of adults aged 55–65 is defined as young-old adults. At the same time, the group of adults who aged 85 and older are defined as old-old adults and they act as a critical user group, especially when designing healthcare-relevant products and applications (Lee and Kirlik, 2013). Therefore, considering the continual increase of average life expectancy, the targeted user group in the research is described as adults aged 55 and older. Specifically, it includes three groups of older adults: young-old (55–65 years old), middle-old (66–85 years old) and old-old (above 85 years old).

2.1.2. Mobile Technology

The rapid development of modern technologies began in 1981 when IBM launched the first personal computer (PC), and the huge success of PCs accelerated the rapid growth of the Internet in 1983. Henceforth, a blooming market of Internet services has developed since the 2000s, including sites like Wikipedia, Facebook, YouTube and Twitter. In 1985, the launch of the traditional feature phone introduced the era of mobile information. The mobility instilled by feature phones completely changed people's behaviour and attitudes regarding technology by breaking restrictions of time and space and enabling improved multitasking and coordination (Park, 2005).

However, the evolution was introduced when Apple released the iPhone and compatible iOS operation system in 2007 (West and Mace, 2010). In addition to high mobility, the iPhone provides an open platform that allows the convergence of various PC-used applications installed on it. At the same, touchscreen displays were introduced, which provide a more intuitive method of direct manipulation than a mouse and keyboard. The Wi-Fi function was also installed for mobile technologies to connect with cellular networks. In this way, mobile technology provides many more functions than sending text messages and making calls (Sarwar and Soomro, 2013).

Thus, the mobile technology mentioned in the research refers to a terminal that is installed with a touchscreen interface, enables the download of applications, connects with Wi-Fi or cellular networks and integrates with a variety of functions such as video and music players, navigation with GPS, web browsing and sending and receiving voice messages (e.g., Facebook, YouTube, WhatsApp). Representative examples of mobile technologies are smartphones, tablets, e-readers and smart watches. Due to the lower popularity of the latter two technologies among older adults, this study mainly focused on the adoption and usage of smartphones and tablets.

2.2. Human Information Processing and Cognitive Ageing

2.2.1. Human Information Processing

When a user interacts with a product or technology, a human information processing cycle occurs that involves perception, cognition and action. Cognitive engineering has a long history of attempting to simulate this process by representing the architecture of the human mind. For example, Wicken and Hollands (1999) proposed a widely applied model to simulate a series of human information processing stages including sensation and perception, cognitive processing, response selection and execution, as shown in Figure 2.1.

Based on the human information processing model, users first accept sensory input and store the sensory information for a short time. Then, the sensory receptors decide how much information can be transmitted to the brain for further processing. Thus, once there are declines in these sensory receptors, such as visual and auditory capabilities, the information quality transmitted to the brain is largely degraded. It also harms information processing in the second stage, in which the person decodes and interprets the sensory information from the previous stage. At the same time, some mental effort is required to integrate the information with long-term memory. The amount of effort mainly depends on whether it is a bottom-up or top-down process. For instance, when the sensory input is of high quality, users need less effort to process this kind of top-down process; whereas, if the sensory input is of bad quality, then the users have to utilise experiences or expectations stored in the long-term memory to process the sensory information.

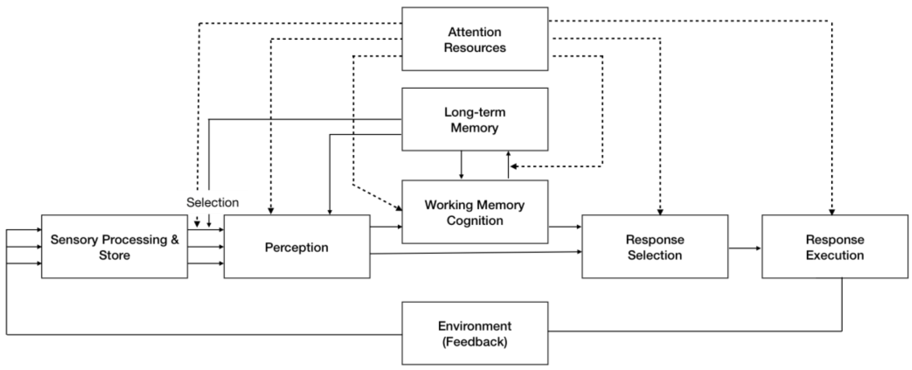


Figure 2.1 A model of human information processing stages (Wicken and Hollands, 1999)

When users are faced with a lot of information displayed by interfaces, they need to rely on different aspects of attention to filter the information, such as sustained attention, selective attention, divided attention and task-switching to shift attention (Drag and Bieliauskas, 2010). Specifically, sustained attention refers to the capability of maintaining attention over a long period. Selective attention is needed when users have to focus on relevant information and ignore irrelevant information. When the task requires users to concurrently attend to multiple inputs and process multiple information resources, divided attention is required. In a similar vein, task-switching ability means users have to rapidly switch between different technological tasks that require different kinds of skills and capabilities. For instance, sustained attention is needed when users are required to set an alarm using their smartphones, selective attention is required to ignore messages at the top of the screen and divided attention is needed to talk with family or friends at the same time.

Working memory is also a vital user capability for human-technology interactions such as information rehearsal, reasoning, planning and problem solving (Wickens and Hollands, 1999). It serves as a temporary storage for information processing. Working memory is estimated to be capable of storing five to nine pieces of information (Baddeley, 2000), and it could be overloaded if more items need to be dealt with or when a task requires a higher level of attention. Thus, when measuring working memory for the use of technology, it could be assessed according to the storage capacity or the speed and accuracy of processing. After a period of time, the information stored in working memory will become well-established within the long-term memory.

The process is completed by the corresponding response selection and execution. This is the final step that determines whether the whole cognitive process can produce an expected result towards the task goals.

2.2.2. Cognitive Ageing

As discussed in the previous section, age-related declines may influence the information processing when users pay attention to multiple resources. Specifically, the loss of inhibitory control with ageing could affect a person’s ability to ignore irrelevant information, thus decreasing older adults’ selective attention (Plude and Doussard-Roosevelt, 1989; Barr and Giambra, 1990). In addition, older adults are particularly susceptible to tasks that require divided attention, as they usually have difficulties attending to and processing multiple information channels at once. Moreover, the influence of age-related changes on divided attention could become more pronounced, especially for complex tasks, when older adults simultaneously experience significant declines in working memory, associative memory and recognition memory (Anderson et al., 1998; Castel and Craik, 2003).

The ageing process is also associated with memory declines. For example, episodic memory, which refers to memorising experienced events such as birthday parties or meetings, declines with age (Nilsson, 2003). Age-related changes also influence the processes of encoding new information and retrieving information from long-term memory. Two kinds of information retrieval are influenced, recall and recognition. Recognition is less affected by ageing than recall because the process of recognition is relatively passive and nonstrategic. However, recall is much more difficult, as it requires the user to recollect relevant information from long-term memory. Working memory can also be significantly influenced by the ageing process, as it requires a lot of information manipulation, storage and processing, thus placing much more demand on the user's cognition. Other categories of memory such as semantic memory, autobiographical memory and implicit memory are not as affected by ageing (Drag and Bieliauskas, 2010). In addition, these kinds of memory are not frequently used in technology tasks and are not included in the present study.

2.3. Review of Technology Acceptance and Adoption

This section reviews theories and models of technology acceptance and adoption. Factors that influence technology acceptance and adoption are also discussed.

2.3.1. Theory of Technology Diffusion

The history of research on technology acceptance and adoption can be traced back to the innovation diffusion theory, which was proposed by Roger (1995) to explain the process of product purchasing and adoption. This theory divides the process of production adoption into five phases:

- the phase where the potential user starts to know about the product
- the phase where the user is being persuaded of a need to buy the product
- the phase where the user is deciding to purchase the product
- the phase where the user is using the product
- the phase where the user confirms her or his decision of purchasing the right product

In 1996, Silverstone and Haddon (1996) developed the theory of domestication of technology to describe the adoption process, which focuses more on the domain of technology. Instead of product purchasing, this theory explains the process of technology adoption, emphasising interaction with products after possession. Specifically, it distinguishes the adoption stages according to the process of acceptance, rejection and use:

- the phase of appropriation, where the potential user is motivated to buy the product
- the phase of objectification, where the user chooses which functions to use and how they should be used
- the phase of incorporation, where the user tries to interact with the product and learn from the difficulties
- the phase of conversion, where the user has determined the intended and unintended features and ways of using the product as well as potential lists of future products

2.3.2. Technology Acceptance Models

The Technology Acceptance Model (TAM) is one of the most widely accepted models in predicting technology acceptance behaviour (Davis et al., 1989). It identifies six factors that are influential in determining a user's attitude to use, behavioural intention to use and the actual use of the technologies, as shown in Figure 2.2. In this model, the perceived ease of use (PEU) and perceived usefulness (PU) are identified as the crucial determinants of the user's attitude towards use (A), which can further predict his or her behavioural intention to use (BI) and the actual use of the technology. Specifically, the PU and PEU are defined as follows: 'Perceived usefulness refers to the degree to which a person believes that using a particular system would enhance his or her job performance, whereas perceived ease of use is the degree to which a person feels that using a particular system would be free of effort' (Davis et al., 1989).

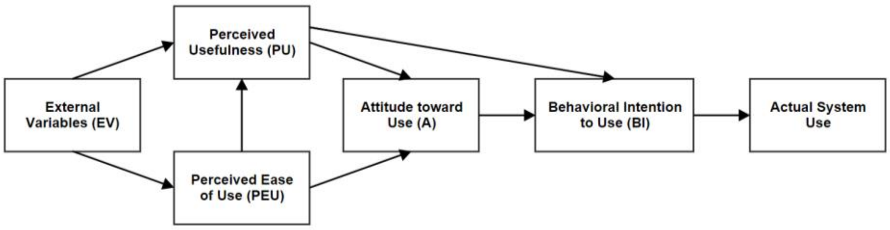


Figure 2.2 Technology Acceptance Model (Davis et al., 1989)

However, there are also some limitations of the TAM, particularly for the exclusion of social influence. Venkatesh et al. (2003) built a model of Unified Theory of Acceptance and Use of Technology (UTAUT) based on a review of eight technology models, as shown in Figure 2.3. Instead of including the BI as the only determining factor for actual system use, the UTAUT tried to explain the intention to use technology through various constructs including performance expectancy, effort expectancy, social influence and facilitating conditions, as well as factors that mediate the influence of these constructs, such as gender, age, experience and voluntariness of use. The impact of the facilitating conditions is emphasised in this model, as it directly impacts the use behaviour. It is defined as 'the degree to which an individual believes that an organization and technical infrastructure exists to support his or her use of the system' (Venkatesh et al., 2003).

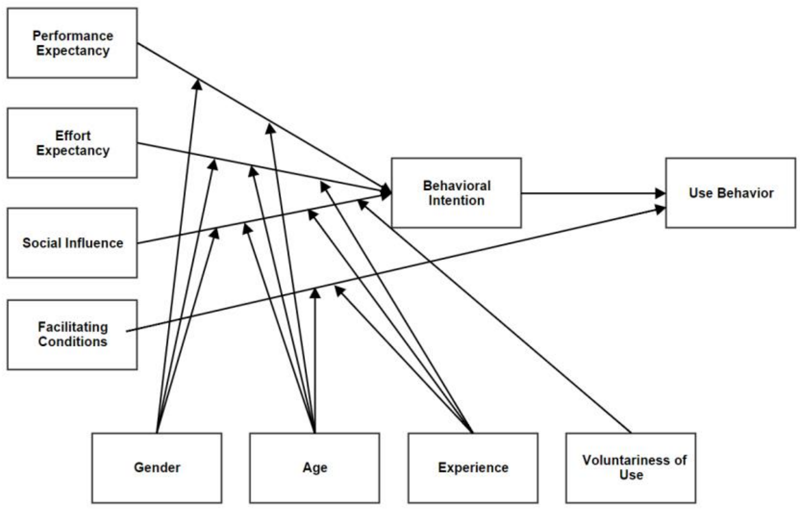


Figure 2.3 Unified Theory of Acceptance and Use of Technology Model (Venkatesh et al., 2003)

The technology acceptance models have been widely applied for different kinds of technologies such as assistive technology (Fischer et al., 2014), information and communications technology (Elliot et al., 2014), computers and the Internet (Sheng and Simpson, 2015), and general technologies (Lee and Coughlin, 2015). Drawing on the model of UTAUT, Van Biljon and Kotze (2007) proposed a Mobile Phone Technology Acceptance Model (MOPTAM), as shown in Figure 2.4. Instead of only considering the influence of facilitating conditions on actual use behaviour, the MOPTAM also emphasises the effect of facilitating conditions on PU, PEU and BI. In addition to the mediators addressed in UTAUT, this model also considers influences from other variables such as socio-economic factors (SF) and personal factors (PF).

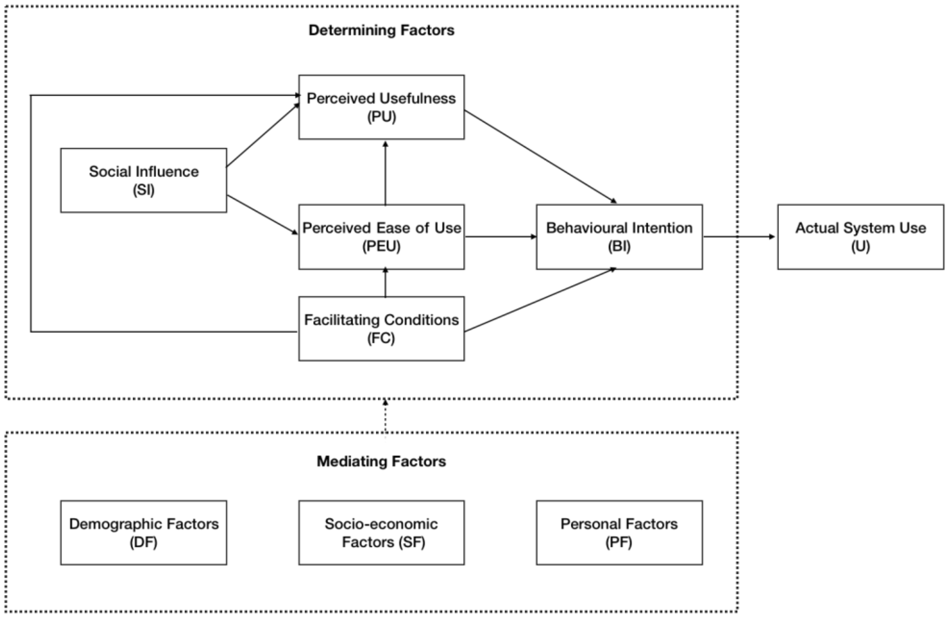


Figure 2.4 Mobile Phone Technology Acceptance Model (Van Biljon and Kotze, 2007)

Although the TAM and UTAUT models are widely used in studies on technology acceptance and adoption, neither considers the special needs and limitations of older adults. Thus, in 2008, Renaud and Van Biljon formulated the Senior Technology Acceptance and Adaption Model (STAM) to predict the technology acceptance behaviour of older adults, as shown in Figure 2.5. The STAM mainly focuses on the phase of post-adoption. It includes three stages—objectification, incorporation and conversion, which correspond to the various adoption stages addressed by the domestication of technology. Specifically, they suggest that older adults' objectification of feature phones is influenced by user context, social influences and perceived usefulness. In the incorporation phase, older adults can determine whether to use the feature phone based on the facilitating conditions, confirmed usefulness and ease of learning and use. In this phase, the process of experimentation and exploration is important because it determines whether the PU can be confirmed and if the ease of learning and use can be assured. The conversion phase presents the results of the whole process, which may lead to acceptance or rejection. Overall, the STAM provides an example of how technology acceptance theory can be extended to the entire technology adoption process.

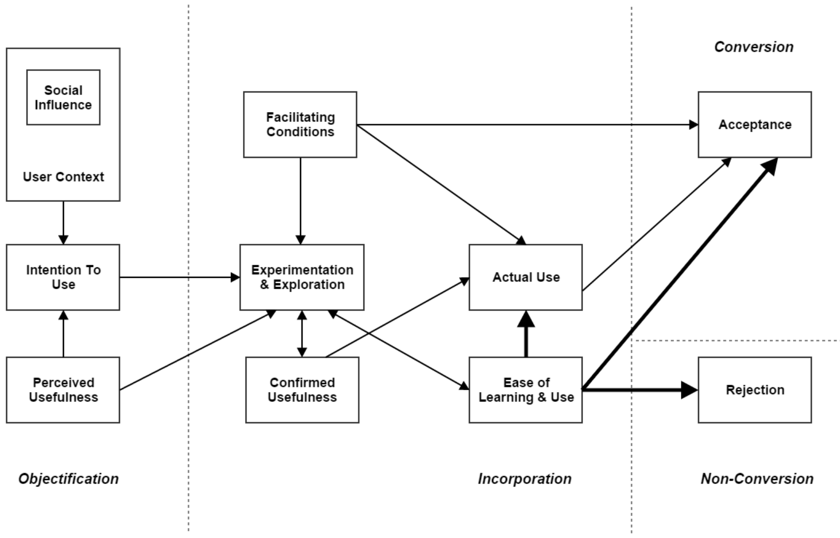


Figure 2.5 Senior Technology Acceptance and Adaption Model (Renaud and Van Biljon, 2008)

2.3.3. Factors Influencing Older Adults' Technology Acceptance and Adoption

A set of influential variables in the most widely used technology acceptance models is summarised in Table 2.1. As suggested, an individual's personal attitudes and perceptions are shown as important predictors of technology acceptance based on the aforementioned theoretical models. PU and PEU are found to jointly determine a user's attitude towards the use behaviour or directly influence the user's intention to use, which will eventually predict his or her actual usage of technologies (Davis et al., 1989; Venkatesh et al., 2003; Van Biljon and Kotze, 2007). The influences of some external factors such as social influence and facilitating conditions are reported and the importance of user characteristics, including demographic and personal factors has been emphasised.

Variables	*Models and Theories*			
	TAM	UTAUT	MOPTAM	STAM
Acceptance and adoption	Actual system use	Use behaviour	Actual system use	Actual use
	---	---	---	Experimentation and exploration
	---	---	---	Acceptance and rejection
Attitudes and perceptions	Perceived usefulness	Performance expectancy	Perceived usefulness	Perceived usefulness
				Confirmed usefulness
	Perceived ease of use	Effort expectancy	Perceived ease of use	Ease of learning and use
	Attitude towards use	---	---	---
	Behavioural intention to use	Behavioural intention	Behavioural intention	Intention to use
External factors	External variables	Social influence	Social influence	Social influence
		Facilitating conditions	Facilitating conditions	Facilitating conditions
		---	Socio-economic factors	---
User characteristics	---	Gender	Demographic factors	User context
		Age		
		Experience	Personal factors	
		Voluntariness of use		
Technology features	---	---	---	---

Table 2.1 Factors addressed by technology acceptance models and theories

Studies also reported that when adopting technologies, users can be initially persuaded or forced by social influence (Renaud and Van Biljon, 2010) or attracted by the features of technologies that enable them to improve task effectiveness and efficiency (Birnholtz, 2010). After the initial adoption, they will continually adapt their usage behaviour to avoid the relevant technology drawbacks. This may lead to further acceptance of technology such as using more functions, or even abandonment, which depends on whether the technology can effectively support the usage behaviour and adapt to the user's abilities. Thus, in addition to the abovementioned variables, successful technology adoption and usage also depend on a perfect match between the user characteristics (e.g., demographic factors, technical experience and well-being/self-efficacy) and technological systems with specific task requirements (Fisk et al., 2009), as shown in Figure 2.6. It is essential to consider the possible effects of user characteristics and technology features in technology perception and usage.

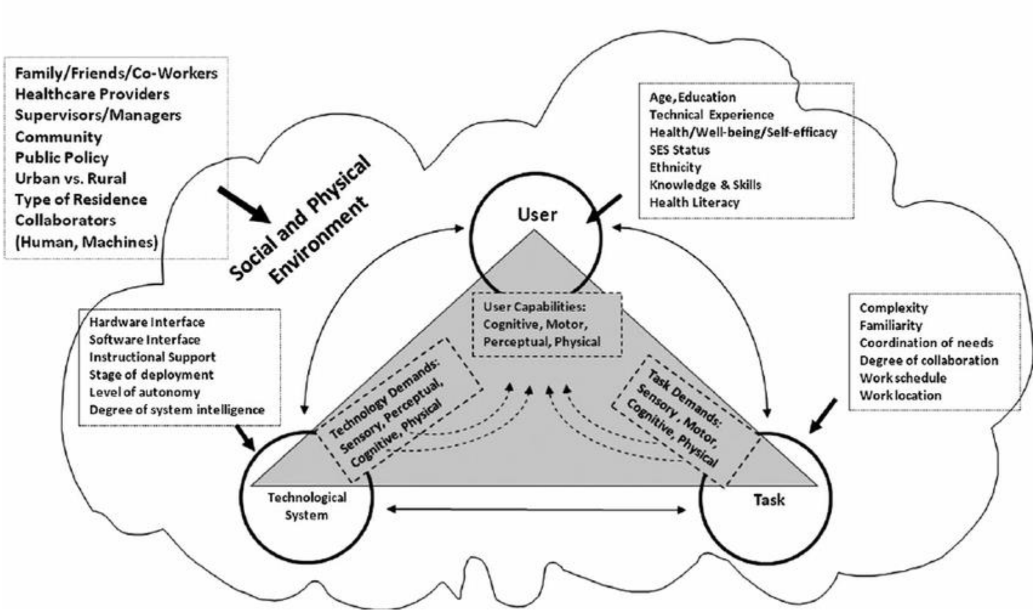


Figure 2.6 CREATE Model on Ageing and Technology (Fisk et al., 2009)

2.3.3.1. Attitudes and Perceptions

The effects of attributes like attitudes and perceptions are also found among older adults (Renaud and Van Biljon, 2008). Specifically, it was suggested that PU plays an important role in determining older adults' intention to use technology in the objectification phase; simultaneously, the confirmed usefulness after experimentation and exploration, together with the PEU, can predict older adults' actual use in the incorporation phase. However, the effects may be different from those of younger adults because older adults perceive technology's usefulness and ease of use in a different way (Chen & Chan, 2011; Pan and Jordan-Marsh, 2010). Older adults regard technology as easy to use when they can use it to complete a task effectively, whereas young adults tend to perceive technology as easy to use when they can use it to solve tasks efficiently (Sonderegger et al., 2016).

In the research, a set variables of attitudes and perceptions derived from the literature review were investigated, including the attitude towards mobile technology (corresponding to the variable of attitude towards use addressed by the TAM), perceived usefulness (similar to the variable addressed in TAM, MOPTAM and STAM, as well as the variable of performance expectancy addressed in UTAUT), perceived ease of use (similar to the variable addressed in TAM, MOPTAM and STAM, as well as the variable of effort expectancy addressed in UTAUT), behavioural intention to use (similar to the variable addressed in TAM, UTAUT, MOPTAM and STAM) as well as other attributes of perceptions expanded from these variables.

2.3.3.2. User Characteristics

The powerful role of user characteristics, especially older adults' capability limitations, has been recently highlighted in studies of technology acceptance and adoption. Particularly, the ageing process is associated with decreased cognitive functions and visual faculties such as memory, attention, visuospatial functioning, colour discrimination, perceptual speed, visual acuity and contrast sensitivity (Drag and Bieliauskas, 2010). Such cognitive and visual changes may have significant influences on older adults' technology acceptance and usage (Kamin and Lang, 2015; Dommes et al., 2011).

For example, Czaja et al. (2006) used a set of questionnaires to investigate the predictors of cell phone use and adoption among participants aged 18 to 91 years. The results indicated that user characteristics including age, computer anxiety, fluid intelligence, spatial visualisation and crystallised intelligence were important predictors for the user's technology use, with cognitive abilities, computer self-efficacy and computer anxiety as the crucial mediators of the relationship between age and technology adoption. In a study conducted with older Hong Kong Chinese adults, Chen and Chan (2014) found that individual characteristics including age, gender, education, self-efficacy and anxiety and health status and user ability could better predict technology acceptance than attitudinal factors. Together with the facilitating conditions, they could explain 68% of variances for the older adults' adoption of gerontechnology.

Therefore, the influence of user characteristics, especially older adults' capabilities and limitations, is a particular emphasis of the current research. Older adults' user characteristics of demographic factors, user capability and technology experience are the three main focuses of the research. Previous studies used the self-reported approach to measure older adults' user capabilities, which may be encompassed by many subjective factors such as personal expectations and aspirations. By contrast, the method of performance tests is more objective by assessing the specific ability of a particular task, although it is more complicated to conduct (Johnson et al., 2010). Therefore, in the research, both simple performance tests and self-reporting methods were employed to measure older adults' capabilities such as working memory, spatial ability, sustained attention, perceptual speed and visual abilities. Five subcomponents of older adults' technology experiences were examined, including the experience of previous generation technology and duration of use, intensity of use and diversity of use of mobile technologies, as well as self-efficacy of mobile technologies (Smith et al., 1999; Langdon et al., 2007; Hurtienne et al., 2013).

2.3.3.3. Technology Features

With plenty of studies focusing on the attributes of attitude and perceptions, as well as factors of user characteristics, less attention has been paid to the effects of technology features on older adults' technology acceptance. It is indicated after the initial adoption of technology, users' perceptions of technology features can become the critical factors that predict further adoption (Birnholtz, 2010). During the phase of experimentation and exploration, users may change their usage behaviour to adapt to the technology and task features. If the technology features cannot support their use intention or match perfectly with user characteristics, they may abandon it.

Instead of only focusing on attitudes towards the use of technology, another stream of studies analyses information technology utilisation with the task-technology-fit model (TTF). This model, proposed by Goodhue and Thompson (1995), emphasises the fit between technologies and tasks. It suggests that the performance impacts when using a specific technology mainly depend on the match between three constructs: technology characteristics, task requirements and individual abilities (see Table 2.7).

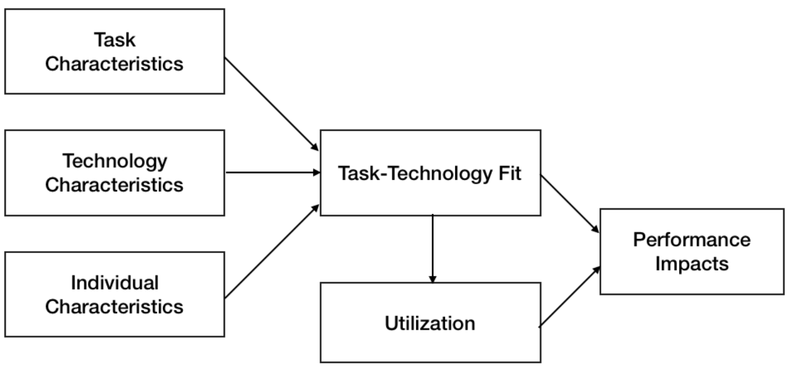


Figure 2.7 Model of task-technology-fit model (Goodhue and Thompson, 1995)

Some researchers have attempted to extend the TAM to include TTF constructs.

For example, Dishaw and Strong (1999) proposed an integrated model of the TAM and TTF and found more explanatory power indicated by the integrated model than either model alone. They reported that the constructs of the TTF could determine three major variables for the TAM: perceived ease of use was affected by tool functionality, tool experience and task-technology fit; perceived usefulness was influenced by tool experience and task-technology fit; and actual tool use was impacted by task-technology fit and task characteristics (see Figure 2.8).

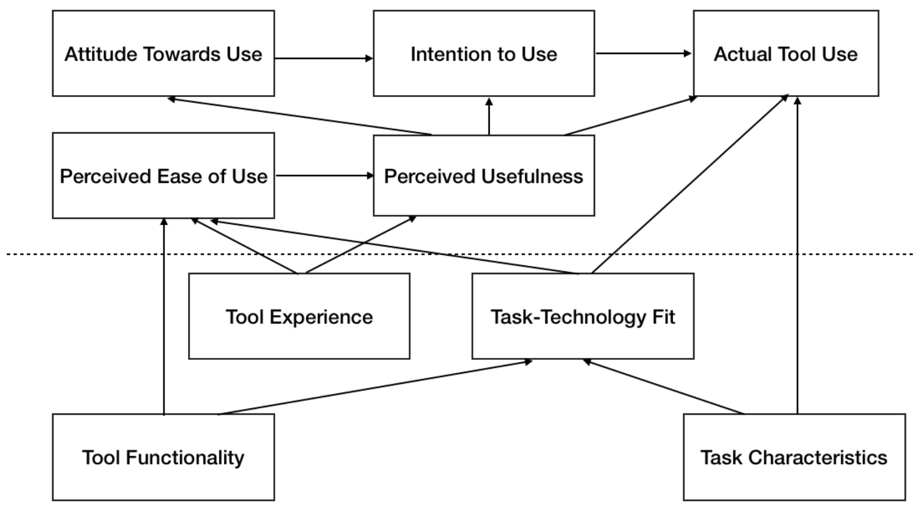


Figure 2.8 Integrated TAM/TTF model (Dishaw and Strong, 1999)

In another study attempting to integrate the TAM and TTF models to explain the use of massive open online courses (MOOCs), the variable of task-technology fit was also found to significantly influence users' PU and PEU (Wu and Chen, 2016). In addition, the results revealed more details about the effects of individual-technology fit. It was reported that the individual-technology fit has a significant and direct influence on users' PEU and a significant but indirect influence on users' PU, which is mediated by their PEU (see Figure 2.9). Nevertheless, the increase of individual-technology fit does not promise improved PU when the users cannot perceive an improved ease of use of the technologies.

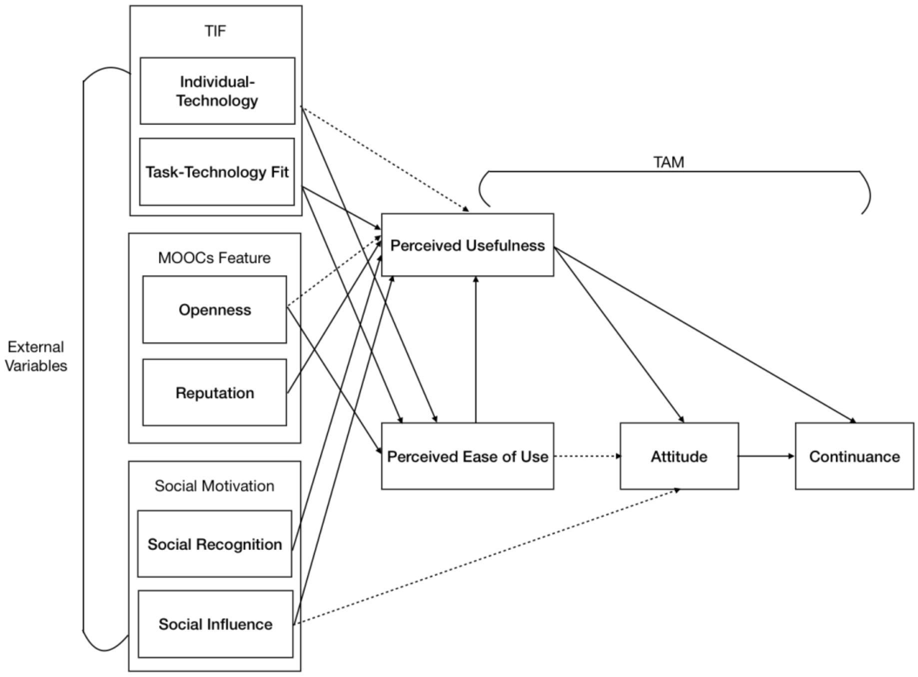


Figure 2.9 Integrated TAM/TTF model for MOOCs (Wu and Chen, 2016)

To conclude, PEU and PU are the most significant factors that bridge the relationships between the constructs of TAM and TTF.

2.4. Review of Information Navigation Behaviour

The word 'navigation' was historically generalised from the domain of geographical space, which refers to how a person can find his or her way and steer a vessel from one location to another. Adopted as a metaphor of geographical navigation, the concept of information navigation is to access chunks of electronically stored information in a goal-direct way. In effect, the information navigation is defined as,

'*In this metaphorical view, perceivable presentations of meaningful information chunks of an overall information space with form the counterparts of physical locations in a geographical space, and information navigation capitalizes on the fact that structural relations between physical locations, such as* *neighbourhood, proximity, distance, connectedness, reachability, or crossway can be mapped onto meaningful relations between information chunks as well' (Strong 2009).*

2.4.1. Behavioural Modes of Information Navigation

A variety of navigation activities exist when using websites and these have been summarised by several studies. Among them, one of the most widely used frameworks was proposed by Lindley et al. (2012) after analysing different user activities with the web and technologies. Five behavioural modes are determined for web information navigation:

- the respite mode, which includes the usage of familiar web pages or applications and usually lasts for a very short duration because the users do not have much information to search or be engaged with, such as social networks or news
- the orienting mode, which is similar to the respite mode; however, the users are willing to be engaged with these pieces of information, which may lead to usage for longer periods of time
- the opportunistic mode, which refers to a 'wandering around' navigation behaviour where the users browse web pages that they may not be familiar with
- the purposeful model, where users navigate a website to achieve specific goals such as searching for a piece of information or buying a product
- the lean back mode, where users navigate the web to watch video or audio content

In more recent research, Vigo and Harper (2017) conducted a study to monitor users' real-time web navigation behaviour for nearly 600 hours. Summarily, they classified several categories of navigation tasks, including consumption use (corresponding to the respite and orienting modes), lean back, web application (the desktop-like web applications stored in the cloud), opportunistic, purposeful and comparison modes (the revisiting behaviour by switching between various tabs and pages). The first three modes interpret user behaviour by analysing the users' purpose and intent of using the website, while the latter three modes classify user behaviour by analysing the way they navigate the websites. In total, they detected 83 cases for consumption mode, 59 for purposeful mode, 36 for opportunistic mode, 15 for web application mode, 9 for lean back mode and 3 for comparison mode.

Therefore, with more focus on how older adults navigate with information, the purposeful behaviour mode of navigation was selected for the scope of the research.

2.4.2. Information Navigation from Web to Mobile

There has been a long history of investigating information navigation within the web context. Hypertext is a popular way to present a collection of links that enable users to move from one information chunk to another on computers (DeStefano and LeFevre, 2005). Later, with the ubiquity of personal computers, various navigation aids including menus, buttons, search options and scrollbars emerged to help users navigate and search for information (Puerta Melguize et al., 2012). The menu is a dominant mechanism to display a collection of options for websites and windows in which the selection of each option can lead to a change in the state of the interface (Shneiderman and Plaisant, 2004). Thus, the structures of both hypertexts and menus are important in reflecting the information hierarchies of the web, which could further influence users' development of the mental models to understand web structures and locate themselves. Nevertheless, it is found that the use of hypertexts and links can disadvantage older adults' navigation performance when compared to younger users, which is mainly due to their increased demand for prior technological knowledge as well as decision-making, visual processing and working memory (DeStefano and LeFevre, 2007).

Later, the launch of traditional feature phones introduced improved mobility for technology use, but screen size was largely limited. Due to the restricted screen size and advanced stored volumes of information, the information structures became nested more deeply. System navigation using feature phones was considerably hampered in this situation, especially for older adults. With the deep menus and nested functions, older adults are met with significant difficulties in understanding how menu items are spatially structured and how the functions, nodes and information are arranged because of their declining memory, spatial ability and perceptual capability. They easily experience disorientation when navigating information on feature phones (Downing et al., 2005; Kim et al., 2007; Ziefle et al., 2007). Accordingly, simple and flat menu structures are highly recommended to improve older adults' navigation behaviour (Ziefle and Bay, 2006). In addition, text labels for icons and buttons have been found to be helpful for older adults in memorising functions, locations and navigation paths (Chen et al., 2003; Hassan and Md Nasir, 2008).

However, with the recent prevalence of touchscreen mobile technologies, the visual-related difficulties and disorientation issues caused by deep hierarchical menus are largely lessened due to the larger touchscreen sizes and higher screen resolutions (Boulos et al., 2011; Zhou et al., 2012, 2013). Meanwhile, with the intense evolution cycle of mobile interfaces, abundant and distinct design styles have been proposed for menu design, content display and interaction techniques, which may make the mobile interface become more complicated and make early findings from the web and feature phone problematic in different ways

(Petrovčič et al., 2017). For example, manipulation of menus and content may require various gestures like tapping, swiping, scrolling or flipping, which can be very difficult for older adults because of the high demands for motor ability and visual synchronisation between button keys and the display response (Zhou et al., 2012; Harada et al., 2013; Motti et al., 2013; Sundar et al., 2014). Moreover, older adults reported difficulties in terms of selecting the areas of menus and content by differentiating between which areas could be touched and which could not (Zhou et al., 2012; Harada et al., 2013).

2.4.3. Current Design Patterns for Mobile Interface Navigation

2.4.3.1. Menu-oriented Navigation Design

As mentioned previously, menu navigation serves as a typical method of information retrieval (Garrett, 2010). Designing for the menu panel and button is especially vital for representing the website or application's information structures (dos Santos et al. 2011). To date, many topics on menu navigation have been studied, such as panel position, menu structure, item organisation, menu design and the possible effects of task complexity and individual characteristics.

For instance, panel position and menu design were extensively studied for web design. As reported, a left menu panel (Torun and Altun, 2014) and intra-article navigation scheme (Cuddihy and Spyridakis, 2012) can improve users' web navigation performance in terms of recall and retention. In addition, the menu design also matters for web navigation. It was indicated that a vertical menu that presents a full context of menu options at once performs better than a dynamic menu that needs additional action to access more menu options, especially for users with declined cognitive capabilities (Leuthold et al., 2011; Puerta Melguizowt al., 2012). Furthermore, the issue of menu hierarchies draws more attention from web design to feature phones and mobile technology design. The usability problems caused by the deep and nested menu structure became especially salient for older adults to use feature phones because of the restricted screens, but the problems of disorientation were greatly reduced with the use of large touchscreen mobile technologies.

Vendors such as Apple and Microsoft have provided specific guidelines for interface navigation on menu hierarchies. For instance, the iOS user interface guidelines proposed three major styles for mobile navigation including hierarchical navigation, flat navigation and experience-driven navigation, as shown in Figure 2.10. In hierarchical navigation, the users can navigate the interface starting from a homepage and follow the linked child pages to their definitions, but they need to make one choice each time. A flat navigation means that users can navigate the interfaces by switching between disparate functions and pages. In content-driven or experience-driven navigation, users can move freely through the content. (Apple Inc, 2018).

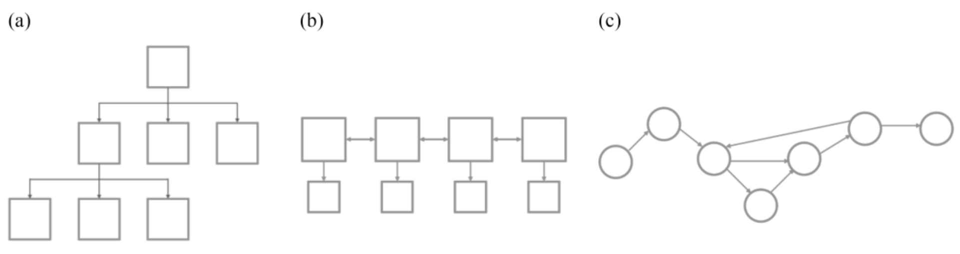


Figure 2.10 Three major navigation design styles proposed by iOS user interface guidelines: (a) hierarchical navigation; (b) flat navigation; (c) experience-driven navigation

Microsoft proposed a set of similar navigation modes including a hierarchical navigation style and a flat navigation style (Basu, 2013), as shown in Figure 2.11. In hierarchical structures, users do not need disparate pages to be linked for navigation, and the homepage can bring together all the entry points of functions. This style is widely applied in applications such as news, photos and others with clear links to navigate up and down the content tree. The flat navigation design usually employs the drill-down views, which are commonly kept at two levels of information hierarchies (Hoehle et al., 2016). In this way, the disorientation caused by hierarchical menus of feature phones may be decreased by flat menu patterns (Boulos et al., 2011; Zhou et al., 2012, 2013).

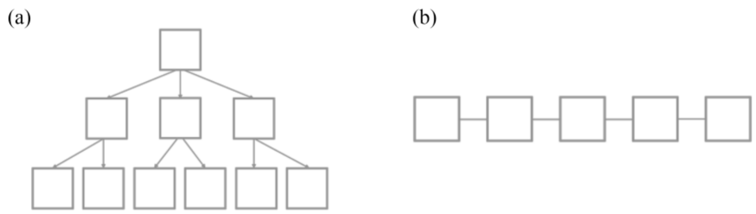


Figure 2.11 Two major navigation design styles proposed by Microsoft: (a) hierarchical navigation; (b) flat navigation

Touchscreen mobile technologies introduce more menu design patterns whose effectiveness is still unexplored. Table 2.2 summarises some of the typical menu patterns (Tidwell, 2010; Neil, 2014), including tab menu, sider drawer and springboard. The tab menu can immediately display three to five top-level destinations and are usually employed to show flat hierarchies. Sider drawers can display more levels of menu hierarchy, which only appear by tapping the entry-point of the sider drawer. The springboard usually works as a launch board with a collection of various functions, and it can also present several categories and functions with more than two levels of menu hierarchies.

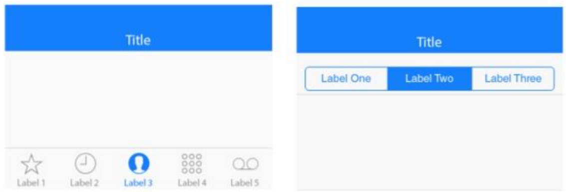
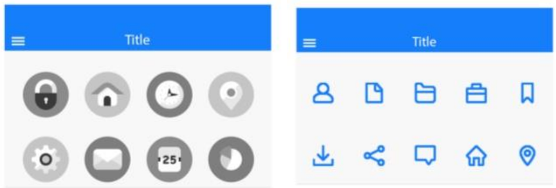
Pattern	*Description*	*Example*
Tabs	Located in a single row above or below the associated content and enables easy exploration and switching between different views	
Sider drawer	Hidden until invoked by the user and displays many navigation targets at once	
Springboard	Serves as a launch board that collects a set of entry points for various functions for more than two levels of menu hierarchy	

Table 2.2 Examples of menu-oriented navigation design

2.4.3.2. Content-oriented Navigation Design

In addition to menus, mobile website and application navigation can also be guided by focuses created by content (Hoehle and Venkatesh, 2015). The content display pattern should be designed in a way that can appropriately reflect a user’s mental model and help him or her to filter and process the relevant information (Punchoojit and Hongwarittorrn, 2017). Though the use of hypertext may disadvantage older adults’ navigation performance, older adults can still maintain good performance in terms of content searching because of their stable reading comprehension and crystallised intelligence (Etcheverry et al., 2012a, 2012b). Therefore, older adults generally outperform when navigating with content than navigating with menus.

For mobile technologies, several widely used navigation design patterns have been examined. In 2009, Osman, Ismail and Wahab compared efficiency, satisfaction and learnability when navigating a fisheye list and vertical list for younger adults. The fisheye list performed better than the vertical list in terms of comprehension and acceptance, but the vertical list outperformed the fisheye list in terms of task efficiency (Osman et al., 2009). A study conducted by Yu and Kong (2016) compared the reading performance and subjective evaluations of three kinds of list design for younger adults, including the list-view design, progressive list design and thumbnail design. It was found that the thumbnail design located target information more efficiently than the other designs, and the progressive list decreased users' reading performances and subjective evaluations. In summary, the effectiveness of various content display patterns is still debated, and further studies are necessary to investigate the usability issues regarding various content display patterns, especially for older adults.

With more content adhered to navigation items in mobile navigation, e.g., explanatory information and graphics, more and more content-oriented navigation design patterns are proposed, but their effectiveness is still unexplored. Table 2.3 summarises some of the most widely applied design patterns. Lists are comprised of a continuous column of rows, with each row containing a title or a short piece of information. This pattern works especially well for data of similar types. The grid and gallery usually consist of a repeated pattern of cells arranged in a vertical or horizontal layout. They are also good at organising content of a similar type. Cards are a recently popular design pattern that normally contains a single subject. They can display more content and enable interactions such as flipping and stacking. Generally, these patterns for content displays help create visual hierarchies, which can better guide users' attention as intended by the designers.

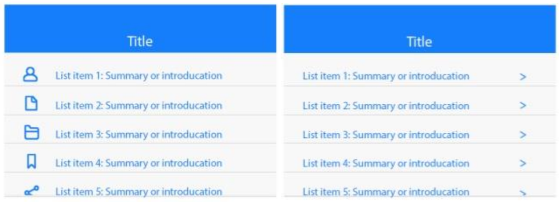
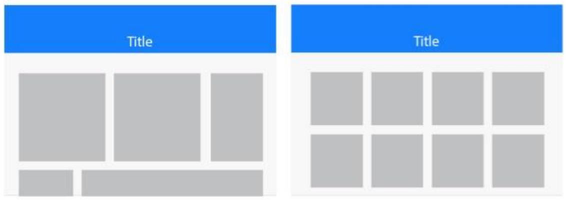
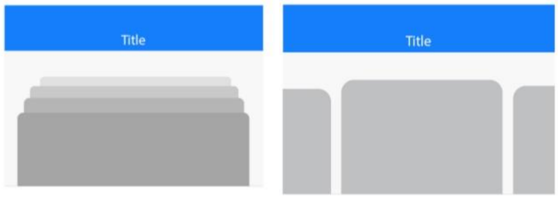
Pattern	*Description*	*Example*
List	Presents a continuous column of list items vertically	
Grid and gallery	Displays a repeated pattern of cells arrayed in a vertical and horizontal layout	
Card	Displays detailed content of a single subject such as photos with captions of variable length	

Table 2.3 Examples of content-oriented navigation design

2.4.4. Factors Influencing Mobile Interface Navigation

Navigation is required when a user needs to follow a path through an application or website by visiting content or pages to complete a task. As indicated by the CREATE Model (Fisk et al., 2009) developed for modelling ageing and technology and the person-artefact-task model (van Schaik and Ling, 2012) proposed for modelling a user's web navigation (see Figure 2.12), a user's mobile technology navigation behaviour could be influenced by the artefact (e.g., the interface of mobile application), the task performed with the artefact (e.g., information searching) and the person performing the task (e.g., the characteristics of the user). Although the possible influences of artefact, task and person on web navigation performance have been studied separately by previous studies, these influences are not independent. They should be considered in an integrated fashion, where the effect of each factor may depend on the influence of the others.

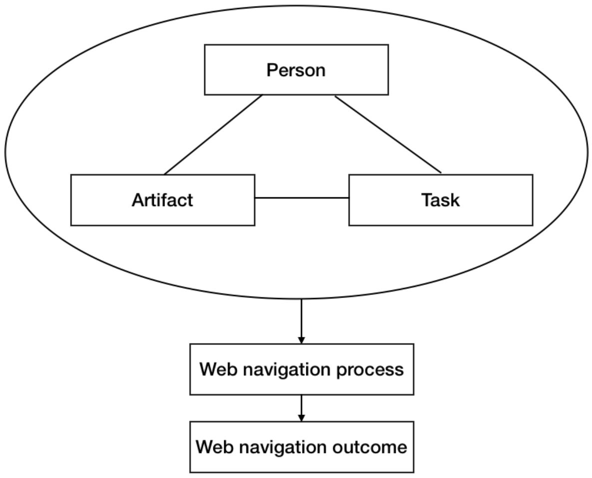


Figure 2.12 Person-Artefact-Task model (van Schaik and Ling, 2012)

2.4.4.1. User Characteristics

The impacts of age-related changes on web navigation have been investigated in previous studies. For instance, spatial ability, which refers to an individual's ability to conceptualise relationships between objects in space and being aware of the current location relative to other objects in a space (Salthouse, 1982), is proven to be one of the most significant factors influencing users' web navigation performance (Chen, 2001; Juvina and van Oostendorp, 2006; Pak, Rogers and Fisk, 2006). In the same vein, it is essential for users to understand the relationships between pages and locating the current position within a website (Ziefle and Bay, 2006). Thus, age-related declines in spatial ability can negatively influence older adults' web navigation performance because of the development of a less accurate mental model of the website (Wagner et al., 2014).

The role of memory and attention on information navigation has also been recognised in previous works (Laberge and Scialfa, 2005). As reported, older adults' cognitive abilities including reasoning, working memory and perceptual speed play important roles in complex information-seeking task performance (Sharit et al., 2008). Working memory was also revealed to be the best predictor of users' disorientation in web navigation, although it did not produce the same impact on task performance as spatial ability (Juvina and van Oostendorp, 2006).

Nevertheless, the launch of touchscreen-based mobile technologies has largely lessened the disorientation problems caused by declined spatial ability because information hierarchies have become flatter and broader. At the same time, navigation with mobile technologies has introduced another challenge for older adults with the higher demand of visual attention (Yang et al., 2012; Punchoojit and Hongwarittorrn, 2017). With more information being accessed by smaller sized touchscreens, users need to quickly shift their attention across different pages within mobile applications by various gestures such as tapping, scrolling and swiping. Since very few studies have investigated the effects of capabilities on navigation behaviour with mobile technologies, the research aimed to address the potential capabilities involved in mobile navigation, such as spatial ability, working memory, concentration attention and perceptual speed.

Other variables of user characteristics can also moderate the cognitive ageing process and may further influence older adults' navigation behaviour with mobile technologies. For example, it was reported that education level is significantly associated with age-related capability declines, as higher education levels may result in lower rates of cognitive decline over time (Habib et al., 2007; Wagner et al., 2014; Biswas 2015). Technology experiences are also directly relevant to the use of mobile technologies. 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). Exposure is usually measured by three aspects of mobile technology usage: duration of use, intensity of use and diversity of use.

2.4.4.2. Task Complexity

Task complexity is noted as one of the major influential factors in terms of goal-directed navigation (Gwizdka and Spence, 2006; 2007). It has been examined in different ways. For example, page complexity can be used to access the task complexity by the number of navigation choices presented, such as hyperlinks and buttons. The indicator of information relevance can also be employed to evaluate the task complexity based on the difficulty when judging the relevance of information items presented in the interface and the information goal proposed by the task (Mosenthal, 1996; Gwizdka and Spence, 2006). As a result, with more navigation items presented in the interface, more times of judgements need to be performed on the relevance between the encountered navigation item and information goal. Thus the path length to the target information is increased, which would considerately influence the web navigation performance such as completion time and accuracy (Puerta Melguizo et al., 2006; Kammerer et al., 2008).

It is also vital to consider the level of task complexity in terms of the difficulty of relevance judgement. When navigating, users always need to retain a goal state of the task in their working memory and check each of the input information items against the goal state. Therefore, the more criteria contained in the task, the more times information retrieval from working memory will occur. For example, when there is only one inherent criterion to be achieved in a task, the user can easily identify whether each information item they encounter meets the criterion. Nevertheless, when the task involves two or more criteria, the user needs to evaluate every information item they encounter to check whether it can satisfy all criteria at the same time. Then, the cognitive loads become greater and task complexity increases, which negatively influence the user's navigation performance (Leuthold et al., 2011). Accordingly, the number of selection criteria was employed as the measurement for the level of mobile navigation task complexity in the research.

2.4.4.3. Content Similarity

During navigation, users need to allocate their attention to various information patches on the interface. Thus, information content is also an important factor that needs to be considered in older adults' navigation behaviour. For instance, if the task is to search for books about 'home cooking', should the user pay attention to the information category of cooking or other information categories such as sports or history instead? Furthermore, if there is more than one subordinate book under the category of cooking, how can the user resolve the conflict about which book they should focus attention on since only one book leads to the target information?

After analysing the regression model for a 424-task dataset, Blackmon (2012) indicated that the semantic similarity of information patches to the user's task goal is a powerful predictor of how users distribute their attention to different information patches across interfaces. In this way, if the information patches presented on the interface are highly similar, users' attention can be easily misdirected due to the overall high semantic similarity of many information patches with the task goal; if the information patches are easily distinguished from each other, it becomes easier for users to identify the single targeted information patch that is semantically similar to the task goal. Therefore, in this study, the content similarity was hypothesised to influence older adults' allocation of attention when navigating, and the information scent is believed to be the primary cue to search the information patches while navigating.

2.5. Approaches to Influencing Older Adults' Mobile Navigation Behaviour through Design

Strides have been made in the process from inspection to evaluation of technology usability for older adults. As indicated by Hartson et al. (2001), the methods for product evaluation can be classified into two major categories, empirical and analytical methods. The empirical method is employed to evaluate the use of products or technology in the experimental scenarios by involving the target users, with the task performance being analysed by parameters such as completion time, percentage of errors and subjective evaluations. Typical methods include user testing and observation. Although this method can be time-consuming and resource-intensive due to its direct involvement with users, the results can provide reliable and detailed references for the technology design.

The analytical method is advantageous because of its reduced cost and time requirements (Gyi et al., 2004). It inspects the usability issues of technology features by heuristics and expert evaluation according to the relevant design guidelines, as well as the predictive user models (Hartson et al., 2001; Cardoso, 2003; Langdon et al., 2010; Petrovcic et al, 2017). Instead of testing a specific technology design by capturing all usability problems, this alternative can be applied to a wider range of technology interfaces and user populations. Some typical analytical evaluation methods are summarised and analysed in Table 2.4.

	Description	*Examples*
Design guidelines and checklists	Evaluation of products and technologies based on the design guidelines, checklists, and heuristics to determine design areas that need further improvement.	Guidelines (Pattison and Stedmon, 2006); Guidelines (Zaphiris et al., 2007); Guidelines (Al-Razgan et al., 2012); Checklist (Mi et al., 2014); Guidelines (Hoehle et al., 2016)
Predictive user models	Estimating and predicting users' performance of technology interaction based on various parameters such as perceptual, motor and cognitive estimates.	Keystroke-level model (KLM) (Card et al., 1980); Goals, operators, methods, and selection rules (GOMS) (Card et al., 1983); CogTool (John et al., 1993); Adaptive Control of Thought—Rational (ACT-R) (Anderson and Lebiere, 1998)

Table 2.4 Comparison of typical analytical evaluation methods

2.5.1. Design Guidelines and Principles

2.5.1.1. Research-derived Design Guidelines

To design technologies that are intuitive for older adults to use, a large amount of laboratory research has been conducted that provides theoretical evidence for the development of usability guidelines (Dumas and Salzman, 2006). Table 2.5 summarises some of the widely applied usability guidelines in 10 categories with their quoted resources. Generally, usability guidelines include the topic of target design, which addresses the design of interface elements such as buttons, icons and texts; the topic of visual design, which describes the colour and background design and relevant graphics design; the topic of layout design, which focuses on the whole interface and structure organisation; the topic of interaction and functionality, which addresses the interaction gestures and transition between functions; the topic of menus and navigation design, which specifies the chain of information navigation behaviour; and the topic of instruction and languages design.

Category	*Description*	*Implied from Previous literature*
Target design (TD)	Visible and clear targets such as texts and buttons	H1.1 (Zaphiris et al., 2007); G1.1 (Patsoule and Koutsabasis, 2014); Font (Hoehle et al., 2016); Look and feel (Al-Razgan et al., 2012)
Use of graphics (UG)	Well-designed graphics and animations	H2.1 (Zaphiris et al., 2007); G1.4 (Patsoule and Koutsabasis, 2014); Aesthetic graphics, subtle animation (Hoehle et al., 2016)
Icon design (ID)	Simple and meaningful icons	H2.3 (Zaphiris et al., 2007); G2.2 (Patsoule and Koutsabasis, 2014); Visual design (de Barros et al., 2014)
Use of colour & background (CB)	Properly used colours and background	H8 (Zaphiris et al., 2007); G1.4 (Patsoule and Koutsabasis, 2014); colour (Hoehle et al., 2016)
Layout design (LD)	Simple, clear, and relevant layout design	H5.2, H5.5 (Zaphiris et al., 2007); P7.4 (Patsoule and Koutsabasis, 2014)
Interaction (IT)	Easy and straightforward way of interaction	Interaction (Al-Razgan et al., 2012); Interaction (de Barros et al., 2014)
Functionality (FC)	Easy and obvious transition and switching between various functions	Entry point (Hoehle et al., 2016); Functionality (Al-Razgan et al., 2012)
Use of menus (UM)	Easy-to-use menus	H3.4 (Zaphiris et al., 2007)
Navigation and controls (NC)	Simple and flatted navigation hierarchy and clear navigation paths	Hierarchy (Hoehle et al., 2016); Functionality (Al-Razgan et al., 2012); Navigation, Interaction (de Barros et al., 2014)
Instruction and language (IL)	Easy-to-understand language and instructions	H5.1 (Zaphiris et al., 2007); G2.1 (Patsoule and Koutsabasis, 2014); Interaction (de Barros et al., 2014)

Table 2.5 General design guidelines for older adults

Nevertheless, sometimes usability guidelines are not consistent or overlap to some extent (Hoehle et al., 2016; Zaphiris et al., 2007); thus, practitioners and designers still face great challenges when applying these high-level guidelines (Tidwell, 2010; Duyne et al., 2002). They must deal very carefully with these guidelines and apply them to different design scenarios to make sure their designs fit into the specified use context and follow the style guides of the current mobile industry (von Wangenheim et al., 2016). Moreover, the previous guidelines for older adults mainly dealt with usability issues related to visual and haptic problems including size, font, space and colour (Baharum et al., 2017). Some aspects related to older adults' perceptual and cognitive information processing have been largely neglected, such as interface navigation (Petrovčič et al., 2017). It was reported that information navigation, including link navigation, content navigation and menu navigation, is ranked as the three least explored issues by usability studies (Punchoojit and Hongwarittorrn, 2017).

Although few studies have proposed usability guidelines that are directly relevant to instruct older adults' mobile navigation behaviour, the research extracted and summarised a list of guidelines that can be applied for mobile navigation design from previous studies focused on general usability principles, as shown in Table 2.6. Specifically, these guidelines were selected according to whether they were practically relevant to older adults' mobile navigation performance. Redundant guidelines were deleted and similar guidelines were combined based on four major principles: visual design, ease of understanding, navigation and interaction, and support for habits.

Principles	***Description***	***Implied from Previous literature***
Visual Design	Use visible and large icons and buttons for menu components	Font (Hoehle, Aljafari and Venkatesh 2016); Look and feel (Al-Razgan et al. 2012); G1.1 (Patsoule and Koutsabasis 2014)
	Use visible and readable texts for the content	Look and feel (Al-Razgan et al. 2012); G1.6 (Patsoule and Koutsabasis 2014)
	Use clear and large titles for content	H9.5 (Zaphiris, Kurniawan, and Ghiawadwala 2007)
	Use properly and standout designed colour, texture and graphics for the menus components	Colour (Hoehle, Aljafari and Venkatesh 2016); G1.4 (Patsoule and Koutsabasis 2014)
	Use properly chosen colour and graphics for the content and its background	Colour (Hoehle, Aljafari and Venkatesh 2016);
	Provide enough blank space between each of the menu component	5.3.1 (de Barros, Leitão, and Ribeiro 2014); Look and feel (Al-Razgan et al. 2012); G1.5 (Patsoule and Koutsabasis 2014)
	Provide enough blank space between each part of the content	5.3.1 (de Barros, Leitão, and Ribeiro 2014); Look and feel (Al-Razgan et al. 2012); H9.3 (Zaphiris, Kurniawan, and Ghiawadwala 2007)
Ease of understandin g	Design simple and meaningful icons	H2.3 (Zaphiris, Kurniawan, and Ghiawadwala 2007)
	Use simple and understandable	5.2.4 ((de Barros, Leitão, and Ribeiro 2014);

	language for the menus.	Simplicity (Ji et al. 2006); H5.1(Zaphiris, Kurniawan, and Ghiawadwala 2007)
	Use simple and understandable language for content.	5.2.4 (de Barros, Leitão, and Ribeiro 2014); Simplicity (Ji et al. 2006); G2.1 (Patsoule and Koutsabasis 2014); H5.1(Zaphiris, Kurniawan, and Ghiawadwala 2007)
	Provide a proper number of components for the menu, not too many or too less.	Functionality (Al-Razgan et al. 2012)
	Provide a proper length for each paragraph and section.	H9.2 (Zaphiris, Kurniawan, and Ghiawadwala 2007)
	Use images that are relevant to the content, with text explanation.	H2.1, H2.2 (Zaphiris, Kurniawan, and Ghiawadwala 2007)
	Provide a consistent way of content presentation and information organization across one application.	Guideline 43 (Mi et al. 2014); Consistency (Ji et al. 2006); G5.1 (Patsoule and Koutsabasis 2014)
	Show the content in a hierarchical way of importance.	Hierarchy (Hoehle, Aljafari and Venkatesh 2016); G1.3, G7.5 (Patsoule and Koutsabasis 2014)
Navigation and interaction	Place the main menus and assisted navigation buttons in proper positions of the screen that are immediately obvious and can prevent mistaken touching	Control obviousness (Hoehle, Aljafari and Venkatesh 2016); 5.3.3 (de Barros, Leitão, and Ribeiro 2014); Functionality (Al-Razgan et al. 2012)
	Provide always existing controlled navigation, such as returning and home screen buttons, to make sure that the users could return to the previous interfaces or home screen to restart the task at any time.	5.1.2, 5.2.1 (de Barros, Leitão, and Ribeiro 2014); Functionality (Al-Razgan et al. 2012); G3.1 (Patsoule and Koutsabasis 2014)
	Make sure that the menu hierarchy is not too deep to prevent the users from feeling lost and confused.	H3.5(Zaphiris, Kurniawan, and Ghiawadwala 2007)
	Group the information and content in meaningful categories.	Gestalt (Hoehle, Aljafari and Venkatesh 2016); Structure principle (Ji et al. 2006)
	Use simple interaction gestures that users can easily interact with when navigation	Fingertip-size controls (Hoehle, Aljafari and Venkatesh 2016); Guideline 28 (Mi et al. 2014); Interaction (Al-Razgan et al. 2012)
	Provide clear and appropriate feedbacks to immediately indicate changes caused by operations, such as interface switching or button tapping	Transition (Hoehle, Aljafari and Venkatesh 2016); Guideline 9, 29, 31 (Mi et al. 2014); Cognition support predictability; Visibility; Interaction support feedback (Ji et al. 2006); G1.1 (Patsoule and Koutsabasis 2014); H1.2 (Zaphiris, Kurniawan, and Ghiawadwala 2007)
	Provide users with indications or cues of her/his exact location of the current interface	H3.3(Zaphiris, Kurniawan, and Ghiawadwala 2007)
	Offer tutorials on the major navigation path at the beginning when users were starting to use the application.	H11.2 (Zaphiris, Kurniawan, and Ghiawadwala 2007)

	Provide sufficient visual cues to inform the user about the interactive mode of menus and content.	G2.3 (Patsoule and Koutsabasis 2014); H3.1(Zaphiris, Kurniawan, and Ghiawadwala 2007)
Support for habits	Consider the specific using habit among elderly users.	Familiarity (Ji et al. 2006)

Table 2.6 Summary of design guidelines for navigation design

2.5.1.2. Relevant Design Approaches

In addition to the general design guidelines developed for older adults, specific design approaches are proposed to solve some of the prominent problems, such as the strategies of redundancy design and interface metaphor.

Redundancy Design

Redundancy design is one of the important principles that could help with older adults' intuitive use of technologies (Blackler, 2006). Specifically, it refers to the repetition description of instructions or functions in a different format, such as picture with text or text with voice (Wicken et al., 2004). Generally, it is suggested that the redundancy design is quite beneficial for novice users who have less prior technology knowledge and declined cognitive capabilities (Gould & Schaefer, 2005).

Icons are extensively used in the user interface as an important way to show the entry points for functions. It was shown that the use of icon-only interfaces can help users interact with technology more efficiently once they have learned the systems (Yvonne, 1989; Camacho, Steiner, and Berson, 1990; Cooper et al., 2007). For example, a study showed that the icon-only interface was reported to work better in terms of improving users' reaction times in searching and selecting (Camacho et al., 1990). The reason may be that the graphic appearances of icon-based interfaces are more distinctively recognisable than text-based interfaces. However, in the same study, the researchers found that the text-only interface makes fewer errors compared to the icon-only interface. It can be explained that the process of understanding with the icon-only interface can be easily influenced by the users' individual interpretations based on their own prior experience and context of use, especially for novices (Yvonne, 1989).

In a study by Schroder and Ziefle (2008), different results were found reporting that the younger participants who used a text-only menu performed the tasks faster and more efficiently than those who used an icon-only menu; however, the icon-only menu was much easier to learn than the text-only menu. However, the outcomes may differ in various situations. Steiner and Camacho (1989) found that the effects of the interface design also depend on the amount of information that needs to be presented. This study indicated that when there were only two to four pieces of information to be presented, no significant differences were found in terms of the task completion time between the icon-only and text-only interfaces. Nonetheless, when the number of information patches was more than eight, the icon-only display performed better than the text-only interface.

The redundancy design is therefore widely employed in the user interface design due to its effectiveness in delivering and interpreting functional and operational meaning for the icon-only interface (Shneiderman and Plaisant, 2005; Cooper, Reimann, and Cronin, 2007). Wiedenbeck (1999) investigated the learnability of a software system based on three kinds of interface—icon-only, text-only and icon-text redundancy interface designs—among participants with an average age of 21.5 years. The results suggested that text-only and icon-text interfaces are more helpful for users' learning process, and the icon-text interface outperformed the text-only interface in terms of users' subjective evaluations.

Based on the cognitive load theory (Sweller, 1999), it was recommended that information presented in dual modalities can help reduce users' working memory, such as menus represented in auditory and visual manners (Sweller, 2002). Thus, the redundancy design is helpful to eliminate individual differences in comprehension (Wicken and Hollands, 2000; Wicken et al., 2004) and is beneficial for compensating users with declined cognitive abilities (Tindall-Ford et al., 1997), which is especially recommended for older adults who have less prior technological knowledge and declined cognitive capabilities.

Interface Metaphor

It is necessary to understand and facilitate older adults' perceptions and cognition during the process of interaction when designing for them. The advantages of design metaphors in organising information were highlighted by Lakoff and Johnson (1980), who suggested that the metaphor works better for conceptualising and communicating means by reminding users of some previous experience. Later, the effects of metaphors were acknowledged for information acquisition in domains like computer systems and learning systems (Borgman, 1999; Cameron, 2002; Stanney et al., 2003). It was suggested that users can access and interact with the screen in a more easily way by referring to its correspondent in the physical world and utilising the knowledge they already have in this domain (Blackwell, 2006), which will increase 'the rate at which users can process, understand, and respond to a display' (Nepon and Cate, 1996).

However, there is still a debate on the effectiveness of design metaphors for novice users who have less technology experience. Although some researchers have suggested that the use of metaphor may help them to construct mental models when learning new systems, it was found that mental models simultaneously increase users' cognitive load during navigation (Lee, 2007). Studies have indicated that this may be because of the users' declined processing abilities with extra information. Thus, novice users may not effectively understand the externally provided information cues of the metaphor (Fix et al., 1993; Hsu, 2005). Furthermore, Hse (2006) reported that, for novice users, the design metaphor cannot help with the development of simple knowledge such as understanding individual concepts, but it can help the users to better learn integrative knowledge such as understanding the relationships among concepts.

As for the navigation design, the 3D metaphor has been employed for the information visualization of computers among younger adults (Cockburn and McKenzie, 2001; Rice and Alm, 2008; Kim et al., 2011). For example, when comparing the efficiency of 3D, 2D and text interface designs for computer use, the 3D interface performed worst in terms of response time, though the performances were greatly improved after practice (Sebrechts et al., 1999). A study by Cockburn and Mckenzie compared 3D and 2D interfaces for web page thumbnail image storage and retrieval with different levels of data density. No statistically significant difference was reported in task efficiency between the two interfaces, but the 2D interface outperformed in terms of completion time. Nonetheless, the participants indicated significantly higher levels of subjective evaluation of the use of 3D interface (Cockburn and McKenzie, 2001).

The 3D menu design also works as a prominent way to represent navigation hierarchies for mobile devices. For instance, a study by Osman, Ismail and Wahab reported that the 3D fisheye list was preferred by younger adults in terms of comprehension and acceptance, but it performed worse than the 2D vertical list regarding execution time. In another study (Kim et al., 2011), the participants were asked to locate the target products using three kinds of 3D menus: carousel, revolving stage and collapsible cylindrical trees. The results revealed that the revolving stage menu induced shorter completion times and higher levels of satisfaction and fun. At the same time, they compared the performances and evaluations between the 2D overview menu and the 3D revolving stage menu with the same navigation tasks and found that the former style of menu outperformed the latter in task efficiency, but the 3D revolving stage menu was preferred by the participants.

2.5.2. Review of User Modelling

2.5.2.1. Theories of User Modelling

Human performance models are widely applied in the disciplines of psychology, physiology and human factors, to simulate human behaviour and performance in human-computer interaction. The models can be used by designers to simulate user behaviour and predict user performance with different input and output devices. They can also estimate users' efficiency and effectiveness when completing relevant computing tasks. When the human performance model is used for consumer products design, it can be termed as a user model, which is defined as a representation of user knowledge and user preferences (Benyon and Murray, 1993). User modelling is another complementary method for technology analytical evaluation. This modelling tool is used to predict user exploration behaviour with a given user interface and task requirement. By evaluating the effectiveness of user interface designs in an early stage, it can help determine probable usability issues during the design process.

Since the Second World War, research has been conducted to simulate user behaviour to predict machine performance. The human performance model was first used to simulate operator performance for military hardware tasks. Several simple computational models such as McCulloch and Pitts' (1943) model of neuron and Marr's (1980) model of vision have been developed. Later, with the accessibility of personal computers, attention shifted to the modelling of human-computer interaction. Examples include Hick's Law (1925) and Fitts' Law (1954), which were applied to estimate users' visual search time and movement time. Nevertheless, these simple HCI models are not enough to simulate complex interaction behaviour. The first acknowledged HCI model, Command Language Grammar, was developed to better predict human-computer interaction by decomposing the computing interaction tasks step by step (Moran, 1981). Yet, it completely neglects the user's capabilities and limitations. Thus, in 1983, Card, Moran and Newell (1983) developed the Model Human Processor from a user perspective, which became a milestone in the history of HCI modelling.

There are two major streams for studies of user modelling. The first stream is the application of the GOMS (Goals, Operators, Method, and Selection) family of models, which was originally developed from the Model Human Processor (Newell and Simon, 1995). These models are used to simulate goal-directed human behaviour based on the assumption that all interactions have a sequence of basic operations with the selected methods. Typical representations of the GOMS include the Keystroke Level model (KLM) (Card et al., 1983), Natural GOMS Language (NGOMSL) (Kieras, 1994), GOMS Language Evaluation and Analysis Model (GLEAN) (Kieras et al., 1995) and CPM-GOMS (John and Kieras, 1996).

The other stream of predictive modelling studies focuses on the development of cognitive architectures aimed to simulate a user's mental model by establishing the user's unified theory of cognition. A typical example of the cognitive architecture is the State Operator and Results architecture (SOAR) developed by Newell (1990). The essence of this model lies in its chunking mechanism, which is 'a way of converting goal-based problem solving into accessible long-term memory' (Newell, 1990). For example, the SOAR can simulate all possible operations and choose the one that brings it nearest to the task goal in a situation when the user does not have sufficient knowledge to conduct the task. In addition to memory, other aspects of cognition can explain users' interaction with technologies, such as perception, recognition and motor skills (Oka, 1991). Thus, later studies began to study cognition processes by classifying them into different levels, such as symbolic and sub-symbolic levels of processing proposed in the adaptive control of the thought-rational system (ACT-R) (Anderson and Lebiere, 1998). The system is simulated as working to achieve a goal by retrieving knowledge from the declarative memory at the symbolic level, and the time of knowledge retrieval and conflict resolution is calculated by the activation values of nodes and links of the semantic network at the sub-symbolic level.

2.5.2.2. User Modelling for Older Adults

To summarise, the GOMS family of models is suitable to simulate goal-directed human computer interaction for skilled users (John and Kieras, 1996), and cognitive architectures are good at simulating uncertain human behaviour but are quite difficult to use for designers who do not have psychological backgrounds. None of these models has addressed the specific user group of older adults. To develop user models that can be applied to such users with less technological experience and declined capabilities, the cognitive impairment when interacting with technology should be considered. It is vital to match the system demands and user capabilities in perceptual, cognitive and physical aspects when analytically evaluating interface designs. Therefore, the quantification of this capability-demand relationship is proposed to calculate product inclusion; the framework is shown in Figure 2.13 (Langdon et al., 2010). However, these studies have not developed executable models and are still in a preliminary stage of exploring the underlying mechanism of older adult user modelling. More research is needed to identify the predictive variables in these user models and to empirically validate them.

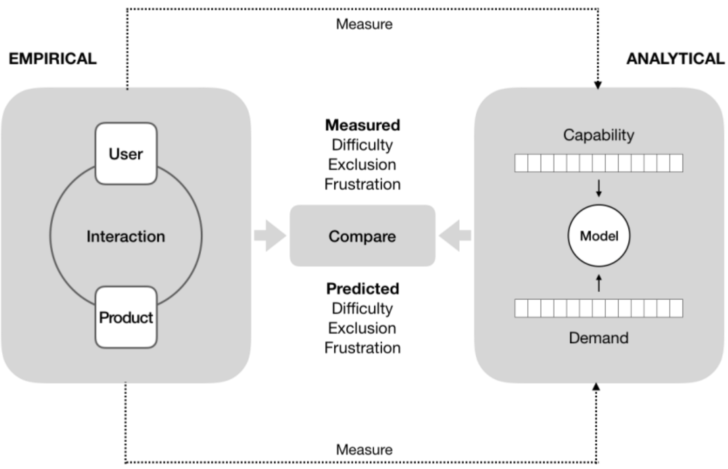


Figure 2.13 An analytical framework for quantification of the capability-demand relationship

2.5.2.3. Cognitive Modelling for Web Navigation

There is a long history of studying cognitive modelling for web navigation behaviour for younger users. Currently, the cognitive modelling of web navigation is mainly based on attention mechanisms related to the theories of label-following and information scent. These studies assume that users mainly distribute their attention to various patches of information according to the semantic similarity between the goal of the tasks and the specific information patches (Blackmon, 2012). For example, the comprehension-based linked-model of deliberate search (CoLiDeS) (Blackmon et al., 2005; Kitajima et al., 2007) proposed five variables that determine the attractiveness of a patch of information related to the exploration goal:

- the extent of semantic similarity between the head titles of the information patch or the link labels and the user's goal of exploration
- the adequacy of background knowledge that can elaborate on the information patch or link label
- the uniqueness of words used in titles of information patches and link labels, which are different from the users' background knowledge
- the frequency that the users may come across such titles and links
- the literal matching between the heading or links and the exploration goals

However, previous studies on user modelling are mainly based on information theories, which largely neglect the effects of interface design layout (Teo, 2011). A wider context of influential factors has not been addressed in the abovementioned models, such as the characteristics of the task, the presentation of information, the organisation of user interface elements and user characteristics (Indurkhya et al., 2012). These variables are also relevant to user modelling for navigation behaviour. Nevertheless, current studies are still exploring what predictive variables should be included and in what way they should be modelled.

2.6. Research Rationale

The preceding discussions have addressed the relevant terms used in the current research including older adults and mobile technologies, reviewed the theories of technology acceptance and adoption and information navigation behaviour and compared various approaches that can help in designing for older adults' use of technologies including design principles, guidelines and predictive user modelling. There are several relevant points revealed accordingly:

- Mobile technology is emerging as a widely used technological platform that is easier and more intuitive for older adults to use; the unique pattern of mobile technology adoption and usage among older adults has been little explored, and the key facilitators and buffers that influence older adults' continued adoption and use of mobile technologies are still unknown.

- Although several general and high-level design guidelines are proposed for elderly-friendly interaction design, designers still face great challenges when designing for low-level user interface details such as mobile navigation. Little is known about where and in what extent usability problems exist in terms of older adults' usage with current mobile navigation design patterns.
- User modelling is a promising method for analytically evaluating mobile technology design at a very early design stage; however, there is a lack of systematic perspective from the user characteristics, interface design and task demands when developing the model.
- During the process of older adults' initial adoption, experimentation and interactions, and their continued or upgraded adoption behaviour with mobile technologies, the roles of user capabilities, especially perceptual and cognitive processes, have largely been neglected, and these age-related specifications in capabilities are especially important for these behaviours.

Accordingly, the research questions were investigated to fill the identified research gaps. This study investigated the significant factors that influence older adults' post-adoption behaviour of mobile technologies, with a focus on user characteristics and technology features. Second, a usability study was conducted to identify older adults' usability challenges when navigating current mobile interfaces, summarising the typical navigation behaviours and analysing popular design patterns. Then, two typical navigation behaviours were investigated, and the possible effects of user characteristics, interface design and task demands were addressed by two experiments. After integrating the results of these two experiments, this study successfully developed user models that can be utilised in the analytical evaluation of mobile navigation design to facilitate mobile technology adoption and improve user experience. The methodology utilised to answer the corresponding research questions is outlined in the following chapter.

CHAPTER 3 Research Methodology

This chapter describes the research methodology and methods used in the research, which mainly deals with understanding and modelling older adults' usage and perceptions of mobile technology. This type of description and explanatory research makes this area of research inherently post-positivist by combining multiple measures and observations to better understand the reality (Mackenzie and Knipe, 2006). In line with post-positivism, the mixed method is employed as the main research methodology to obtain an in-depth understanding of older adults' post-adoption usage and perceptions regarding mobile technologies and quantification of the possible factors that affect the process by considering user characteristics, task demands and interface design. The research methods of interviews, usability testing and experiments are outlined. A comparison of various methods is provided by analysing the advantages and disadvantages of each method. The rationale for the selection of each method is discussed, and the methodology framework is proposed accordingly. Methods are planned by describing how the methods could work together to draw the expected conclusions. Following, the scientific methods of data collection and analysis are described.

3.1. Methodology

3.1.1. Qualitative Methods: Interview

The first three research questions aim to understand the general situation of older adults' usage and perceptions regarding mobile technologies, investigate factors that may influence the process and identify key technology features that buffer acceptance and adoption. In this context, the best way to obtain a deep and multifaceted insight into older adults' user experience and subjective perceptions is to ask them to freely discuss it. Therefore, the interview was utilised to better understand the comprehensive meaning behind participants' behaviour and understand the complicated situations (Seidman, 2013). The format of semi-structured interview allows interviewers to schedule the interview process and prepare the interview questions in advance. In addition, with cognitive ageing, the interview questions may be difficult for older adults to understand. Thus, another strength of the semi-structured interviews is allowing questions to emerge from the conversation between the interviewer and interviewee.

Although the semi-structured interview has many benefits, researchers should carefully interpret interview transcripts (Dilley, 2004). First, the meaning behind behaviour is not 'just the facts'. Researchers need to understand the reasons behind the older adults' behaviour and experience (Seidman, 2013). Therefore, this could propose considerate challenges for interviewers when dealing with the conflicts between what the interviewers are attempting to ask and what the participants are trying to answer (Dilley, 2004). Furthermore, previous research has reported that older adults are more likely to show their positive feelings of an experience (Sayers, 2004). They focus more on the positive aspects, in spite of the difficulties and inconveniences they may encounter, which may impact the validity of interview research. To compensate for these shortcomings, strategies need to be applied, such as rephrasing questions and employing multiple approaches to interpret each answer (Seidman, 2013). For example, to compensate for the possibility of missing any details caused by self-reporting, we summarised a set of problems and difficulties related to mobile technology use based on established usability guidelines. Simultaneously, we elaborated on the questions by reminding the participants of related scenarios they might experience in daily use. In this way, the validity and trustworthiness of the research are enhanced.

3.1.2. Quantitative Methods: Usability Testing and Experiment

To address the fourth research question, which aims to inform designers of the advantages and drawbacks of current UI design, usability testing can help to identify the difficulties and challenges that older adults may experience. Both laboratory experiments and field studies have been widely applied to conduct usability testing with mobile technologies, depending on the research objectives and usability attributes (Zhang and Adipat, 2005). For example, laboratory experiments provide full control over the usability attributes and the task process by controlling the irrelevant variables in the laboratory environment. This method is more helpful when comparing the effectiveness of different interface designs. However, it ignores the usage context to a large extent and may not reflect potential problems that may occur in a real situation. Rather than directly comparing the effectiveness of various navigation design patterns, the research aims to investigate specific interaction details and detect key usability challenges older adults may face in realistic scenarios. Thus, the method of field studies is helpful to capture a rich set of data about older adults' mobile interaction behaviour in a naturalistic environment.

Nevertheless, the limitations of performing usability testing through field studies should also be considered (Beck et al., 2003). It is quite challenging in terms of data collection. When a test is performed in the field, it is more difficult to employ evaluation techniques such as verbal protocol or observation. In addition, it is not easy to sufficiently control the process of testing or the participants. Therefore, to compensate for the possible drawback of field studies, the usability testing employed in the research designed a thorough list of tasks in advance to control the testing process. In addition, the whole process was voice and video recorded, and the method of activity analysis was applied to analyse the results of usability testing in detail, which is specifically useful in analysing the video data of interaction behaviour.

For the fifth research question, which aims to quantify and model the relationships between the predictive variables that influence older adults' mobile navigation performance and perceptions, experiments are more appropriate because the quantitative method is more effective in checking influences of factors of user, task and system design. In the research, the independent variables were factors related to user characteristics, task demands, and interface design and the dependent variables were participants' objective performances and subjective evaluations of technological tasks.

Research validity can be influenced in different ways. For example, if the experiment is designed repeatedly, changes can happen because of the environmental factors other than the experimental treatments. In addition, participants may perform better after the second try, which may also influence the research validity (Hopkins, 2008). Therefore, this study followed several principles to assure research quality. For example, the generation of samples was selected to represent the specific population of older adults in Hong Kong. Second, the materials used in the experiment were designed to assure an overall familiarity for the participants by removing complicated words through local literacy experts and introducing the experimental materials in detail by the experimenter. Third, to ensure the research validity, a pilot study was conducted to help the researchers calculate the sample size and check the experimental design. By following these principles, the research validity could be further assured.

3.2. Development of Methodology Framework

To comprehend older adults' post-adoption usage and perceptions of mobile technologies and to build a predictive user model addressing multiple aspects of user, task and interface, these methods were designed to work together systematically. A research framework is proposed, as shown in Figure 3.1. Literature reviews formed the foundation for the research by providing a deep understanding of relevant theories and related studies such as ageing, human capabilities, technology acceptance and adoption, human-technology interaction and user modelling. In the phase of general understanding, a semi-structured interview comprised of questionnaires and capability tests was employed to comprehend how older adults use and perceive mobile technologies in their daily lives and to determine their use habits, limitations and expectations. Possible factors of user, task and system design were defined through this phase. Based on results from the systematic literature review and semi-structured interviews, the research scope was narrowed down to one difficult technology-related task for older adults: mobile navigation. Then, a series of usability testing studies were conducted with several design patterns to explore older adults' mobile navigation behaviour, which was video and voice recorded. An activity analysis was utilised to analyse the video data by analysing every interaction involved in the navigation process. The data generated in the usability testing were useful in characterising older adults' navigation behaviour with different navigation design patterns. Two typical navigation behaviours were identified: menu-oriented navigation and content-oriented navigation. Accordingly, experimental methods were applied to quantify the complex relationships among predictive variables within the context of these two navigation behaviours. In the final stage, user models were developed to help designers analytically evaluate the complexity and efficiency of mobile technology navigation design for older adults.

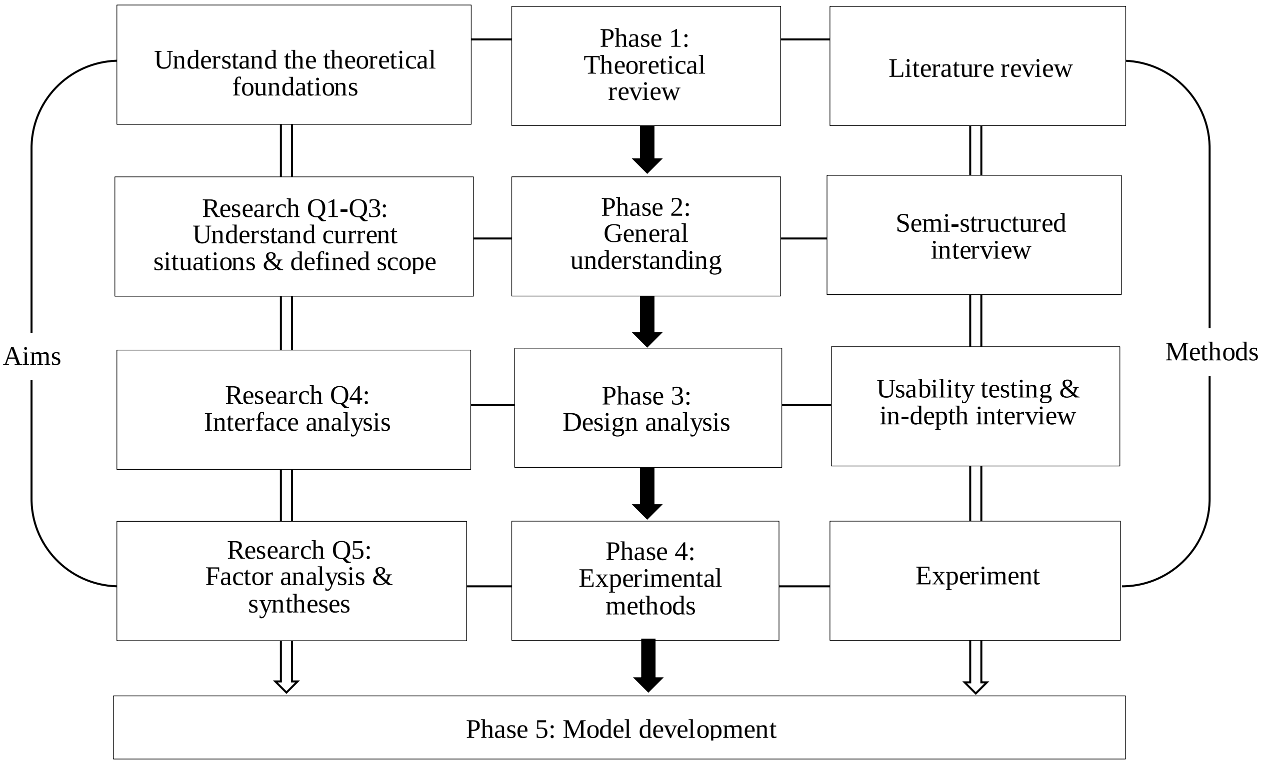


Figure 3.1 Framework of methodology

3.3. Implementation of Methods

As shown in Figure 3.2, the use of mixed methods entails a concurrent triangulation design by collecting and analysing data separately. The integration of data collected from both qualitative and quantitative methods in different stages helps to better understand older adults' usage and perceptions and test hypotheses about the relationships between influential factors regarding mobile technologies. Specifically, the qualitative data focused on understanding users' perceptions and acceptances with mobile technologies from semi-structured interviews and usability testing to answer the confirmatory questions, and the quantitative data was obtained through experiments, part of the semi-structured interviews and usability testing with the goal of exploring and explaining the relationships among selected variables related to older adults' interactions with mobile technologies (Castro et al., 2010)

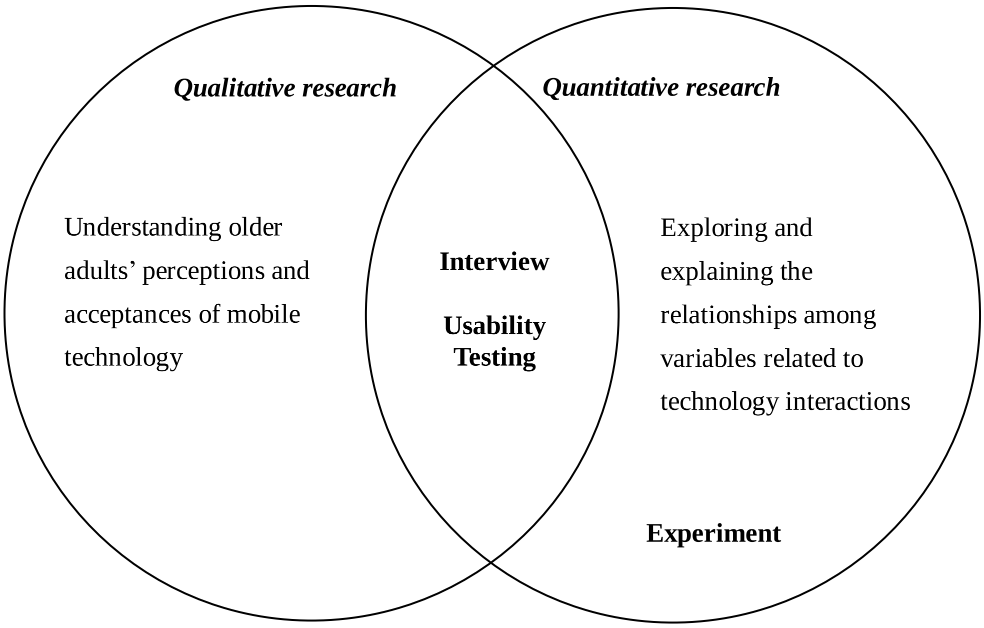


Figure 3.2 Mixed methods using concurrent triangulation.

3.3.1. Semi-structured Interview

The semi-structured interview was conducted to investigate how older adults use and perceive mobile technologies, how they adopt the technology and what problems and difficulties they encounter when using mobile technology in terms of learnability, efficiency, error prevention, memorability and user satisfaction. This study used a random sampling procedure to recruit the participants to further assure research validity. Participants were provided with basic information about the research project, the privacy right of participants, a brief introduction of interview procedures and the approximate time the interview would take. Two interviewers who had training experience with usability studies, cognitive tests and volunteer work with elderly people conducted the interviews. The interview questions were asked in different forms and explained in detail when the older adults could not easily understand them. Because of the older adults' physical limitations, the entire process took approximately 30 minutes for each participant.

3.3.2. Usability Testing and In-depth Interview

The first semi-structured interview explicitly addressed the possible factors influencing older adults' usage and acceptance of mobile technologies and assisted in narrowing the research area to mobile navigation behaviour. Emphasising the factor of interface design, the research aims to investigate whether current mobile UI design patterns properly support older adults' navigation behaviour and usage habits and to determine potential usability challenges for older adults. Thus, this phase was conducted with a series of usability testing studies, followed by in-depth interviews. An experimental mobile application that included six of the most widely used navigation patterns were utilised in the usability testing. Participants were first asked to carry out 19 tasks using all different navigation patterns in the experiment. Then, an in-depth interview was conducted asking the participants to describe the challenges and problems they encountered when interacting with these interfaces. The whole process lasted approximately 1.5 hours for each participant.

3.3.3. Experiments

To quantify the relationships between the influential factors defined by prior studies and literature reviews, two experiments were employed to investigate older adults' menu-oriented and content-oriented mobile navigation behaviour identified by the usability testing. Instead of employing a laboratory experiment, we conducted the experiments in local community elderly centres in consideration of the older adults' physical limitations. A quiet and comfortable room was provided for the participants to maintain the experiment validity. Pilot tests were conducted to test the experimental process.

A $2 \times 3 \times 3$ mixed factorial design was implemented to investigate the effects of age, menu design and task complexity on older adults' menu-orientated navigation performance and subjective evaluation, with menu-design (icon-text, icon only and text only) and task complexity (low, medium, and high) as the within-subject variables, and age (younger and older) as a between-subject variable. To study the influences of perceptual speed, interface design, information content and task complexity on older adults' content-orientated navigation performance and subjective preferences, a $2 \times 2 \times 2 \times 2$ mixed factorial design was employed, with the factors of interface design (2D list and 3D card), content similarity (high and low) and task complexity (high and low) as the within-subject variables, and perceptual speed (low and high) as the between-subject variable. Dependent variables were participants' navigation performance and subjective evaluation of tasks and interfaces.

3.4. Analysis Techniques

3.4.1. Content Analysis

Interview transcripts were analysed using content analysis to gain the qualitative data. Content analysis is a systematic and effective data reduction technique to compress data from numerous words and texts (Krippendorff, 2012). Based on explicit coding rules, it allows researchers to easily filter data in a systematic fashion. Thus, it is quite useful for discovering and describing the experiences and perspectives of older adults while using information technology. However, qualitative data is time-consuming and difficult to analyse. Rather than just using word frequency counts, content analysis relies on coding and categorising the qualitative data (Stemler, 2001).

The semi-structured interview of Study One was particularly interested in usage behaviour, user perceptions and some other impacted factors mentioned by the participants corresponding to technology acceptance models including TAM, UTAUT and STAM. The in-depth interview in Study Two mainly focused on the detailed reasons behind the failure of each usability issue. A usability checklist summarised and extracted from the established usability guidelines was employed as the framework to compensate for possible missed details by self-reporting. Thus, the factors summarised from theoretical models and usability guidelines constructed the rules and scheme for coding and categorising in this interview. The data was then organised into relevant topics and subtopics. Through integrating and summarising, a thorough understanding of the data was achieved.

3.4.2. Activity Analysis

Activity theory is one of the most influential theoretical frameworks in HCI studies. It emphasises the emergence and development of the human mind within the context of an activity that combines prespecified and situated components (Kaptelinin and Nardi, 2006). In particular, an activity is comprised of an intentional actor ('subject'), the objective reality ('object') and mediating artefacts through which the activity is carried out (Baumer and Tomlinson, 2011). Activity theory has been widely applied in technology design and evaluation (Clemmensen et al., 2016). As a tool for empirical analysis, activity theory provides a set of concepts for understanding technology. For instance, the concept of tool mediation was extensively studied to understand artefacts such as collaborative writing tools (Pargman and Waern, 2003), surgical tools (Bardram, 1998) and user interfaces for higher learning activities (Oviatt et al., 2012). The concept of context was mainly utilised when discussing meaningful human activity such as collaborative activity (Barthelmess and Anderson, 2002) and workplace learning (Owen, 2001). Additionally, the concept of contradiction and breakdown was also frequently employed in the empirical analysis of technologies and systems such as network systems (Miettinen and Hasu, 2002) and video gaming (Law and Sun, 2012).

Hence, the activity theory works effectively in helping to understand technology usage in various contexts. In 1996, Bødker attempted to systematically apply the activity theory to video analysis in HCI research. Activity theory-based video analyses have frequently been employed to support usability testing in HCI research (Harris, 2004; Bødker, 1996). Thus this study employed a structural activity analysis method to investigate the usability challenges when older adults navigate mobile technologies to analyse the advantages and disadvantages of current mobile UI design.

3.4.3. Experimental Analysis

The experiment results were measured by task performance and the subjective preferences of the participants. The performance data in the experiment were measured by the completion time and correctness rate as indicators of the participants' effectiveness and efficiency when performing tasks. The data of subjective evaluations were measured by 5-point Likert scales on the difficulty level of each task and perceived ease of use, usefulness, effort, disorientation, satisfaction and behavioural intention to use regarding each interface design.

All quantitative data were analysed through SPSS. An alpha level of .05 was used for statistical analysis. A descriptive data analysis was conducted for the factors of user characteristics, including mean, median, standard deviation (SD), frequency, etc. Pearson and Spearman correlation analyses were used to analyse the possible relationships between user characteristics and navigation behaviour. In addition, an ANOVA analysis was used to evaluate the interaction effects of the variables on dependent variables. A Friedman test and Wilcoxon signed-rank test were employed to analyse the differences between various experimental settings for the dependent variables. Furthermore, a multiple regression analysis was used to ascertain factors of user characteristics and user capabilities associated with participants' navigation performance and subjective perceptions overall and for different conditions.

CHAPTER 4 Study One: Understanding Older Adults' Post-Adoption Usage and Perceptions of Mobile Technology

4.1. Introduction

To explain the process of technology acceptance and adoption, researchers have proposed various theories and frameworks. One strand regards the intention to use technology as a symbol of acceptance, including the technology acceptance model (TAM) (Davis et al., 1989) and unified theory of acceptance and use of technology (UTAUT) (Venkatesh et al., 2003). They mainly emphasise the roles of internal personal attributes and external influential factors that result in technology acceptance. Other researchers have attempted to investigate technology adoption as a continuous process through the innovation diffusion theory (Roger, 1995), the domestication of technology (Silverstone and Haddon, 1996) and the senior technology acceptance and adoption model (STAM) (Renaud and Van Biljon 2008). This emphasis on a continuous process is specifically essential for older adults' acceptance and adoption of mobile technologies because many older adults do not fully adopt or reject mobile technologies. They are still in a phase of initial adoption and use only limited and basic functions, even with many years of mobile technology experience (Gelderblom et al., 2010). How older adults use and perceive mobile technologies after their initial adoption and what characteristics of the user and mobile technology may facilitate or buffer older adults' further acceptance and adoption are seldom discussed.

This chapter focuses on older adults' usage and perceptions regarding mobile technologies after their first adoption, which emphasises the post-adoption behaviour corresponding to the incorporation and conversion stages in the STAM. It helps to answer the research questions Q1–Q3 by pursuing three main objectives. First, by explicitly examining older adults' technology exposure and usage variety, this chapter investigates older adults' post-adoption usage of mobile technologies. Second, this chapter investigates older adults' perceptions and attitudes regarding post-adoption use of mobile technology by inviting participants to discuss and evaluate them based on several attitudinal factors derived from previous acceptance models. Third, by examining the possible influences of user characteristics and technology features, this chapter identifies the facilitators and barriers that affect older adults' usage and perceptions. Specifically, user characteristics were investigated by participants' demographic information of age and education level, as well as user capabilities of working memory, spatial ability, perceptual speed and visual perceptions. Ten aspects of technology features were evaluated, including target design, use of graphics, icon design, use of colour and background, layout design, interaction, functionality, use of menus, navigation and controls and instruction and language.

4.2. Method

A semi-structured interview was used to investigate the mobile technology post-adoption behaviour for the participants (see Appendix A). Due to the older adults' physical limitations, the entire interview took about 30 minutes for each participant. Two interviewers who had extensive training experience in usability studies and cognitive tests conducted the interviews.

4.2.1. Participants

It was reported that the majority of the cognitive abilities start to decrease as early as the mid-50s and quickly decline at the beginning of the 70s (Drag and Bieliauskas, 2010; Schaie, 2012). Thus this study recruited Hong Kong Chinese adults who were above 55 years old and had experience using mobile technologies by snowball sampling (Goodman, 1961). The recruitment was conducted in three local centres for elderly adults who were residing in domestic households in Hong Kong. This group of participants was selected because this group is a representative sample of older adults in Hong Kong (Census and Statistics Department, 2009). Besides, all participants indicated that they could read Chinese characters and reported being in good physical condition without any cognitive impairment.

4.2.2. Measurements

There were four aspects examined during the interview: (a) user characteristics, including the demographic factors of age and education level, and the user capabilities of working memory, spatial ability, perceptual speed, and visual perceptions; (b) technology features; (c) usage behaviour; and (d) user perceptions. The participants were interviewed by questions in different forms, and each question was explained in detail once the participants could not well understand it.

4.2.2.1. User Capabilities

The performance tests and self-reporting were employed to measure the participants' levels of cognitive capability and visual perceptions respectively. First, a clock drawing test (CDT) was used to evaluate the participants' spatial dysfunction and neglect (Agrell and Dehlin, 1998) and a word recall test (WRT) was employed to measure the participants' working memory (Borson et al., 2000). Firstly, three unrelated words were first given to the participants to memorise in the WRT. Following, in the CDT, the participants were instructed to write the correct numbers and draw the hands of a clock in a circle to represent a clock with the time of 11:10 am. After that, the participants were asked to repeat the three previously memorised words to complete the WRT.

The total scores for the performances of the WRT and CDT were ranged from 0 to 5 points; 1 point was allotted for each correctly recalled word and 2 points were marked if all the numbers were placed in correct positions and the hands legibly read the requested time.

Then, the Symbol Digit Modalities Test (SDMT) was used to evaluate the participants' levels of perceptual speed (Benedict et al., 2012). Specifically, this test presented a table with a coding key system to the participants, which was comprised of nine abstract symbols and their paired numbers from one to nine. For each symbol, there was one number assigned to it respectively. In the test, the participants were asked to complete a test table with all the abstract symbols randomly arranged within it. During the test, the participants were asked to fill in as many of the paired numbers as possible in the test table by referring to the coding table that always presented in 90 seconds. The performance was calculated according to the number of correctly matched symbols.

In the end, a self-reporting evaluation was employed to examine the participants' daily visual perceptions in reading texts and detecting targets on physical and display-based materials. Specifically, it addressed three aspects of visual perceptions, namely the visual ability to read texts on paper (VAP), the visual ability to complete tasks that require close observation (VAO), and the visual ability to read texts on digital displays (VAD).

4.2.2.2. Technology Features

Improving the match between technology features and older adults' unique characteristics is one of the major concerns for designers. Numerous design guidelines have been developed for different technologies in multiple usage contexts to address the older adults' capabilities and requirements for technology use (Kurniawan and Zaphiris, 2005; Zaphiris et al., 2007). With the aim of further understanding the older adults' perceived difficulties with various technology features in their post-adoption behaviour, this study encouraged the participants to share their worries, difficulties, and concerns about mobile technology use. The explanations and comments were collected at the same time for further analysis. During the interview, this study summarized a set of difficulties and issues related to mobile technology use based on the established guidelines mentioned in Section 2.5.1.1 (Zaphiris et al., 2007; Al-Razgan et al., 2012; de Barros et al., 2014; Patsoule and Koutsabasis, 2014; Hoehle et al., 2016), to compensate for the possibility of missing any details caused by the method of self-reporting, as shown in Table 4.1. The interview questions were elaborated by reminding the participants of the related usage scenarios they might encounter during their daily use. The participants were instructed to verbally evaluate each technology feature based on a 5-point Likert scale ranged from strongly disagree to strongly agree.

Items	*Interview Questions*
Target design (TD)	Is the target clear and visible for you, such as text and buttons?
Use of graphics (UG)	Is the number of graphics and animations appropriate on the screen? Will they make you feel comfortable and clear?
Icon design (ID)	Is the icon simple and meaningful enough to you?
Use of colour & background (CB)	Are the colours and background used properly for you?
Layout design (LD)	Is all the displayed information relevant? Is the interface simple and clear for you?
Interaction (IT)	Do you know how to slide between different interfaces by tapping, swiping, dragging or dropping?
Functionality (FC)	Do you know how to switch between different functions?
Use of menus (UM)	Can you easily find the pull-down menu or sider drawer?
Navigation and controls (NC)	Do you know how to return to the previous interface or homepage?
Instruction and language (IL)	Can you understand the language or instruction used?

Table 4.1 Semi-structure interview questions on technology features

4.2.2.3. Usage Behaviour

As shown in Table 4.2, four subcomponents were investigated regarding the participants' usage behaviour, including the duration of use, intensity of use, diversity of use, and adoption of advanced functions with mobile technologies. The duration of use means the length of time during which the mobile technology is used; the intensity of use refers to the frequency with which the mobile technology is used; and diversity of use means the number of various functions used with the mobile technology. In addition, the older adults' adoption of advanced functions was evaluated to differentiate between the phases of initial adoption and upgraded usage. Specifically, the basic functions mainly include the native applications such as calls, messages, daily alarm, camera, and the calendar (Huh and Kim, 2008; Nimrod, 2016); whereas the advanced functions refer to those third-party applications, which were categorized into five kinds, including the social communication, leisure and entertainment, information searching, health care, and online purchasing (Wagner et al., 2010).

Items	*Interview Questions*
Duration of use	How long have you been using mobile technologies?
Intensity of use	How many hours per week do you use mobile technologies?
Diversity of use	How many functions do you use on your mobile technologies?
Adoption of advanced functions	How many advanced functions do you use on your mobile technologies?

Table 4.2 Semi-structure interview questions on usage behaviour

4.2.2.4. User Perceptions

A set of perception attributes was discussed and evaluated by the participants, all of which were derived from the models above and theories regarding technology acceptance, as shown in Table 4.3. Specifically, it includes: (a) general attitude that was evaluated based on older adults' positive or negative feelings towards the use of mobile technologies, which was related to the attribute of the attitude towards use in the TAM; (b) perceived usefulness that was examined by whether the mobile technologies are useful for their daily life usage, which is relevant to the construct of perceived usefulness addressed by the TAM and STAM, and the performance expectancy defined by the UTAUT; (c) perceived usability that addressed the degree of mobile technology usability in more detail depending on five constructs, namely learnability, efficiency, error prevention, memorability, and satisfaction, which is similar to the perceived ease of use of the TAM, the effort expectancy from the UTAUT, as well as the ease of learning and use of the STAM; and (d) self-efficacy that was investigated according to the participants' judgments of their capabilities in learning and using the mobile technologies or relevant functions. The participants responded to these questions verbally by a 5-point Likert scale (1-strongly disagree, 2-disagree, 3-neural, 4- agree, 5-strongly agree).

Items	***Interview Questions***
General attitude	Do you like the idea of using mobile devices? Or do you feel pleasant when using mobile devices?
Perceived usefulness	Do you think using the mobile devices would bring some convenience to your life? Or do you find the mobile device useful in your life?
Perceived usability	
Learnability	Do you feel easy when started to learn a new mobile technology or related application?
Efficiently	Can you complete most of the tasks efficiently using your familiar mobile technology?
Error prevention	Can you easily recover from the mistakes using your mobile technologies?
Memorability	Can you easily remember how to use the technologies or applications when there has been a long time since you haven't used them?
Satisfaction	Do you feel pleasure and satisfied when you using mobile technologies and related functions?
Self-efficacy	Do you think you are capable to learn a new kind of mobile technology or related application?

Table 4.3 Semi-structured interview on user perceptions

4.2.3. Data Analysis

The descriptive analysis was performed on the participants' user characteristics and evaluations of the technology features, usage behaviour, as well as the user perceptions. Following, the spearman correlation analysis was conducted to examine the correlations between the variables from these four aspects. Finally, the multiple regression analysis was applied to ascertain the factors of user characteristics and technology features that associated with the older adults' post-adoption usage and perceptions.

4.3. Results

4.3.1. Characteristics of Participants

In total, there were 51 participants were recruited in the investigation of user characteristics, including 12 male and 39 female Hong Kong Chinese older adults aged from 61 to 90 years old (mean age= 75.92 years; SD = 6.98). Their education levels ranged from below primary school to the university and above, with a median level of primary school. After the section of user characteristics investigation, 35 older adults continued the subsequent interview sections of evaluations of the technology features, usage behaviour, and user perceptions, including 7 males and 28 females aged from 61 to 84 years older (mean age= 75.06 years old; SD = 6.58). As for their education level, the median education level of the 35 participants was also primary school. Table 4.4 presents the frequency distributions of age and education levels for all participants. It was reported that the age and education level distributions of the 35 participants overall followed a quite similar pattern to that of the 51 participants.

Table 4.5 shows the results of descriptive data analysis for the capability assessments. It was reported that the mean scores of participants' cognitive capability tests on WRT, CDT, and SDMT were 2.37, 1.06, and 17.39, respectively. Additionally, the majority of participants indicated no difficulty or only slight difficulties to read texts on paper (82.3%), engage in daily tasks

(84.3%), and read texts on the digital displays (76.5%). Even though older adults reported that they had more difficulties to recognise characters on digital displays, no severe visual problems were reported when they were wearing corrective lenses. Specifically, there were 23.5% of the participants indicating a medium to high level of difficulty when recognizing characters on digital screens.

	N=51		*N=35*	
	Frequency	Percentage (%)	Frequency	Percentage (%)
Age				
60-64	4	7.8	3	8.6
65-69	6	11.8	5	14.3
70-74	7	13.7	5	14.3
75-79	15	29.4	10	28.6
80-84	16	31.4	12	34.3
85-89	2	3.9	0	0
90-94	1	2.0	0	0
Education level				
Below the primary school	12	23.5	4	11.4
Primary school	20	39.2	18	51.4
Secondary school	13	25.5	11	31.4
Post-secondary school	3	5.9	1	2.9
University and above	3	5.9	1	2.9

Table 4.4 Participants' age and education level distributions

	Minimum	***Maximum***	***Mean***	***SD***
Word Recall Test (WRT)	0	3	2.37	0.85
Clock Drawing Test (CDT)	0	2	1.06	1.01
Symbol Digit Modalities Test (SDMT)	3	44	17.39	10.90
Visual ability to read texts on paper (VAP)	1	5	4.22	1.08
Visual ability to do tasks require close observation (VAO)	1	5	4.39	1.02
Visual ability to read texts on digital displays (VAD)	1	5	4.02	1.32

Table 4.5 Descriptive statistics on the capability assessment (N = 51)

According to the results of the following discussions, several major problems that troubled the older adults were determined. First, though there were no severe problems reported from the self-reporting evaluations, the long-term use of digital displays was complained frequently by some of the participants, which can easily make them feel uncomfortable. Second, some of the participants also reported that they could easily forget the functions they have learned or the meanings of the icons, buttons, and menus due to their declined memory. In addition, there were several participants who also mentioned the difficulties when using mobile technologies and ascribe these problems to their poor literacy.

4.3.2. Technology Features

Ten categories of technology features were verbally evaluated on 5-point Likert scales by the participants. Nevertheless, it was observed that older adults had some difficulties when identifying the usage problems that related to specific technology features. For example, most of the comments were quite general such as perceiving the technology features as too complex, by stating "*these technologies are too changeable and complex for us*" or "*the design should be simplified, otherwise it means nothing for us*". In addition, the older adults tended to ascribe the difficulties of technology features to their personal ignorance, stating, "*I could not easily find the buttons or targets just because I don't know how to*".

Therefore, the results of self-reporting evaluations of each technology feature can help to reveal more details. It was shown that the technology features that related to the use of menus were then evaluated as the lowest, with 91.4% of the participants perceived a medium or high level of difficulty. The technology feature that related to icon design was evaluated as the second lowest, with 68.6% of the participants reported a medium or high level of difficulty for this feature.

Then it was following by the remaining features, which were presented in descending order with the percentage of participants indicating a medium or high level of difficulty: difficulty of interaction such as sliding between interfaces (65.7%), difficulty with the instructions and language understanding (97.1%), difficulty related to the layout design (62.9%), difficulty with switching between functions (60.0%), difficulty in navigation and controls such as returning to the homepage (51.4%), difficulty related to the use of graphics (54.3%), difficulty related to the target design (45.7%), and difficulty related to the use of colour and background (34.3%). Table 4.6 lists the detailed descriptive statistics for the evaluations of technology features.

Although some of the comments from the participants were broad to some extent, some valuable insights were also obtained from the discussions. For instance, it was complained by some of the participants that finding the target functions by menus or the point of entry was very difficult for them. Some typical answers were stated, "*It's difficult to find those menus and functions*" or "*I could not find the apps that other people have downloaded for me*". Additionally, there was another frequently reported problem that related to the possibilities of making mistakes and difficulties of recovery. Many of the participants said they were very worried about making mistakes by clicking the incorrect buttons and difficult to recover from these mistakes, by stating "*I'm afraid to click the button because I'm afraid to make mistakes*" or "*I don't know what the buttons are used for and where I will go if I press them*".

	Minimum	***Maximum***	***Mean***	***SD***
Target design (TD)	2	5	3.17	1.01
Use of graphics (UG)	2	5	3.00	1.03
Icon design (ID)	1	4	2.51	0.95
Use of colour and background (CB)	2	5	3.43	1.04
Layout design (LD)	1	4	2.60	0.98
Interaction (IT)	1	4	2.57	0.98

Functionality (FC)	1	4	2.66	0.94
Use of menus (UM)	1	4	2.11	0.53
Navigation and controls (NC)	1	5	2.86	1.19
Instruction and language (IL)	2	5	2.60	0.98

Table 4.6 Descriptive statistics on participants' evaluations of technology features (N = 35)

4.3.3. Usage Behaviour

The results reported a wide range of mobile technologies usage among older adults, as shown in Table 4.7. Among the 35 participants who participated in the following section of interviews, the majority of them indicated the use of both smartphones (88.6%) and tablets (62.9%) in their daily life. For this group of older adults, they have adopted the advanced mobile technology for an average duration of 1.93 years (SD = 1.67). In particular, 77.3% of them had adopted advanced mobile technologies for less than two years. As for their current usage behaviours, average usage of 0.89 hours per day (SD = 0.94) was reported by the participants. Specifically, 45.7% of the participants reported a usage of low intensity (fewer than 0.5 hours per day); 40.0% of them indicated a usage of medium intensity (0.5–2 hours per day); and 14.3% of them reported a usage of high intensity (2–5 hours per day). In addition, the participants averagely used 2.86 (SD = 1.40) functions, which include 1.97 (SD = 1.36) advanced functions. In detail, 14.3% of the participants only used some basic functions including calls, messages, the camera, the daily alarm, and the calendar. Among the remaining participants (85.7%) who have adopted the advanced functions, 36.7% of them adopted three or more functions; 33.3% of them adopted two functions simultaneously; and 30% of them used only one advanced function. Multiple usage purposes were collected including hobbies and entertainment (60.0%), social interaction (51.4%), information, learning, and education (51.4%), health care and wellness (28.6%), and some other aspects (5.7%).

	Minimum	***Maximum***	***Mean***	***SD***

Duration of use (years)	0.21	7.50	1.93	1.66
Intensity of use (hours)	0.50	31.50	0.89	0.94
Diversity of use	1	6	2.86	1.40
Adoption of advanced functions	0	5	1.97	1.36

Table 4.7 Descriptive statistics on participants' usage behaviour (N = 35)

4.3.4. User Perceptions

As shown in Table 4.8, four attributes of user perceptions were evaluated by the 5-point Likert scales and the related discussions were analysed at the same time. Among the participants, 80.0% of them reported positive attitudes towards the use of mobile technology for reasons including their willingness to learn new things and their enjoyment when playing games used mobile technology. In addition, 91.5% of them believed that mobile technologies could offer a higher degree of convenience and usefulness. Nevertheless, these beliefs were mainly influenced by their friends and family, for example, "I*t seems to be very convenient because my family members can play games and search for traffic routes using smartphones, and I also want to learn*". Some of the participants also believed that mobile technologies are useful because of the so-called social tendency, as stated such as "*It's about the tendency to chase new technologies*".

As for the participants' perceived usability of the mobile technologies, the results of self-reporting evaluations were overall lower than those for the general attitudes and perceived usefulness. Specifically, the participants indicated the lowest evaluation for the learnability of technology, followed by error prevention, memorability, efficiency, and satisfaction. Based on the results of the interview analysis, the usability problems could be explained by two aspects. Firstly, as mentioned, the technologies were generally reported as quite complicated for older adults to learn and adopt. Secondly, the participants thought the mobile technology was very difficult because of their poor memory, decreased vision, and low literacy. When they were further asked about the self-efficacy for learning and using mobile technologies, the majority of participants (85.8%) indicated a medium to high level. Nevertheless, there were also some participants who were not confident with their capability in learning and using mobile technologies due to their declined capabilities and the lack of patience.

	Minimum	*Maximum*	*Mean*	*SD*
General attitude	2	5	3.83	1.01
Perceived usefulness	2	5	4.09	0.70
Perceived usability				
Learnability	1	5	2.29	0.93
Efficiency	2	5	3.51	1.07
Error prevention	1	4	2.46	0.95
Memorability	1	5	2.54	1.15
Satisfaction	2	5	4.26	0.66
Self-efficacy	2	5	3.97	0.86

Table 4.8 Descriptive statistics on participants' user perceptions (N = 35)

4.3.5. Correlations among Variables

4.3.5.1. Within User Characteristics and Technology Features

Before the identification of factors that were related to the older adults' post-adoption usage and perceptions, the interrelationships within user characteristics and technology features were analysed by the Spearman test. As shown in Table 4.9, results reported several significant correlations, such as a moderate negative correlation between age and perceptual speed (p = 0.004), a weak positive correlation between education level and working memory (p = 0.038), a moderate positive correlation between education level and spatial ability (p = 0.002), and a high positive correlation between education level and perceptual speed (p = 0.000). Nevertheless, there was no significant correlation found between demographic factors and visual abilities.

Additionally, the correlations between the user characteristics and technology features were also analysed. The results also identified some significant correlations, such as several weak positive correlations between the evaluation of target design and VAP (p = 0.047), the evaluation of target design and education level (p = 0.048), and the evaluation of the use of graphics and VAD (p = 0.044), as well as a moderate negative correlation between the evaluation of functionality and age (p = 0.006).

	WRT (N=51)	***CDT (N=51)***	***SDMT (N=51)***	***TD (N=35)***	***UG (N=35)***	***FC (N=35)***
Age			-0.394**			-0.456**
Education level	0.292*	0.422**	0.719***	0.337*		
VAP				0.338*		
VAD					0.342*	

Note: *p < 0.05; **p < 0.01, ***p < 0.001.

Table 4.9 Significant correlation coefficients (r) for user characteristics and technology features

4.3.5.2. Within Usage Behaviour and User Perceptions

The Spearman test was employed to analyse the correlations between the factors of usage behaviour and user perceptions. A marginal and positive correlation was observed between the participants' diversity of use and their general attitude towards mobile technologies (r = 0.332; p = 0.051). Additionally, the results also found several significant positive correlations between the factors of usage behaviour and perceived usability. For example, the perceived efficiency was observed to be moderately correlated with participants' duration of use of mobile technologies (r = 0.370; p = 0.028) and the perceived memorability was found to be moderately correlated with participants' intensity of use of mobile technologies (r = 0.364; p = 0.031).

4.3.5.3. Between User Characteristics, Technology Features, and Usage Behaviour

The Spearman test was also used to identify the relationships between demographic factors and usage behaviour. The results of significant correlations are presented in Table 4.10. Several significant correlations were identified, including a moderate negative correlation between the participants' duration of use and age (p = 0.020) and a weak negative correlation between the participants' intensity of use and age (p = 0.039). In addition, a marginally significant relationship was also reported between the diversity of use and the participants' education levels. Thus, the Mann–Whitney test was used to further investigate the differences between two groups of participants with different education levels: one group with lower than high school level and one group with the level of high school and above. The results observed a significant difference in the diversity of use between these two groups (U = 78.500, p = 0.026). Specifically, it was reported that the group of participants with higher education levels used significantly more diverse use of mobile technology (mean rank = 22.960) compared with the group of participants with lower education level (mean rank = 15.070).

Regarding user capability, there were several significant correlations identified by the Spearman correlation analysis. For instance, a moderate and positive correlation was observed between the participants' intensity of use and their strength of working memory (p = 0.038). In addition, the participants' perceptual speed was found to be weakly positively correlated with their intensity of use of mobile technologies (p = 0.044), moderately positively related to their diversity of use of mobile technologies (p = 0.023) and weakly positively correlated with their adoption of advanced functions (p = 0.047). Nevertheless, the relationships between the evaluations of technology features and usage behaviour were not significant, except for the significant but weak correlations between the evaluation of functionality difficulty and duration of use (p = 0.040), as well as the evaluation of functionality difficulty and intensity of use (p = 0.039).

	Duration of use	*Intensity of use*	*Diversity of use*	*Adoption of advanced functions*
Age	-0.390*	-0.350*		
WRT		0.352*		
SDMT		0.342*	0.384*	0.338*
FC	0.348*	0.350*		

Note: *p < 0.05.

Table 4.10 Significant correlation coefficients (r) between user characteristics, technology features, and usage behaviour (N = 35)

4.3.5.4. Between User Characteristics, Technology Features, and User Perceptions

The Spearman correlation analysis was employed to examine the correlations between user characteristics, technology features, and user perceptions, specifically on the participants' general attitude, perceived usefulness, perceived usability, and self-efficacy. The significant correlations were shown in Table 4.11. Specifically, several significant correlations were observed between user perceptions and user capabilities. A moderate and positive correlation was found between the participants' perceived usefulness of mobile technologies and their VAP (p = 0.022) and a weak and positive correlation was found between the participants' perceived usefulness of mobile technologies and their VAO (p = 0.048). In addition, some significant correlations were also reported among the participants' cognitive capability, visual ability, and their perceived usability. In particular, two moderate and positive correlation was observed between the participants' perceived efficiency and their perceptual speed (p = 0.025) as well as VAP (p = 0.031), a weak and positive correlation was found between the participants' perceived memorability and their VAO (p = 0.045), and a weak and negative correlation was reported between the participants' satisfaction and their spatial ability (p = 0.044).

The results of the Spearman test also indicated significant correlations between participants' evaluations of user perceptions and technology features, with the significant results being shown in Table 4.11. However, there was no significant correlation existed between the participants' evaluations of the technology features and their general attitude, perceived usefulness, and self-efficacy; but several significant relationships were reported between their evaluations of technology features and perceived usability. Specifically, there existed two moderate and positive correlations between participants' perceived learnability and their evaluation of icon design (p = 0.012) as well as the evaluation of layout design (p = 0.022). There were also several moderate to weak positive correlations were exhibited between the participants' perceived error prevention and their evaluations of the use of colour and background (p = 0.006), use of menus (p = 0.007), use of graphics (p = 0.017), and navigation and controls (p = 0.049). In addition, the participants' perceived memorability was also found to be moderately positively related to their evaluations of navigation and controls (p = 0.004) and layout design (p = 0.019), as well as to be weakly positively related to their evaluation of instruction and language (p = 0.044).

	Perceived usefulness	***Perceived usability***				
		Learnability	Efficiency	Error prevention	Memorability	Satisfaction
CDT						-0.342*
SDMT			0.379*			
VAP	0.387*		0.366*			
VAO	0.337*				0.341*	
UG				0.402*		
ID		0.422*				
CB				0.456**		

LD		0.387*			0.394*	
UM				0.448 **		
NC				0.335*	0.478**	
IL					0.343*	

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

Table 4.11 Significant correlation coefficients (*r*) between user characteristics, technology features, and user perceptions (N = 35)

4.3.6. Factors Associated with Post-Adoption Behaviour

Four multiple regressions were developed for the usage behaviour regarding the participants' duration of use, intensity of use, diversity of use, and adoption of advanced functions; nevertheless, there was no regression model performed for the adoption of advanced functions. The final regression models that reported significant associations were presented in Table 4.12 using standardised coefficients (β). The proposed factors of user characteristics and evaluations of technology features could explain 36.1% of the variance for the participants' duration of use of mobile technologies, 24.5% of the variance for the participants' intensity of use of mobile technologies, and 11.6% of the variance for the participants' diversity of use of mobile technologies. Specifically, the results indicated that the participants' age (β = -0.489, p = 0.003) and evaluations of the use of menus (β = 0.349, p = 0.019). Participants who were older tended to use mobile technologies for a short duration, and those who evaluated the use of menus (β = 0.349, p = 0.019) more difficult tended to have a longer duration of use of mobile technologies. Also, the participants' evaluations of the technology features of functionality (β = 0.462, p = 0.007) and use of menus (β = -0.334, p = 0.043) were found to be associated with their intensity of use of mobile technologies positively and negatively respectively. Furthermore, the results also revealed a significant positive influence of the participants' capabilities of perceptual speed on their diversity of use of mobile technologies (β = 0.341, p = 0.045).

Eight multiple regressions were developed for the user perceptions regarding general attitude, perceived usefulness, five constructs of perceived usability, and self-efficacy; nevertheless, there was no regression equation performed for the participants' general attitude and the self-efficacy. Table 4.12 presents the final regression models that reported significant associations. Specifically, it was reported the VAO explained 24.0% of the variance for the participants' perceived usefulness, with a significant positive association with the dependent variable (β = 0.490, p = 0.003). The participants' evaluations of the use of menus could explain 16.9% of the variance for their perceived learnability, with a significant positive influence on the dependent variable (β = 0.411, p = 0.014). Besides, it was revealed the better VAP could predict the participants' higher evaluations of the perceived efficiency (β = 0.447, p = 0.007), which explained 20.0% for the dependent variable. Participants who had higher evaluations of the use of menus (β = 0.449, p = 0.003) and the use of colour and background (β = 0.421, p = 0.004) tended to perceive the mobile technologies as error prevention, with 40.5% of variances explained for the dependent variable. Furthermore, the participants' VAO (β = 0.343, p = 0.023) and evaluations of the navigation and controls (β = 0.540, p = 0.001) were found to positively influence their perceived memorability, which explained 35.4% of the variance for the dependent variable. Also, the participants' spatial ability could explain 11.8% of the variance for their perceived satisfaction, with a significant negative influence on the dependent variable (β = -0.334, p = 0.043).

Dependent Variable		***Independent Variable***									
		User characteristics					Technology features				
		Age	SDMT	CDT	VAP	VAO	CB	FC	UM	NC	R^2
Usage Behaviour	Duration of use	-0.489**							0.349*		0.361
	Intensity of use							0.462**	-0.334*		0.245
	Diversity of use		0.341*								0.116
User Perceptions	Perceived usefulness					0.490**					0.240
	Perceived usability										
	Learnability								0.411*		0.169
	Efficiency				0.447**						0.200
	Error prevention						0.421**		0.449**		0.405
	Memorability					0.343*				0.540**	0.354
	Satisfaction			-0.344*							0.118

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

Table 4.12 Standardised coefficients of stepwise regression analysis concerning usage behaviour and user perceptions (N = 35)

4.3.7. Other Findings from the Interviews

During the discussion, the facilitators and barriers that mentioned by the participants were also collected and classified into six topics: lifestyle, personal concerns, expected benefits of technology, concerns regarding technology, social influences, and facilitating conditions (Peek et al., 2014). As shown in Table 4.13, the facilitators for the adoption of mobile technologies or applications were frequently reported including the positive lifestyle, interests in technology, perceived benefits influenced by others' or personal experience, and the obvious improvements of technology. Specifically, the desire for being independent and persuasion from families and friends can encourage older adults to adopt mobile technologies. Some related comments are stated as follows: "*Once I learned more about the mobile technologies, I could search for information by myself and no longer bother my daughter*" and "*My grandchildren persuaded me to use this mobile application so that they can send me pictures*".

Older adults had much more concerns and barriers during the adoption of mobile technologies. Some of the comments are discussed in the preceding sections, which were related to such topics as fewer expectations for the applicability of technologies in their daily life, the beliefs of being too old to learn, concerns about their declined capabilities and poor literacy, as well as the perceived difficulties with various technology features. Some interesting points were highlighted by these findings. For example, too much pressure from the families and friends may hamper older adults' intention of adoption with mobile technologies. The older adults may easily be frustrated especially when their families are too impatient to teach them. In such cases, it was found that the group of older men tended to be hesitant to talk about their difficulties and ask for help than the group of females. Some comments are stated as follows: "*Sometimes I asked my son to help me. I felt frustrated when he was impatient*", "*I felt embarrassed if I asked a lot of questions. Gradually, I lost interest*", and "*I feel annoyed because all of my family members asked me to learn how to use a smartphone*". Additionally, there were several participants who thought the use of mobile technologies might be harmful to their health, such as the eye dryness that caused by the long-term use of digital screens.

Categories	***Facilitators highlighted from the study***	***Barriers highlighted from the study***
Lifestyle	Open-minded towards new things; Following the trend	Satisfied with the current situation; Hesitant to ask for help
Personal concerns	Interests in technology	Too old to learn; Declined capabilities; Low-literacy
Benefits expected of technology	Expected benefits based on personal and others' experience; Increased independence	Negative effects on health
Concerns regarding technology	Obvious improvements of technologies;	Perceived complexity of technology features The possibility of making mistakes and recovery issues
Social influence	Influence of families and friends	Excessive pressure from familiars and friends
Facilitating conditions	Needs of independence from others; Instructions from families and friends	The impatient attitude of others No instructions from others

Table 4.13 Additional findings from the interviews

4.4. Discussion

4.4.1. Mobile Technology Usage Behaviour

This study reports a wide use of advanced mobile technology among older adults in Hong Kong. Smartphones and tablets are the two major mobile technologies used in their daily life. Though the majority of the older adults were still in an early adoption stage with less than two years' experience, most of them had adopted the usage of advanced functions. Furthermore, older adults are aware of the various opportunities in improving their quality of life brought by the mobile technologies, including communication, entertainment, and learning. This finding is partly agreed with some of the previous studies on everyday technologies (Mitzner et al., 2010; Chen and Chan, 2014), which reported that older adults were willing to use technologies for a wide range of purposes such as for home, work, and health. However, the findings did not conform to the usage pattern of the traditional feature phones (Renaud and Van Biljon, 2008), which is found to be limited to a minimal set of functions. This may be resulted from the simple interaction mode, high mobility and improved security brought by the advanced mobile technologies, which largely facilitate the use of mobile technologies among older adults. In addition, the social influences, specifically the pressure from families and friends, can also influence older adults' adopt of mobile technologies in the objectification stage (Venkatesh et al., 2003; Renaud and Van Biljon, 2008). Nonetheless, when comparing with the younger users who have embraced mobile technologies enthusiastically, the older adults did not spend as much time and did use fewer kinds of advanced functions when using mobile technologies. Therefore, there still exists a necessity to investigate the possible factors that involved in older adults' post-adoption behaviour.

Specifically, the role of user characteristics was examined in the current study. Though the STAM model only includes the factors of user context in the objectification phase, the impacts of user characteristics were also identified in the stage of post-adoption by the present study. It was reported that age was negatively associated with the participants' duration of use of mobile technologies and negatively correlated with the participants' intensity of use of mobile technologies at the same time. Furthermore, the participants' diversity of use of mobile technologies was reported to be positively correlated with their education levels, which may be explained that the older adults with higher education levels tend to be more motivated when accepting new concepts (Pan and Jordan-Marsh, 2010; Chen and Chen, 2014). Additionally, the findings are agreed with some of the previous studies, which suggested that the higher fluid and crystallized intelligence might lead to a broader range of technology use (Czaja et al., 2006; Werner et al., 2011; Chen and Chan, 2014). For example, the results indicated that the declined cognitive capabilities, such as the working memory and perceptual speed, might inhibit older adults from frequently using mobile technologies. Besides, the participants' declined perceptual speed could negatively influence their diversity of use of mobile technologies, therefore slowing the progression from initial adoption to upgraded usage behaviour.

Although the previous studies have extensively examined the technology features that may influence the usability for older adults by interviews and focus groups with users and designers (Kurniawan and Zaphiris, 2005; Zaphiris et al., 2007), the guidelines derived from these studies may be too broad for the designers to apply during the design process. Designers may concern more about which are the critical features rather than applying all the relevant guidelines. Thus this study investigated the correlations and associations between the participants' evaluations of various technology features and their usage behaviour, to identify the most critical technology features that influenced older adults' post-adoption use of mobile technologies. The findings revealed that the participants' evaluations of the functionality were particularly influential on their duration and intensity of use of mobile technologies. For instance, the older adults who thought they could easily access or switch between different functions tend to use mobile technologies for a longer duration and in a higher frequency. Also, the evaluations of the use of menus also matter, that the older adults who believe the menus are easier to find tend to use the mobile technologies for a longer duration. Nevertheless, they may try more times of the menus are difficult to access since the menus are an unavoidable feature of mobile technology usage. Therefore to conclude, when designing the mobile technologies for older adults, the technology features that related to mobile navigation including functionality and use of menus are particularly important for the designers and practitioners.

4.4.2. Mobile Technology User Perceptions

Stereotypically, older adults are reported as negatively biased towards technology, thus tend not to the advanced technologies (Saunders, 2004; Cazja et al., 2006;). Nonetheless, the results from this study presented relatively positive attitudes towards the mobile technologies among the older adults. Consistent with some previous studies, it was found that older adults with an active lifestyle tend to positively embrace technology acceptance (Werner et al., 2011). For example, several participants reported that they enjoyed learning new applications and playing games using their smartphone. To a large extent, the participants have perceived the usefulness and benefits brought by the advanced mobile technologies, either according to their own usage experience or through the observations of others' usage experience. Nevertheless, some of the participants were occasionally frustrated with mobile technology because it was very complicated and easily damaged. In addition, this study found that older males were not as positive as older females for the use of mobile technologies. This may be explained that the Chinese older males are resistant to learning new things and unwilling to ask for help than the older females (Zhou et al., 2014). Together with the results of some previous studies (Mitzner et al., 2010; Goddard and Nicolle, 2012), it was suggested that the majority of older adults were neither unable nor unwilling to use advanced technologies. Instead, they were considerably interested in and had positive attitudes towards technology use; nonetheless, they reported that some of the features of mobile technologies are not suitably designed for their capabilities and requirements. Thus, further investigation was performed to understand the factors that influenced older adults' perceptions of the post-adoption use of mobile technologies, from the perspectives of user characteristics and technology features.

Although the majority of older adults indicated normal visions with the corrective lenses, the negative effects of the long-term wearing of corrective lenses need to be considered. First, the results indicated that the declines in vision perceptions could largely hamper the older adults' perceived usefulness of mobile technologies; nevertheless, others' positive experiences can help in improving older adults' awareness of the usefulness brought by the mobile technologies. Nonetheless, consistent with the previous studies (Chen and Chan, 2014), there was no significant relationship found between the older adults' age-related decline in capabilities and their general attitudes as well as self-efficacy. The reason may lie in the general enthusiasm for the mobile technology use among Hong Kong older adults in recent years.

As for the perceived usefulness, this study provides insights to older adults' perceived usability based on five constructs: learnability, efficiency, error prevention, memorability, and satisfaction. The results supplement more details for the previous studies that suggested the perceived ease of use as an influential factor in technology acceptance (Arning and Ziefle, 2007), specifically for the progression from the usage to the conversion phases in the STAM (Renaud and Van Biljon, 2008). Overall, the majority of the older adults indicated difficulties to some extents in their post-adoption behaviour, implying that the current mobile technologies are still not sufficiently inclusive. Specifically, the results showed that the obstacles to learnability, error prevention, and memorability were the most substantial difficulties pertaining to the adoption of mobile technologies. The learning process is especially problematic because the older adults tend to be cautious about their operations when using technologies and seldom use the trial-and-error strategy when learning. Nevertheless, the older adults in the current study reported high levels of perceived efficiency and satisfaction once they were familiar with the use of mobile technologies.

It was found that the age-related capability declines were significantly associated with the older adults' perceived usability of mobile technologies. The results are agreed with previous studies that have shown the cognitive and physical to be important predictors for the usage of general technologies (Werner et al., 2011; Gell et al., 2013; Chen and Chan, 2014). In this study, the older adults' perceived efficiency and memorability of mobile technologies were found to be decreased by the declines of their VAP and VAO, respectively. Their perceived efficiency of mobile technologies may also be harmed by the declined perceptual speed as revealed by these two being positively correlated. However, diminished spatial ability was negatively associated with the participants' level of satisfaction, which could be interesting to explore in further studies. This negative association may be attributable to the two aspects. On the one hand, the older adults' subjective feelings, such as satisfaction, strongly varied between individuals, which may be mediated by other factors (Wagner et al., 2014). On the other hand, the results of the CDT are mainly sensitive to the severe decline of spatial ability; thus the scores become dichotomous and may not completely reflect the trend of declines in spatial ability.

The process of learning is a vital phase when moving from the incorporation stage to the conversion stage for the older adults (Barnard et al., 2013). They only adopt mobile technology when the perceived usefulness of using the technology outweighs the perceived difficulties of learning the technology. Regarding the obstacles that may prevent the adoption process, this study suggested the lowest evaluations of technology features were related to the use of menus and icon design; specifically, the use of pull-down was particularly problematic. It was also indicated that participants' evaluations of various technology features were significantly associated with their perceived usability. For instance, the older adults' perceived difficulties for learning were found to be significantly correlated with the icon design and layout design. If designers aim to prevent the system errors, the use of colours, menus, graphics, and design of the navigation and controls need to be carefully considered since the evaluations of these technology features can significantly influence the older adults' perceived error prevention. In addition, to improve the memorability of mobile technologies, designers must pay more attention to the design of navigation and controls, layout, as well as the instructions and language, because the participants' evaluations of these features were significantly associated or correlated with their perceived memorability.

4.5. Summary

This study obtained a unique perspective of older adults' post-adoption usage and perceptions of mobile technologies. Specifically, this phase of post-adoption corresponds with the incorporation and conversion stages addressed by the STAM. It was found that older adults' demographic factor of age, the ability of perceptual speed and technology features of functionality and menus significantly influence older adults' post-adoption usage behaviour with mobile technologies. Older adults' visual perceptions, spatial ability and technology features including the use of menu, colour and background and navigation and controls were found to significantly influence their perceived usefulness and various aspects of perceived usability with mobile technologies.

Overall, this chapter yields a comprehensive understanding of the relationships between user, task and system design within older adults' post-adoption usage and perceptions regarding mobile technologies. It also provides a theoretical basis to develop further design guidelines or user models to encourage a continued and upgraded adoption of mobile technologies among older adults. The results of this study also assist in narrowing the research scope. Technology features related to mobile navigation, such as the use of menus, switching between functions and navigation and controls were selected to study in-depth because they significantly influence older adults' post-adoption usage and perceptions of mobile technologies.

As this study aims to collect more data from older adults' realistic usage with mobile technologies, there does exist a lack of investigation into the specific challenges that the current interface designs introduce for older adults, especially those related to mobile navigation. This will be examined through the usability study described in Chapter 5. The detailed experimental investigations that examine the relationships between the user, task and system design are presented in Chapter 6 and Chapter 7 within the context of technology features related to mobile navigation.

CHAPTER 5 Study Two: Investigating Older Adults' Usability Challenges while Navigating Various Mobile Interfaces

5.1. Introduction

In Chapter 4, technology features related to mobile navigation were identified as significant factors that affect older adults' post-adoption usage and perceptions regarding mobile technologies. Nevertheless, previous research did not provide sufficient evidence about how older adults navigate various mobile interfaces and the challenges they face while navigating (Punchoojit and Hongwarittorrn, 2017). Without knowing which navigation design patterns are intuitive and easier to use for older adults, designers and practitioners may be confused and struggle when faced with many possible design solutions. Thus, this chapter investigates older adults' navigation behaviour with various design patterns and identifies potential usability issues for older adults while navigating. It addresses the research question Q4 inquiring about the advantages and drawbacks of current mobile navigation UI design by answering the following sub-questions: first, it addresses how current mobile navigation UI designs support or diminish older adults' navigation behaviour and usage habits; second, it identifies potential usability challenges older adults face when navigating various mobile UIs; third, it examines how older adults feel and evaluate various mobile navigation UI designs.

One of the traditional methods of retrieving information and functions on websites or applications is navigation by menus (Garrett, 2010). Older adults tend to encounter difficulties in understanding how menu items are spatially structured due to their declined spatial abilities; therefore, they can easily experience disorientation when menu structures are deep and nested (Downing et al., 2005; Ziefle and Bay, 2006; Kim et al., 2007; Ziefle et al., 2007). In addition to menus, the content itself also creates hierarchies and focuses to help users filter and process information on websites and applications (Hoehle and Venkatesh, 2015; Punchoojit and Hongwarittorrn, 2017). Older adults have been found to perform better at content-oriented seeking than menu-oriented seeking because they maintain a stable, crystallised intelligence and reading comprehension in content searching (Etcheverry et al., 2012a, 2012b) but suffer from declined capabilities of decision-making, visual processing and working memory with menu navigation (DeStefano and LeFevre, 2007). Thus, content-oriented navigation provides a new opportunity to improve older adults' mobile navigation behaviour, but the effectiveness and usability of relevant design patterns are seldom examined.

Correspondingly, this study summarised six of the most widely employed mobile navigation UI designs to conduct studies of usability testing and follow-up interviews for older adults. According to the amount of content attached to each menu item, these UI designs were categorised into menu-oriented navigation design patterns or content-oriented navigation design patterns (Tidwell, 2010; Neil, 2014), as mentioned in Section 2.4.3.1. Typical menu-oriented menus include a tab menu, sider drawer and springboard and act as hyperlinks and buttons (see Table 2.2). The content-oriented navigation design may work better for navigation items with more content adhered (see Table 2.3). For example, lists and grids can display information in a repeated pattern arranged in a vertical or horizontal layout, and cards present more content and enable interactions such as flipping and stacking.

5.2. Method

5.2.1. Participants

To gain an in-depth understanding of older adult' post-adoption usage and perceptions of mobile technologies, Hong Kong Chinese adults who aged above 55 years old and resided in domestic households were recruited in this study. All the participants have been used mobile technologies and applications. They were recruited from the local elderly centres by verbal advertisement and leaflet.

5.2.2. Study Design and Materials

This study was conducted in the quiet meeting rooms at the local elderly centres. It was comprised of a usability testing and the following interview. The six navigation patterns that mentioned above were utilised for the usability testing, which was conducted on a Samsung smartphone (Galaxy C7 Pro) with a resolution of 1080×1920 pixels. An in-depth interview was then implemented after the usability testing, to further understand the older adults' challenge and the behind reasons when navigating with these interfaces.

5.2.2.1. Design patterns

Since this study was a pioneering work in examining older adult' mobile navigation behaviour, it mainly focused on exploring the specific usability challenges that older adults may encounter in the naturalistic usage scenarios instead of comparing their navigation performances between different design patterns. Thus the existing mobile applications were determined to be chosen for the usability testing. Three existing mobile applications were selected based on two standards: first, the applications were chosen to include the six abovementioned design patterns for the menu- and content-oriented navigation; also, the applications were selected from the most widely used ones among the Hong Kong older adults (Li and Luximon, 2016). Specifically, the testing applications included a social networking application named 'WhatsApp', a local media and entertainment application named 'myTV SUPER', and a news application named 'Flipboard'.

These applications were firstly analysed according to the design patterns involved in each other, which was marked from pattern [1] to pattern [18], as shown in Figure 5.1-5.3. There were at least two levels of hierarchy contained by each application: a primary navigation pattern and several secondary navigation patterns. As shown in Figure 5.1, the application of WhatsApp employed the tab menu that had three text buttons and placed at the top of the screen as its primary navigation pattern and the lists that presented the information summary in a vertical fashion as the secondary navigation patterns. In addition, there were several assisted navigation buttons arranged in the upper and lower parts of the screen, such as the buttons for searching, starting a new dialogue and launching additional functions. For the application of myTV SUPER, it has two primary navigation patterns including a scrolling tab and a sider drawer, as well as several secondary navigation patterns including the lists, gallery, and springboard, as shown in Figure 5.2. Specifically, the tab could be scrolled horizontally, and the sider drawer, lists, galleries and springboard could be scrolled vertically in either direction. It also had some assisted navigation buttons such as keyword searching, adding to favourites, and hamburger button for the sider drawer, which were located at the top part on the screen. In addition, the application of Flipboard has a primary navigation pattern of scrolling tabs that can be slide horizontally and a secondary navigation pattern of stacked cards that can be flipped up and down, with several assisted navigation buttons of adding to favourites and keywords searching that were located at the top of the interface (see Figure 5.3).

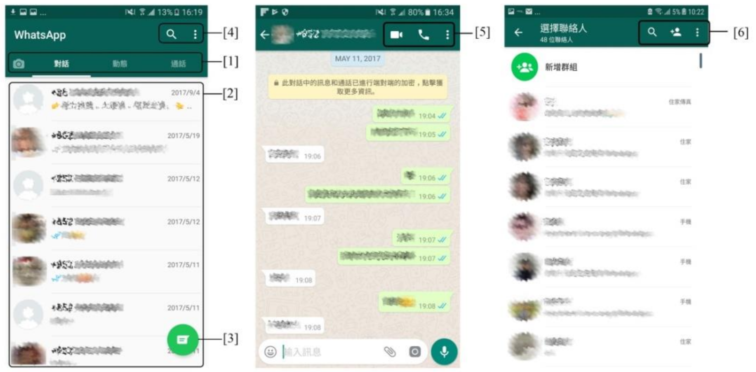


Figure 5.1 Design patterns of WhatsApp: [1] tab menu; [2] lists; [3] [4] [5] [6] assisted navigation buttons

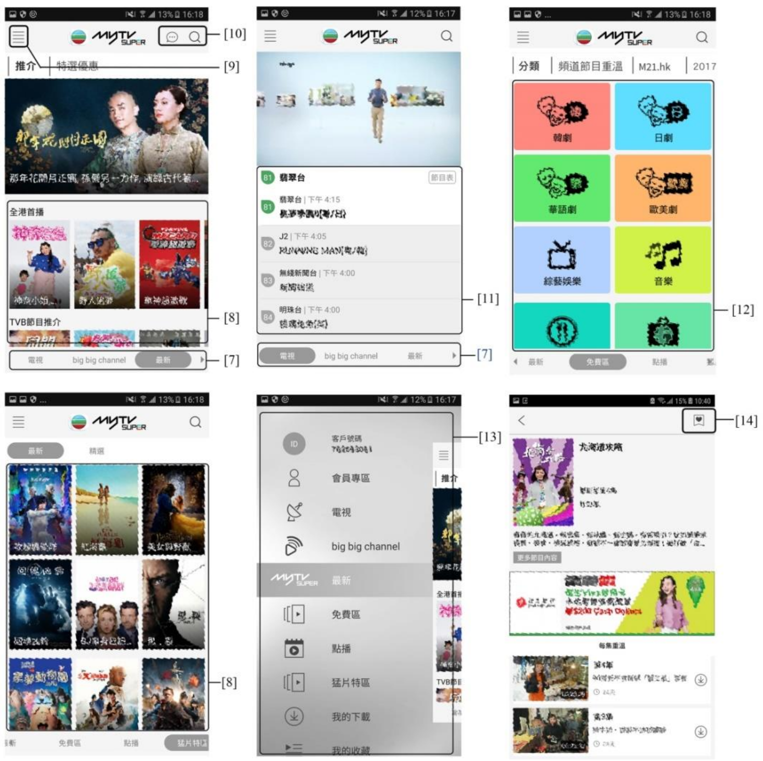


Figure 5.2 Design patterns of myTV SUPER: [7] tab menu; [8] gallery; [9] entry-point of sider drawer; [10] [14] assisted navigation buttons; [11] lists; [12] springboard; [13] sider drawer

Figure 5.3 Design patterns of Flipboard: [15] tab menu; [16] cards; [17] assisted navigation buttons; [18] lists

5.2.2.2. Tasks

In the usability testing, the participants were asked to conduct 19 tasks that were included in the routine usage of these applications. The task scenarios are described in Table 5.1, with the design patterns that involved in each task listed accordingly. For instance, the five navigation tasks for the application of WhatsApp were dialogue browsing, voice chatting, keyword searching, call log searching, and initiating contact with a new friend. The seven navigation tasks for the application of myTV SUPER included TV station searching, TV show searching, program searching, movie searching, keyword searching, playlist searching and adding favourites. In addition, the seven navigation tasks using Flipboard included travel article searching, design article searching, food article searching, adding favourites, cover story browsing, article sharing, and adding a new category. Participants were able to navigate the interfaces freely with the task objectives kept in their minds, without any time limitation.

Application	*No.*	*Task Description*	*Design patterns*
WhatsApp	1	Browse the dialogue lists and find the historical dialogue with one contact named 'Kayan'	[2]
	2	Initiate a voice conversation with Kayan	[5]
	3	Search for a dialogue that included the keyword 'happy birthday'	[4]
	4	Search for the video call log with one contact named 'Yao'	[1]
	5	Create a new contact named 'Li, 123456' and initiate a dialogue with him	[3] [6]
myTV SUPER	6	Search for a TV station named TVB Pearl under the category of 'TV'	[7] [11] or [9] [13] [11]
	7	Search for a TV show named 'Triumph In The Skies' under the category of 'new'	[7] [8] or [9] [13] [8]
	8	Search for a diet program named 'food and life' under the category of 'free zone'	[7] [12] [8] or [9] [13] [12] [13]
	9	Search for a movie named 'Beauty and the Beast' under the category of 'quality movies'	[7] [8] or [9] [13] [8]
	10	Add the movie as mentioned above to the favourites	[14]
	11	Search for a show whose name included a keyword 'Victoria'	[10]
	12	Find the movie that just added to the favourites in the 'playlist'	[9] [13]
Flipboard	13	Search for an article that introduces Hong Kong Tourism under the category of 'tourism'	[15] [16]
	14	Search for an article that introduces Asia design under the category of 'design'	[15] [16]
	15	Search for an article that introduces Chinese food under the category of 'food'	[15] [16]
	16	Add the article as mentioned above to the favourites	[17]
	17	Search for an article that introduces the football match under the category of 'sports'	[15] [16]
	18	Share the article as mentioned above to WhatsApp friend	[17]
	19	Add a new category of 'advanced technology'	[18]

Table 5.1 Task scenarios for usability testing.

5.2.2.3. Interviews

After completing the tasks for each application, participants were instructed to describe the problems and challenges they encountered when navigating with the interfaces by a follow-up interview. The interview was conducted to further identify the usability issues behind these interaction challenges, especially those related to the six kinds of design patterns. Since there was a possibility of lacking details when using the method of self-reporting, a usability checklist was developed according to the established usability principles and guidelines. These usability checkpoints were mainly collected from the previous mobile UI guidelines specifically for older adults (Hoehle et al., 2016; de Barros et al., 2014; Mi et al. 2014; Al-Razgan et al. 2012; Ji et al. 2006) and were then supplemented by some critical points that exacted from the desktop usability guidelines for older adults (Patsoule and Koutsabasis 2014; Zaphiris et al., 2007), as mentioned in Section 2.5.1.1. These usability principles were selected based on whether they have possible impacts on older adults' mobile navigation behaviour, with the redundant ones removed and similar ones combined. In total, 25 principles that related to the interface navigation were summarised, as shown in Table 5.2

Three major usability aspects were covered in the usability checklist. Specifically, the principle of visual design required that the navigation components such as menu items and content organisation need to be visible and clear to guide to interface navigation. Ease of use means that the presentation of these navigation components such as menu items and content organization should be easily understandable regardless of the users' technological experience, knowledge level and reading ability. Besides, the principle of navigation and interaction means that the navigation components and content organisation should provide a clear cue to inform users about their current position and historical path, employ easy and straightforward interaction techniques, as well as provide appreciable feedbacks. During the interview, questions were elaborated based on each of the usability principles addressed in the checklist, by showing the participants of the relevant design patterns in the application that they just finished using. In the end, the participants were also asked to evaluate their personal preferences of these design patterns by comparing various design patterns used in the same application and across various applications.

Principles	***Items***	***Description***
Visual Design	V1	Use visible and large icons and buttons for menu components
	V2	Use visible and readable texts for the content
	V3	Use clear and large titles for content
	V4	Use properly and standout designed colour, texture and graphics for the menus components
	V5	Use properly chosen colour and graphics for the content and its background
	V6	Provide enough blank space between each of the menu component
	V7	Provide enough blank space between each part of the content
Ease of understandin g	E1	Design simple and meaningful icons
	E2	Use simple and understandable language for menus.
	E3	Use simple and understandable language for content.
	E4	Provide a proper number of components for the menu, not too many or too less.
	E5	Provide a proper length for each paragraph and section.
	E6	Use images that are relevant to the content, with text explanation.
	E7	Provide a consistent way of content presentation and information organization across one application.
	E8	Show the content in a hierarchical way of importance.
Navigation and interaction	N1	Place the main menus and assisted navigation buttons in proper positions of the screen that are immediately obvious and can prevent mistaken touching
	N2	Provide always existing controlled navigation, such as returning and home screen buttons, to make sure that the users could return to the previous interfaces or home screen to restart the task at any time.
	N3	Make sure that the menu hierarchy is not too deep to prevent the users feeling lost and confused.
	N4	Group the information and content in meaningful categories.
	N6	Use simple interaction gestures that users can easily interact with when navigation
	N7	Provide clear and appropriate feedbacks to immediately indicate changes caused by operations, such as interface switching or button tapping
	N8	Provide users with indications or cues of her/his exact location of the current interface
	N9	Offer tutorials on the major navigation path at the beginning when users were starting to use the application.
	N10	Provide sufficient visual cues to inform the user about the interactive mode of

		menus and content
Support for habits	H1	Consider the specific using habit among elderly users.

Table 5.2 Checklist for usability testing.

5.2.3. Procedure

Before the experiment, the detailed instructions were provided for the participants to make sure that the participants were familiar with the operations and interfaces of these applications. After that, participants were given sufficient time to familiarise the three applications by themselves. When the usability testing started, the participants were required to conduct the 19 tasks that described in Table 5.1 using the three applications. The following interview was then carried out after the completion of tasks using each application. Participants were asked to describe the problems and challenges they encountered when navigating with various interfaces of these applications. The whole usability testing lasted 1.5 hours approximately for each participant. All the interactions during the usability testing and the discussions in the interviews were voice and video recorded, supplemented by the field notes taken by the researchers.

5.2.4. Data Processing and Analysis

There were around 30 hours of video data generated from the usability testing and interviews. The data of video, voice records, and transcripts were compiled together in chronological order. Firstly, the activity analysis was employed to process the video data and the Atlas.ti software was used to analyse the interview transcripts. The completion level of each task was analysed at an action level, and the usability challenges when using various design patterns were identified by the activity analysis. Then, the reasons for these usability challenges were compared with the established usability principles outlined in the usability checklists of Table 5.2 one by one and further interpreted by the results of the interview analysis. For some usability issues that cannot be ascribed to present principles, this study summarised the possible problems and developed some additional principles, which are described in the section of results.

5.2.4.1. Activity Analysis

The method of structural activity analysis was employed in this study to analyse the video data of the usability testing by classifying the discrete actions happened in each task. The goal, object, and tools that involved in each action were also identified (Harris, 2004; Bedny and Karwowski, 2004) at the same time. A discrete action was characterised by a motor action like clicking an assisted navigation button or scrolling the interface. Figure 5.4 presents an example of the activity analysis for the task 13 for one participant. It showed that there were two actions happened to complete the task goal. For each action, there was an internal goal (e.g., searching for the category), an object on the interface (e.g. text button) and a tool that mediated the action (e.g., tab button).

It also draws on Bødker’s (1996) method for video data analysis, which emphasizes two concepts: breakdown and focus shift. Specifically, the breakdown occurs when an action is disrupted by an unanticipated divergence between the actual results and projected goals, which is highly indicative of usability issues and can be easily identified by the video data and (Harris, 2004). Thus, this concept was employed in this study to detect the usability challenges, as shown in Figure 5.4. Instead of measuring the specific performance data such as success rate or completion time, it analysed participants' action performance according to whether there was breakdown detected, in other words, usability challenges, during the process. For each action, it examined the participants' action performance in three completion levels: (a) successful action without usability challenges; (b) action with usability challenges that users managed to overcome; (c) action with usability challenges that users failed to overcome.

5.2.4.2. Interview Analysis

In the end, transcripts for the in-depth interviews were analysed according to the 25 usability principles outlined in the checklist using the Atalas.ti software, for mentions of visual design, ease of understanding, navigation and interaction of the assisted navigation buttons, menus, and content. The interview results were then analysed and integrated with activity analysis, as shown in Figure 5.4. In particular, the causes of the detected usability problems were ascribed to the failures of applying corresponding usability principles that addressed by the checklist. The reasons behind these usability challenges were further explained by the interview analysis, as quoted in the rightmost column of Figure 5.4. Additionally, those usability challenges that were not mentioned by the established guidelines were also analysed, with the additional principles summarised and added to the initial checklist.

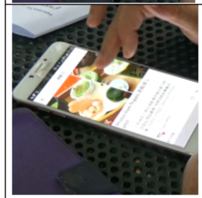
Screen Image	Action	Time	Narrative	Screen Action	Goal	Object	Tool	Usability challenges and cause of problems	Corresponding quote from interview transcript
	12-1	1:02:24-1:02:27	M: Please find the magazine category of Travelling. 10: Travelling… Here it is.	Successfully clicked the tab button at the top of screen	Searching and clicking the targeted tab button	Text button	Tab button	No issue detected	*'the font of the tab menu is large enough for me'; 'it is very easy to notice'*
	12-2	01:02:27-01:05:00	M: Let us find an article about travelling in Taiwan. 10: Here it is. M: There may be more articles inside. 10: I don't think so. M: Maybe you can find travelling first. 10: (switching the tab) M: How can we find more articles about Taiwan? Maybe you can try to flip this page. 10: (flipping the content) This is talking about Taiwan? M: Okay.	1. Participant 10 selected the content display by clicking the "more" button at the upper right corner of content. 2. Participant 10 flipped about 3 pages of content and clicked the "category" button at the upper part of content display. 3. M reminded her to flip more articles. Participant 10 returned to the content page and flipped 3-5 pages forward and backward twice. The task failed.	Flipping content pages	Content	Touchable interface areas of content display	N6: Novice users were very cautious about flipping too many pages because they did not know the pages' location. The interface did not provide appropriate location cues. Others: The gesture of "flipping" was difficult for novice users to understand.	'*I didn't know there were still many pages behind'; 'I'm afraid to lose previous pages*'

Figure 5.4 Frequency of actions observed with different completion levels and associated usability principles for content-oriented design patterns

5.3. Results and Discussions

5.3.1. Description of Participants

Twenty two Hong Kong Chinese older adults participated in this study with an average age of 71.05 years old (age range: 60 to 84 years old; SD= 7.09 years). In addition, they had an average education experience of 8.55 years (SD=3.20), from the level of primary school, secondary school and above college. The age and education distribution are shown in Table 5.3. Particularly, all of the participants reported they were in good physical and cognitive health without any impairment.

	Frequency	*Percentage (%)*
Age (years)		
60-64	3	13.6
65-69	7	31.8
70-74	4	18.2
75-79	5	22.7
80-84	3	13.6
Mean	71.05	
SD	7.09	
Education (years)		
Primary school (1-6)	7	31.8
Secondary school (7-12)8-15	14	63.6
Above college (13-14)16-17	1	4.5
Mean	8.55	
SD	3.20	

Table 5.3 Participants' age and education distribution (N=22)

Participants' technology experiences were described in Table 5.4. Averagely, the participants had adopted advanced mobile technologies such as smartphones and tablets for 3.80 years (SD=1.96) and reported usage of 14.25 hours per week (SD=5.66). Among them, 68.2% of the participants had the experience with computers, with an average duration of 4.90 years (SD=5.87) and an average number of 4.95 kinds of mobile functions used (SD= 1.05). Besides, the results showed that the majority of participants (45.5%) thought they were at a medium level of competence when using the mobile technologies, followed by those who were at a relatively good level (31.8%) and relatively poor level (22.7%).

	Minimum	*Maximum*	*Mean*	*SD*
Duration of use of computers (years)	0	20	4.91	5.87
Duration of use of mobile technologies (years)	0.25	7.50	3.80	1.96
Intensity of use of mobile technologies (hours/week)	7.00	24.50	24.50	14.25
Diversity of use of mobile technologies	2	7	4.95	1.05
Self- efficacy with mobile technologies*	2	4	3.10	0.75

*Likert scale: 1- very bad; 2- bad; 3- Medium; 4- good; 5- very good.

Table 5.4 Descriptive statistic on technology experience (N=22)

5.3.2. Summary of Usability Testing

Overall, 1002 actions were collected from the entire usability testing for 19 tasks among 22 participants. This study clustered all the actions into categories based on their interaction techniques such as clicking, scrolling and flipping, tools that mediated the actions such as lists, tabs, side menus, springboards, cards, gallery and other assisted navigation buttons, and types of mobile application. In total, 30 distinct action categories were identified, which was marked as action ID ranging from 1 to 30. Table 5.5 shows the annotation schema, with the design patterns that involved in each action outlined in the before columns.

For the actions of level B and level C, which were happened with breakdowns, this study analysed the reasons behind these challenges and tried to explain these issues through the usability principles mentioned in Section 2.5.1.1 (Table 2.5). Those usability issues that could not be ascribed to the existing checklists were also marked and analysed. Summarising, there were four additional principles abstracted from this study, with one principle for the topic on visual design, one principle for the topic on ease of understanding, and two principles on the topics of navigation and interaction (see Table 5.6). Finally, the participants' comments were further collected and analysed to interpret the results of activity analysis.

			WhatsApp		*myTV SUPER*		*Flipboard*	
Design patterns		***Interaction techniques***	***Pattern type***	***Action ID***	***Pattern type***	***Action ID***	***Pattern type***	***Action ID***
Menu-oriented	Tab menu	Tab clicking	[1]	1	[7]	2	[15]	3
		Tab scrolling			[7]	4	[15]	5
	Springboard	Springboard scrolling			[12]	6		
		Springboard selection			[12]	7		
	Sider drawer	Entry-point clicking of sider drawer			[9]	8		
		Sider drawer menu scrolling			[13]	9		
		Sider drawer menu selection			[13]	10		
Content-oriented	List	List scrolling	[2]	11	[11]	12		
		List clicking	[2]	13	[11]	14	[18]	15
	Gallery	Gallery scrolling			[12]	16		
		Gallery clicking			[12]	17		
	Card	Card flipping					[16]	18
Assisted navigation buttons	Button	Voice chatting	[5]	19				
		Keyword searching	[4]	20	[10]	21		
		Starting a new dialogue	[3]	22				
		Adding new friends	[6]	23				
		Adding to favourite			[14]	24	[17]	25
		Sharing					[17]	26

Table 5.5 Activity analysis annotation schema for actions in navigation activities.

Principles	*Items*	*Description*
Visual design	V8	Provide obvious distinction between the touchable and non-touchable text and icons
Ease of understanding	E9	Use distinctive titles for content to prevent confusion with others
Navigation and interaction	N11	Reduce the number of dominant menus used in the same application to prevent confusion
	N12	Avoid the use of multiple interaction gestures in the same interface

Table 5.6 Additional usability principles based on activity analysis.

5.3.3. Menu-Oriented Design Patterns

The analysis for menu-oriented design is shown in Table 5.7. The results presented the number of actions collected, percentages of three levels of action performance, as well as associated principles that behind these usability challenges. Regarding selecting tab menus using WhatsApp (Action 1, Pattern [1]), there were 58.6% of actions occurring with usability issues that participants managed to overcome, and there were 10.3% of actions happening with usability challenges that participants failed to overcome. The results of activity analysis indicated that these difficulties and failures occurred when participants were looking for the text tab of 'calls'. According to the interview analysis, problems may be because of the violation of Principle V1 and N1, that tab menus were not noticeable enough. Specifically, instead of paying attention to the upper tabs, 8 participants first scrolled the content lists under the tabs. Another reason was that of the participants' old habits (Principle H1). For instance, there were two participants who tried to search for the tab of 'calls' by clicking some shortcut buttons including 'finding more' or 'searching', because they were more familiar with these buttons. When selecting the tab menus in myTV SUPER (Action 2, Pattern [7]), it was found that 23.0% of actions happening with usability issues, and 1.4% of actions occurring with complete failures. Challenges mainly occurred due to the similar reason mentioned above

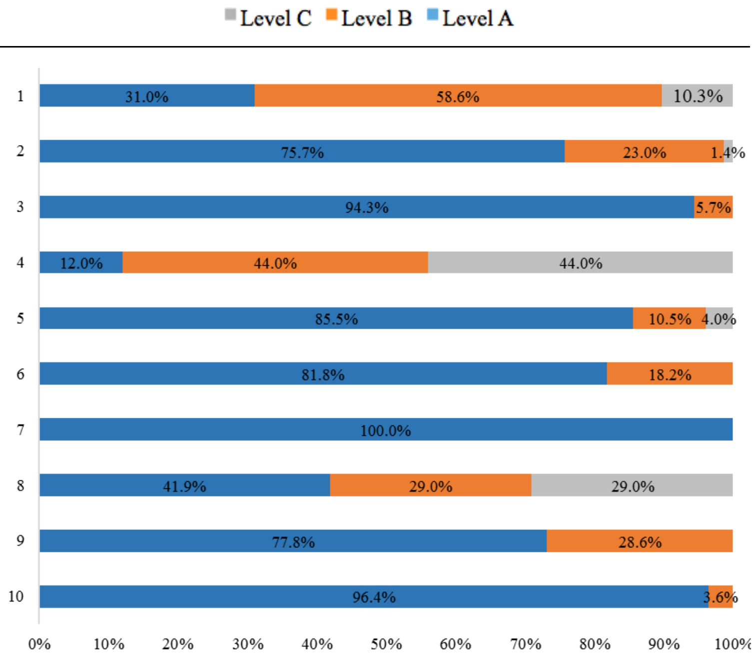
(Principle V1 and N1), when 9 participants scrolled galleries rather than noticing the tab menus at first. Difficulties were also frequently detected when participants clicked the tab buttons, that two participants could not precisely tap the targeted button (Principle V1 and V6). As for the tab menus selecting using Flipboard (Action 3, Pattern [15]), nearly all of the actions (94.3%) were performed successfully by the participants. Only two participants reported difficulties when finding the targeted tab buttons, because of the reason of habits (Principle H1), e.g., using shortcut button of 'searching'.

However, when the tab menu became scrollable, complete failures and breakdowns happened at varying degrees for myTV SUPER (44.0% and 44.0%) and Flipboard (4.0% and 10.5%). The tab scrolling using myTV SUPER (Action 4, Pattern [7]) seemed to be quite difficult for participants. Failures and breakdowns were detected both when they attempted to locate the tab menus and scrolled the tab bars. For example, twenty-one participants didn't realise the tab bar could be scrolled horizontally because it was not indicative enough (Principle N10). After reminding from experimenters, eight participants still had difficulties with the fine movement of bar scrolling (Principle N6). Additionally, the position of tab menu also caused usability problems (Principle V1 and N1). Six participants didn't notice the lower placed tab bar thus they attempted to scroll the content instead. In contrast, searching and scrolling the tab menus using Flipboard were much easier (Action 5, Pattern [15]). Majority of participants could understand how to scroll the tabs at first, with only three of them encountering difficulties due to the inadequate indication of interaction techniques (Principle N10). However, the major problem lay in the confusion that caused by the simultaneous existing interaction areas, which was against with the Principle N12. Since the areas of tab menus and card content could be scrolled in the horizontal and vertical direction at the same time, four participants felt confused and flipped the area of content instead. Additionally, the precise interaction techniques proposed high demands for the participants (Principle N6), in which three of them could not perform the scrolling gestures very well and mistakenly touched other areas.

Regarding the springboard menus in myTV SUPER, all participants could successfully select the menu buttons (Action 7, Pattern [12]). Nevertheless, usability difficulties (18.2%) occurred when participants were scrolling the menu panel (Action 6, Pattern [12]). Breakdowns mainly happened when two participants did not realise that the springboard could be scrolled, due to the lack of interaction indication (Principle N10). By comparison, actions related to the use of sider drawer revealed some interesting results. First, the participants faced additional challenges when searching for the entry point of the sider drawer, namely the hamburger button (Action 8, Pattern [9]), resulting in 29.0% of breakdowns and 29.0% of complete failures. Primary reasons lay in the icon comprehensibility (Principle E1) and position of the hamburger button (Principle N1). For instance, eleven participants could not correctly understand the meaning of the hamburger button, nine participants could not appropriately locate the entry point of sider drawer at first, and two participants could not precisely tap the hamburger button because it was very close to the edge of the screen. Some other issues were also detected when three participants did not distinguish between the touchable and non-touchable text (Principle V8) and three participants were confused by the two simultaneous existing menus in the same interface (Principle N11). Then, when scrolling the menu lists within the sider drawer (Action 9, Pattern [13]), it was found that 77.8% of actions were completed successfully without any usability issues, and 28.6% of actions were finished after overcoming the usability challenges because few participants did not realize that the menu could be scrolled (Principle N10). Nevertheless, once the participants have found the entry point of the sider drawer, they could select the target menu items very effectively and efficiently. For the actions of simply searching and selecting the sider drawer menu items (Action 10, Pattern [13]), 96.4% of actions were performed with complete success, and 3.6% of actions were conducted after overcoming the usability issues.

Based on the results of activity analysis, it was found that one of the major usability issues that influence the action of tab clicking using WhatsApp and myTV SUPER (Action 1, 2) was whether the menu items were noticeable enough (Principle V1 and N1). Older adults focused more on the content area but seldom manipulated with tab menus. Interpreted by the interview analysis, it may be explained by two reasons. First, participants believed that the functions presented on the default page were enough for them. Second, participants would not like to switch between tab menus because they were afraid of touching and selecting mistakenly and hard to recover from that. Furthermore, the scrolling actions with tabs, springboard and sider drawer using myTV SUPER (Action 4, 6, 9) was particularly difficult for participants because of their poor indication for interaction techniques and high requirements for fine motor skills (Principle N10 and N6). A majority of the participants indicated that they had no idea about whether the menu items should be scrolled.

Nevertheless, these difficulties related to tab switching and scrolling were less pronounced using Flipboard (Action 3, 5). Possible reasons may lie in the tab menus' located position and font size, as well as the spaces between menu items. Participants reported that the tab menu located on the upper position was much easier to be noticed when navigating. They also expressed their preference for the larger font used in the Flipboard menus (Principle V1). As for the spaces between tab buttons, participants indicated several considerations. On the one hand, they preferred wider spaces between buttons like Flipboard, which they could not easily touch the wrong spots. On the other hand, the participants would not like to scroll the tab items if space became wider and the dynamic width was increased. Overall, most of the participants preferred the use of sider drawers, followed by springboard and tabs. Typical answers were stated such as ‘*I would like to glance at all of the choices at once*’ and ‘*I would like to avoid the scrolling and swiping gestures*’.

Action ID	***Count***	***Associated usability principles***	***Percentages of completion levels of actions****
1	28	V1, N1, H1	
2	75	V1, N1, V6, N6	
3	106	H1	
4	125	N10, N6, N1	
5	76	N12, N6, N10	
6	22	N10	
7	22	NA	
8	31	E1, N1, V8, N11	
9	10	N10	
10	30	NA	

*Note: level A-successful actions without usability challenges; level B- action with usability challenges that users managed to overcome; level C-action with usability challenges that users failed to overcome.

Table 5.7 Frequency of actions observed with different completion levels and associated usability principles for menu-oriented design patterns.

5.3.4. Content-Oriented Design Patterns

Overall, it was much easier for participants to navigate the content rather than menus (see Table 5.8). For the design pattern of lists, the selection action using Flipboard (Action 15, Pattern [18]) and scrolling action using WhatsApp (Action 11, Pattern [2]) performed the best: 5.0% actions were completed after overcoming usability challenges. Following was the action of list selection using WhatsApp (Action 13, Pattern [2]), in which 5.0% of actions occurred with breakdowns, and 5.0% of actions happened with complete failures when one participant did not know how to select the targeted list items. On the contrary, the actions of list selection (Action 14, Pattern [11]: 9.0% occurred with breakdowns) and list scrolling (Action 12, Pattern [11]: 18.2% occurred with breakdowns) using myTV SUPER achieved the worst performance. Two breakdowns of Action 14 happened when participants could not precisely tap the list item (Principle V6 and N6). Regarding Action 12, one breakdown occurred due to the same reason (Principle V6 and N6) and one breakdown happened because the user did not realize that the list could be scrolled (Principle N10).

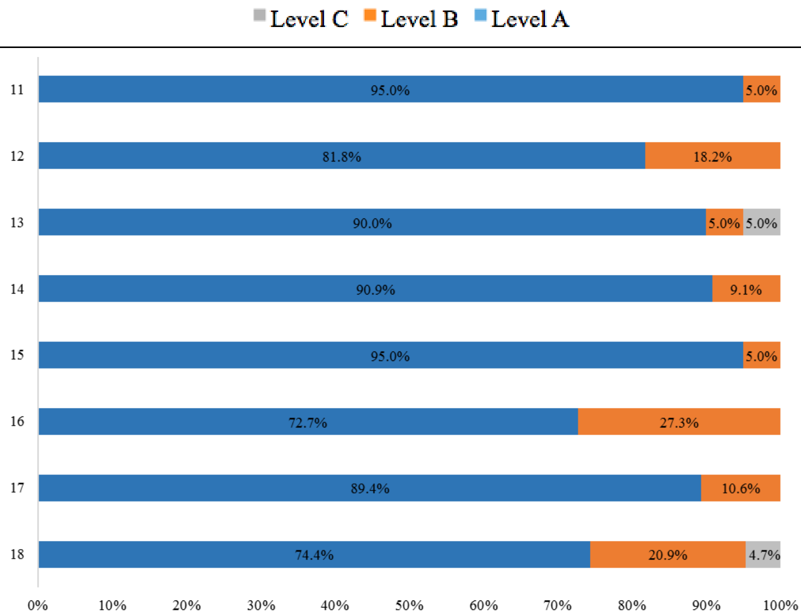
The action of gallery selection using myTV SUPER (Action 17, Pattern [12]) also achieved strong performances, with 10.6% actions completed after overcoming usability issues. Significant challenges were reported because the titles for gallery items were not noticeable enough (Principle V3), that two participants missed the targets when navigating. The action of gallery scrolling (Action 16, Pattern [12]), whereas, seemed to be more difficult, with 27.3% actions finished after overcoming usability challenges. Several reasons were found by the results of activity analysis. First, the interface did not provide sufficient cues to inform the user about how to interact with the interfaces

(Principle N10). Six participants scrolled the gallery in the wrong direction. Second, five participants could not distinguish the name of targeted gallery items from others, which led to incorrect tapping (Principle E9). Third, breakdowns also occurred when two participants mistakenly tapped an un-clickable text (Principle V8), and two participants missed the targeted gallery item when searching due to the unobvious titles (Principle V3).

As for the action of card flipping using Flipboard (Action 18, Pattern [16]), 20.9% of actions happened with breakdowns, and 4.7% of actions met complete failures. Usability challenges primarily occurred when participants did not understand how to initiate the interaction with cards due to the inadequate visual cues (Principle N10). Specifically, seven participants tried to swipe the cards left and right, and three participants attempted to use the assisted navigation buttons around the corners. In addition, some other usability issues were also reported. First, there were five participants who had difficulties with the gesture of card flipping. They could not precisely flip the cards, leading to many accidental touching and tapping (Principle N6). The results of the interview analysis showed that it was because the participants were less familiar with the gesture of flipping than those of taping and clicking. Second, five participants could not immediately realise the interface changes. Thus they missed the target content (Principle N7). Third, specific challenges were caused by the unclear indication of location (Principle N8). Five participants flipped forward and backwards several times because they were afraid of losing current positions by flipping too many cards. Besides, five participants were confused between the tab menus, which should be scrolled horizontally, and the cards, which is flipped vertically (Principle N12).

Based on the comments of participants, the majority of content was clear and visible, and the spaces between content were appropriate to navigate in the applications of WhatsApp and myTV SUPER. There was one exception, the font of cards in Flipboard, which was quite small for older adults to read (Principle V2). At the end, when the participants were asked to compare these design patterns. Fourteen participants preferred the use of list or gallery because they can take in more content at a glance. Furthermore, participants reported that it was quite easy to lose previous content and difficult to compare between the content using cards. However, five participants indicated preferences for the card pattern in Flipboard, because the card was much clearer, easier and more interesting to flip.

Action ID	*Count*	*Associated usability principles*	*Percentages of completion levels of actions**
11	20	NA	
12	11	V6, N6, N10	
13	20	NA	
14	22	V6, N6	
15	20	NA	
16	56	N10, E9, V3, V8	
17	66	V3	
18	86	N10, N6, N7, N8, N12	



*Note: level A-successful actions without usability challenges; level B- action with usability challenges that users managed to overcome; level C-action with usability challenges that users failed to overcome.

Table 5.8 Frequency of actions observed with different completion levels and associated usability principles for content-oriented design patterns

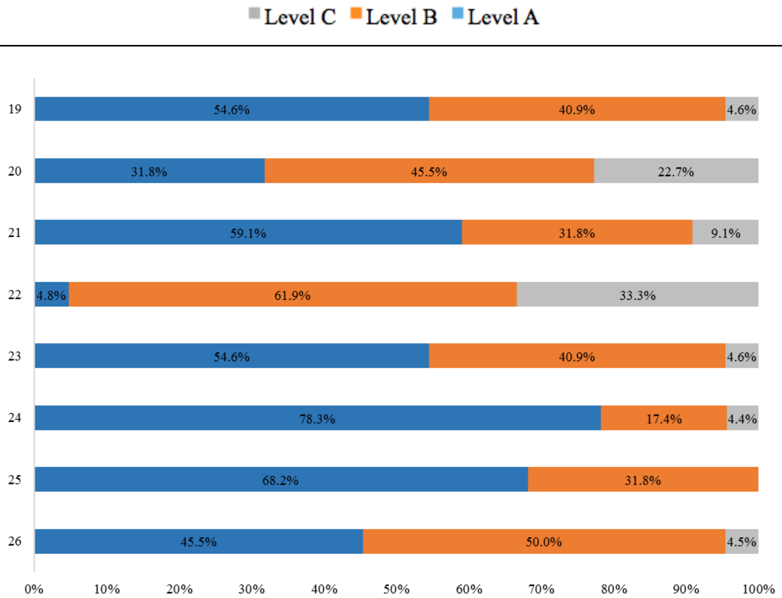
5.3.5. Assisted Navigation Buttons

In addition to the design patterns that related to menu-oriented and content-oriented navigation, the frequent use of assisted navigation buttons was also identified, including the keyword searching, adding to favourites, sharing with friends, and returning to previous interfaces. As shown in Table 5.9, the results of activity analysis revealed significant difficulties regarding the use with assisted navigation buttons. Specifically, the most challenging actions were related to starting a new dialogue (Action 22, Pattern [3]) using WhatsApp. Thirteen participants met with difficulties when finding the button (Principle V1 and N1). Besides, ten participants had problems with understanding icons (Principle E1), and two participants mistakenly tapped other areas as they could not distinguish between the touchable and non-touchable icons (Principle V8). When participants were asked to search for the keywords using WhatsApp (Action 20, Pattern [4]), 45.5% of actions were detected to be completed after overcoming usability issues, and 22.7% of actions were found to completely fail. It was reported that breakdowns and failures mainly occurred when six participants had problems to locate the buttons (Principle V1 and N1), nine participants could not understand the meaning of the icon (Principle E1), and two participants met difficulties with distinguishing the touchable and non-touchable icons (Principle V8).

Usability challenges were also reported for keyword searching using myTV SUPER (Action 21, Pattern [10]), article sharing using Flipboard (Action 26, Pattern [17]), as well as the video chatting (Action 19, Pattern [5]) and adding new friends (Action 23, Pattern [6]) using WhatsApp. Usability problems for Action 21 were mainly because of the difficulty in understanding the meaning of icons (Principle E1). Thus the participants may select the incorrect buttons (three participants), switch the tab menus (three participants), or swipe the content (two participants). Also, there was one participant who mistakenly tapped the edge of the targeted button (Principle V1 and N6). As for the Action 26, participants encountered significant difficulties in distinguishing the icon of ‘sharing’ with several other icons (Principle E1). For example, eight participants mistakenly selected buttons such as ‘adding comments’, ‘returning’, or ‘finding more’ instead. Because of the similar reason (Principle E1), six participants mistakenly selected the button of ‘voice messaging’ instead of ‘video chatting’ for Action 19, which was located near the area of text entry, and eight participants mistakenly chose the button of ‘start group chat’ for Action 23, which was quite similar to the targeted button of ‘add new friends’. However, adding favourites using myTV SUPER (Action 24, Pattern [14]) and Flipboard (Action 25, Pattern [17]) were found to be relatively easier for the participants. According to the comments, it was because the icon for ‘add favourite’ is shaped like a heart, which was much easier for them to understand.

Results of the activity analysis showed that the location of buttons, understanding and distinguishing of icons, as well as the connection between icon meaning and operational function, were major usability principles when using assisted navigation button usage. Participants tended to focus more on the content. Thus they seldom notice or use the assisted navigation buttons around the corners. Moreover, even when the participants knew the fact that each of the navigation buttons carried a specific function, they still had difficulties when comprehending the icon meaning or distinguishing between neighbouring icons or icons with similar shapes. Furthermore, older adults faced significant problems when connecting the aimed functions to the targeted buttons. Participants reported that they could not easily understand the meaning of various icons, even when they had previous experience with similar icons. Therefore, they attempted to avoid the use of buttons because of the fear of making irrevocable mistakes. In the end, when they were provided with some potential design solutions for icon design during the interview, all participants asserted that a button with text would be better to explain the meanings and functions for icons.

Action ID	*Count*	*Associated usability principles*	*Percentages of completion levels of actions**
19	22	E1, N1	
20	22	E1, V1, N1, V8, H1	
21	22	E1, V1, N6	
22	21	V1, N1, E1, V8	
23	22	E1, E2	
24	23	NA	
25	22	NA	
26	22	E1, H1	



*Note: level A-successful actions without usability challenges; level B- action with usability challenges that users managed to overcome; level C-action with usability challenges that users failed to overcome.

Table 5.9 Frequency of actions observed with different completion levels and associated usability principles for assisted navigation buttons

5.4. Design Guidelines for Older Adults' Mobile Navigation

5.4.1. Designing for Menu-Oriented Navigation

5.4.1.1. Horizontal Scrolling Navigation: Tab Menu

Tab menu is one of the major navigation patterns that used widely for the flat application design. The users can access all the primary categories by merely switching the tab menus within the flat information structures (Neil, 2014). However, this study showed that the tab menus could also cause great usability challenges for older adults. Participants reported significant challenges in directing the attention to the tab menus, understanding the interaction mode of tab menus and precisely interacting with the tab menus. This study revealed several important aspects that designers need to consider to lessen the usability issues brought by tab menus.

First, results indicated that participants tended to focus more on the content area rather than tab menus. Thus they performed poorly in menu-oriented navigation, especially for Action 1 and 2. The results were consistent with the findings from previous studies on web navigation, reporting that older adults had more difficulties than younger users in directing their attention towards the navigation links and menus (Etcheverry et al., 2012a, 2012b). Nevertheless, this usability problem was largely lessened for Action 3, which may be because of the improved noticeability of tabs in Flipboard. On the one hand, it can be explained that larger buttons can help to attract user's attention, which was similar to the physical buttons of feature phones and desktops (Kurniawan, 2008; Olwal et al., 2011; Caprani et al., 2012). On the other hand, tab menus that placed on the top of an interface can facilitate older adults' menu navigation to some extent. It may be because top and left placed menus can elicit higher correctness rate, fewer mouse clicks and higher preferences based on previous studies on desktop websites (Murano and Oenga, 2012; Burrell and Sodan, 2006). Thus, it is recommended that,

Using top-tabbed menus and larger tap buttons to facilitate older adults' mobile *navigation behaviour*

Second, additional requirements for interactions with tab menus, such as scrolling, were specifically challenging for older adults (e.g., Action 4). Older adults were reported to have increased chances to do unintentional taps because of their declined motion abilities (Harada et al., 2013; Motti et al., 2013). Thus, designers are recommended to avoid using scrolling bars. If not, sufficient visual cues should be applied to inform users about whether the tab menu can be scrolled and in which direction it should be scrolled. Adding to the established guidelines, this study suggests that an explicit visual cue, such as half-present menus, can lessen the usability issues resulting from scrolling tab bars. Overall, it is suggested that,

Avoiding using scrolling tab menus; if not, providing sufficient visual cues such as a half-present menu bar

Generally, older adults would like to reduce the times of scrolling when using tab menus, but the results reported that they could scroll and tap the tab menus using Flipboard (Action 5) more easily. The reason may also lie in the menu position, target size, and space between each tab buttons, which agreed with some of the previous research. Hwangbo et al. (2013) indicated that a user's pointing performance was increased when targets were placed in the upper right area of the interface. They also reported the pointing performance was decreased when spaces between each button were narrower, but these effects were eliminated to some extent once the button size was large enough. Therefore, designers are suggested that,

Using larger fonts for tab texts and narrower spaces between tab buttons when *designing scrolling tab menus*

5.4.1.2. Vertical Scrolling Menus: Springboard and Sider Drawer

Overall, the use of vertical scrolling menus, such as the springboard and sider drawer (e.g. Action 6, 7, 9, 10) was preferred by the participants rather than tab menus. It was explained by the participants that they would like to glance at all the menu items at one time. It may be because that vertical menu can provide a cognitive-cost-efficient way for information navigation (Pirolli, 2007; Ware, 2010). Users can process a number of menu items at once, rather than spending more time on considering about which menu entry they should choose or what action they should take to access more categories (Leuthold et al., 2011; Puerta Melguizoet al., 2012).

Although vertical menus such as sider drawer and springboard proposed fewer usability challenges than tab menus, they could also cause difficulties in various ways. For example, some participants didn't realise that the springboard and sider drawer needed to be scrolled vertically to access more options. Thus, similarly, this study suggested that visual cues are also critical in indicating the interaction mode for vertical menus. Besides, the sider drawer could only be revealed by an additional tap on the hamburger button (Action 8). It also caused some other usability issues, which is discussed in the next section about design for assisted navigation buttons. In general, it is suggested that,

Using vertical menus instead of tab menus if possible, and providing enhanced visual cues to indicate the interaction direction of menu items

5.4.1.3. Assisted Navigation Buttons

The results showed that using assisted navigation buttons was especially difficult for older adults. They were found to encounter significant challenges in understanding the meaning of icons and distinguishing the target buttons from others.

Agreed with previous research, this study confirmed that older adults had major problems in understanding icons due to their difficulties in building accurate mental models between graphical representation and its operational meaning (Action 8, 19-23) (Leung et al., 2011; Remington et al., 2016). For instance, they were asked to search the keywords (Action 20, 21), several participants could verbally indicate the icon's graphic representation as 'magnifying glass', but they could not associate this icon with its functional meaning of 'keyword searching'. Overall, older adults tried to avoid using the assisted navigation buttons; whereas, they said buttons with text explanation could help in improving the understandability of icons. In this way, it is recommended that,

Minimising the use of icons when designing navigation systems for older adults; if possible, using simple and semantically closed icons, and marking the icons with texts.

Moreover, older adults faced significant difficulties in distinguishing between the similar-appearing icons (Bruder et al., 2007; Hassan and Md Nasir, 2008; Caprani et al., 2012). Therefore, in addition to the established principles, designers should use distinctive icons in the same interface to avoid possible misunderstanding. Simultaneously, designers should carefully deal with the placement of navigation buttons. As mentioned previously, older adults seldom directed their attention to buttons placed at the lower and bottom part of interfaces. Thus, it is recommended that, *Using distinctive graphic representations for icons in the same interface and locating important buttons at the top area of interfaces*

Differentiating between touchable and non-touchable buttons also caused usability issues for older adults, which is also addressed in some previous studies (Zhou et al., 2012; Harada et al. 2013). Therefore, visual differences should be further enhanced to facilitate older adults' process of distinguishing. Though previous studies indicated that older adults preferred the use of raised buttons, which can provide visual highlighting and immediate tactile feedback (Kim et al., 2007; Sulaiman and Sohaimi, 2010; Olwal et al., 2011), the results of the current study suggested that designers should be careful with the floating action button. Participants reported that they seldom noticed or tapped this button though it provided an obvious visual cue by raised shadows. As their decreased visual perception, older adults may have difficulties in understanding the depth cues of 3D shapes, which is also worthy of future study (McAvinue et al., 2012). In general, it was suggested that,

Enhancing visual differences between touchable and non-touchable buttons and providing sufficient feedbacks for interaction gestures

5.4.2. Designing for Content-Oriented Navigation

5.4.2.1. Lists and Galleries

Lists and galleries are widely used design patterns for mobile navigation (Tidwell, 2010), but they are suited for various situations. This study reported that lists and galleries could enable more content items to be presented at once, providing an easier way for information review with less scrolling (Harley, 2014). Furthermore, the activity analysis indicated that lists outperformed galleries and cards, with fewer breakdowns and failures. On the one hand, lists are usually arranged by visual priority and create a hierarchy of information, which makes it easier for users to scan and browse the content (Flaherty, 2016). Thus, the lists work better for older adults, who are proved to apply a linear mode of visual exploration (Etcheyerry et al., 2012a). On the other hand, lists could provide clearer interaction indications than galleries and cards by vertically stacking the information items. Participants reported they could not lose previous content when scrolling with lists, which made them feel secure.

Nevertheless, it was found that lists with limited height easily led to mistaken touches and imprecise tapping and the issue was worsened when the list contained two touch-enabled areas that required different interaction techniques or when lists needed to be scrolled vertically (Action 12, 14). Thus, this study suggests that,

Using the pattern of lists to show broad and diverse categories of information and reducing the use of multiple interaction gestures to the maximum extent

Furthermore, it is quite difficult to compare details by lists, which may lead to visual fatigues or result in the loss of information when information items are similar to each other. Based on previous studies, the gallery is more suitable for showing information in details (Harley, 2014). Nevertheless, this study found that participants could easily skip the targets when navigating with the gallery. In addition, older adults were found to have significant difficulties because of the lack of visual cues. To overcome these usability issues, this study recommends that,

Using the pattern of gallery when comparing detail, providing additional *interaction indications and employing larger and distinctive titles for gallery items when designing for older adults*

5.4.2.2. Cards

Card is emerging as a popular design solution that works both for the desktop and mobile platforms. Previous studies on card pattern mainly focused on usability guidelines for computerised website design. For instance, researchers reported that card pattern is good at grouping heterogeneous content, providing additional details, and enabling quick actions (Laubheimer, 2016). This study found that navigating with cards was quite easy for older adults. On the one hand, card pattern is a metaphor taken from the physical world. It may facilitate older adults' mental model through their previous experience with physical cards or books (Zhou et al., 2017). On the other hand, card pattern enables simple interaction techniques and allows for a large interactive area, which is easy to learn and execute.

At the same time, the results provide several vital insights into how to design the cards pattern design for older adults. First, some participants could not understand how to initiate the interaction with card items at the very start. Second, although the card had a larger interactive area than others, flipping with card items required a longer gesture distance, which had higher demands for older adults' controlling force. Third, the card pattern could not provide users with overviews of previous and next content, which can easily result in disorientation and lost. To conclude, it is recommended that,

Using flipping gestures with shorter gestural distance and providing appropriate visual cues to inform users about how to initiate the interaction *with cards and about their current location during the navigation*.

The results also reported that older adults could not immediately realise interface changes. Thus they could easily miss the targeted content. Designers should provide clear and visible feedbacks to immediately indicate the changes of the interface, such as the interface switching and button pressing. Multimodal feedback such as voice and vibration may work better for older adults (Hwangbo et al., 2013). Also, older adults experienced significant difficulties when interacting with multiple touchable areas that required various gestures. It even worsened when these interaction gestures were performing in different directions, such as scrolling horizontally and swiping vertically. In summary, this study suggests that,

Providing clear visible, tactile, or multimodal feedbacks to indicate the immediate changes of card flipping, and reducing the number of simultaneous existing interactive areas in the same interface

5.5. Summary

This chapter described the method and analysis of a series of usability testing and in-depth interviews that address the research question Q4. As one of the pioneer studies investigating older adults' mobile navigation behaviour, this study yielded rich details about how older adults interact and navigate with current navigation design patterns by capturing fruitful data through an activity analysis of video data and a content analysis of in-depth interviews. After analysing older adults' usability issues with several state-of-the-art navigation UI design patterns, this study provided insights into how current design patterns facilitate or buffer older adults' mobile navigation behaviour. The results are especially beneficial in advancing the usability studies from the paradigm of desktop and feature phones to contemporary, advanced mobile technologies.

For example, it was found that older adults faced significant difficulties in directing attention to menu-oriented navigation items, comprehending the meanings of icons and interacting with menu items by clicking, scrolling and tapping. Older adults experienced fewer challenges when using content-oriented navigation designs regarding understanding, navigation and interaction. Overall, it showed that the content-oriented navigation design could be a promising strategy when designing for older adults' mobile navigation. In addition, through explicitly analysing the advantages and disadvantages of each design pattern, this study proposed a variety of possibilities for mobile navigation design to address difficulties with previous design guidelines for older adults.

Though this study captured several usability issues for older adults' mobile navigation behaviour in real-use situations, more research is required. First, the method of usability testing was employed to understand older adults' navigation behaviour with menus and content from a broad perspective, but there is a lack of details regarding each of these design patterns. Further studies are still needed to investigate older adults' navigation behaviour with each design pattern in a controlled experiment. Second, although this chapter proposes some important design suggestions for menu-oriented and content-oriented navigation design, the reasons behind the usability issues with various design patterns, particularly the influences of user characteristics, task context and interface design, are still not explained in detail.

These issues are addressed in the following experiments. Older adults' menu-oriented navigation behaviour was analysed by experiments manipulated by different kinds of menu designs and levels of task complexity, and the roles of user characteristics were addressed, as described in Chapter 6. Chapter 7 outlines the experimental analysis of older adults' content-oriented navigation behaviour with different levels of interface design, task complexity and content similarity, as well as the possible roles of user characteristics.

CHAPTER 6 Study Three: An Experimental Analysis of the Menu-oriented Navigation Behaviour

6.1. Introduction

Chapter 5 presented the study comprised of usability testing and in-depth interviews. The results indicated that older adults experience significant usability challenges when performing menu-oriented navigation. For designers, navigating through menus is a typical way to represent the website and application structures and direct users to their desired targets by selecting menu items such as hypertexts, icons and buttons. To assure a better user experience, researchers have extensively evaluated the menu design of desktops and feature phones, such as menu structure, panel positioning and item categorisation. However, the results presented in Chapter 5 showed that, for older adults, the most frequently mentioned usability issues of menu-oriented navigation are related to the visual design of font and button size, ease of understanding of icons and buttons and gestural interactions.

Thus, to build a user model for older adults' navigation behaviour with mobile technology, this study was mainly dedicated to investigating the relationships between user characteristics, task contexts and menu design during menu-oriented navigation. In particular, it aimed to examine how different design strategies can facilitate or detriment the understandability of menus and further influence menu-oriented navigation performance and subjective preferences. The assumptions of the current study were formulated based on the literatures reviewed in Section 2.5.1.2 indicating that a redundancy design can assist older adults and average users to build a more accurate mental model between their graphic representations and operational functions, especially for those with less technology experience and declined user capabilities.

In this experiment, with the aim of addressing the roles of user characteristics, participants were recruited with a wide range of ages and divided into two age groups: younger and older adults. Three menu designs were employed depending on the different levels of redundancy design. The impacts of task complexity were examined by manipulating different levels of memory loads. Individual characteristics such as demographic factors of education, technology experience and several types of user capabilities were also evaluated. Four hypotheses were developed in this study: H6.1. The younger adults will perform better in terms of the menu-oriented navigation performance and have higher level of subjective evaluation towards the menu-oriented navigation design; H6.2. The interface with redundancy design will improve the participants' menu-oriented navigation performance and subjective evaluation, both for the groups of young and older adults; H6.3. The task with higher level of complexity will decrease the participants' menu-oriented navigation performance and subjective evaluation, both for the groups of young and older adults; H6.4. The participants' education, cognitive and visual capabilities, and technology experience will influence their menu-oriented navigation performance and subjective evaluation.

6.2. Method

6.2.1. Participants

A total of fifteen participants were recruited by verbal advertising from the local universities and community centres who were residing in domestic households in Hong Kong. Participants reported no cognitive and visual impairments and indicated the usage experiences of mobile technologies such as smartphones and tablets. The participants were divided into two groups: the young group aged between 24 to 38 years older and the older group aged between 52 to 81 years old. As rewards, participants received one hundred Hong Kong dollars after the experiment.

6.2.2. Experiment Design and Materials

The experiment was conducted in local elderly centres and the university laboratory. To investigate the effects of age, menu design and task complexity on older adults' menu-oriented navigation behaviour, a $2 \times 3 \times 3$ factorial design was designed with age (younger and older) as a between-subject variable, and menu design (icon-text, icon only and text only) and task complexity (low, medium, and high) as within-subject variables. The possible roles of user characteristics, such as education, technology experience and user capabilities were also examined in this study. Dependent variables were measured by participants' navigation performance of completion time, correctness rate, the number of incorrect clicks and return steps, as well as subjective evaluation of ease of use, disorientation, effort needed, and satisfaction.

6.2.2.1. Investigation of User Characteristics

Participants' user characteristics were first investigated. Participants' demographic information including age, gender and education experience was collected. Technology experience was evaluated regarding the experience with both previous generations of technology and current mobile technologies. Thereby, the technology experience was examined by the duration of use of computers, and the duration of use, intensity of use, diversity of use, and self-reported efficacy with mobile technologies.

Then, three types of cognitive capabilities were tested concerning the working memory, spatial ability, and perceptual speed. Working memory was measured by the word recall test (WRT), spatial ability was evaluated by clocking drawing test (CDT), and perceptual speed was evaluated by the spatial digit modalities test (SDTM). In addition, participants' visual acuity and contrast sensitivity were measured, and their visual perceptions of digital screens were evaluated.

Word Recall Test (WRT)

Participants' working memory were evaluated by the WRT. The test required participants to remember five unrelated words at first and then asked participants to complete the following CDT. After that, participants were instructed to repeat the five previously stated words. The WRT performance was recorded according to the number of correctly recalled words, which was scaled from 0 to 5.

Clock Drawing Test (CDT)

Participants' spatial ability was measured by the CDT. In the test, participants were provided a paper with a circle on it. Participants were asked to draw a clock face with numbers displayed and to draw the clock hands to read time of 09:20. Task performance was marked from 0 to 2. Each point was given when they correctly drew the numbers along the clock circle or stated the clock hand to read the correct time.

Spatial Digit Modalities Test (SDMT)

Participants' perceptual speed was tested by the SDMT. This test was administered by requiring the participants to match between nine pairs of abstract symbols and digital numbers, such as ‘>’ and ‘3’, ‘&’ and ‘9’, and ‘(’ and ‘1’. Participants needed to finish as many as pairs within 90 seconds. The test performance was recorded as the number of correctly matched pairs, which was scaled from 0 to 90.

Vision Acuity (VA), Contrast Sensitivity (CS) and Self-reported Visual Perception (VP)

A tumbling E chart and a Pelli Robson contrast sensitivity chart were employed to test participants’ vision acuity and contrast sensitivity that calibrated and shown by a tablet with a solution of 2048×1536. When testing the vision acuity, participants were instructed to read the chart from a distance of 1.9 meters with corrections. The test performance was calculated by the minimum visual angle of each participant. Participants’ contrast sensitivity was then measured regarding their ability to distinguish the finer and finer ink fading against the white background. Besides, participants were also instructed to evaluate their visual perceptions of recognising the characteristics on the tablet screen. Questions were asked such as ‘is it easy for you to recognise the characteristics on the tablet screen overall?’ One to five points were remarked for the response based on a 5-point Likert scale from extremely difficult, very difficult, medium difficult, a little difficult, and not difficult at all.

6.2.2.2. Materials and Tasks

Interface and Menu Design

An iOS mobile application was developed by the programming language of Unity as a simulated medication reminder to reduce the possible influences of users’ prior experience with such applications. Five pages were developed for this application, including the pages of task instruction, main menu page, sub-pages of patient, medication, dose and time, as well as the resting and completing instructions, as shown in Figure 6.1. In the main page, the menu panel was presented as a springboard with eight navigation buttons. Four buttons acted as the entry-points of the four sub-pages including patient page, medication page, dose page, and time page. There was an answer choosing area in each sub-page and some relevant information at the bottom of each sub-page. The other four navigation buttons acted as the confounding factors, which would direct the users to a blank page. In the test, participants were instructed to correctly choose the name of the patient and medication, the dose and time for taking the medication according to task descriptions.

(a) Task instruction (b) Main page (c) Sub-page: patient (d) Sub-page: medication

(e) Sub-page: dose (f) Sub-page: time (g) Resting (h) Completing

Figure 6.1 Interface design for the experimental mobile application

Three kinds of menu-oriented navigation design were developed based on different levels of redundancy: icon-text design, icon-only design and text-only design, as shown in Figure 6.2. To maintain the possible confounding influences from other factors, the menu design followed a set of principles proposed by previous guidelines, such as choosing concrete and semantic-closed icons, applying simple coloured and simple shapes graphics and texts, and providing with dynamic feedback (Leung et al., 2011). For each task, the icons and texts were presented with the same sizes, and the positions of each navigation buttons were arranged randomly.

(a) Icon-text design (b) Icon-only design (c) Text-only design

Figure 6.2 Menu designs for the experiment

Task Complexity

Three levels of task complexity were developed based on how many information sources were required to be remembered or integrated. For the tasks with a low level of difficulty, participants were instructed to select the patient, medication, dose and time by directly following the task description presented at the top of interfaces. It didn't require any cognitive loads for remembering or integrating information, (e.g. please remind Wen to take two pieces of Aspen after dinner). For the tasks with a medium level of difficulty, the task instruction was the same as the task with a low level of difficulty; however, the instruction disappeared once the task started. Participants needed to remember the task description during the experiment. For the tasks with a high level of difficulty, in addition to remembering the task instruction, participants needed to refer to the relevant information presented at the bottom of each sub-page and integrate several information patches to select the correct answers. For example, if the task asked the participants to 'make a medication plan for Wen who had got a cold', the participant needed to first select the medication based on the relevant information of symptom descriptions in the sub-page of medication. Then, the participant needed to choose the name of a patient and read the relevant information of patient description such as age in the sub-page of the patient. Finally, the participant could then decide the dose and time to take the medication by integrating the relevant information of the dose and time instruction, as well as the patient's age and medication description. For each participant, nine tasks were randomly generated with different patient names and symptoms.

6.2.2.3. Measures: Navigation Performance and Subjective Evaluation

Navigation performance was measured by the participants' completion time, correctness rate, as well as the number of incorrect clicks and return steps. Completion time was counted when the participants tapped the button of starting tasks until they finished all the selections of medication, patient, dose and time. Correctness rate was calculated by the percentage of correct answers chosen for each task. Incorrect clicks were recorded once the participants chose the wrong menu tabs in the main menu page and returns were counted when participants made a return to the previous sub-pages that they have visited.

Participants' subjective evaluations of the interfaces and tasks were also investigated. Five aspects were evaluated using 5-Point Likert scales, including the ease of use, disorientation, effort needed, helpfulness and satisfaction (Ahuja and Webster, 2001; Leuthold et al., 2011). The results were scaled from 1 to 5 from strongly disagree to strongly agree. Questions were asked including whether it was easy to learn and use this application (ease of use), whether it was easy to feel oriented and hard to feel lost (disorientation), whether it needed less effort to finish the tasks (effort needed), whether this interface could help in completing tasks (helpfulness), and whether the application was overall satisfied (satisfaction).

6.2.3. Procedure

The whole experiment was conducted in a separate and quiet area, with the disturbing factors controlled at an acceptable level. Before the experiment, consent forms and experiment instructions were given to the participants. Participants' demographic information and technology experience were collected, and the user capabilities were measured.

Before the experiment, the experimental mobile application was introduced by the experimenters in details (see Figure 6.3), including the icons and texts used in the main menu page and relevant information presented in the four sub-pages. Following, five minutes were given to each participant to freely explore the application, and they were allowed to ask any question about this application during the process. Participants were then instructed to complete three trials to familiarise themselves with the interfaces and tasks. With no questions remaining, the experiment was conducted.

For each participant, they were instructed to complete nine menu-oriented navigation tasks as soon as possible without the sacrifice of correctness rate (see Figure 6.3). The section of subjective evaluation was completed after each task finished. Between every task, participants were given three minutes to rest to avoid the possibility of fatigue. The whole experiment was lasted for about one hour.

Figure 6.3 Experimental process: an experimenter was explaining how to use this mobile application (left); a participant was completing the experimental tasks by herself (right)

6.2.4. Data Analysis

Descriptive analysis was employed for user characteristics of demographic factors, technology experience and user capabilities. Relationships between these user characteristics and navigation performances and subjective evaluations were analysed by the Spearman correlation analysis in SPSS. The results of the Shapiro-Wilk test indicated that all the data of dependent variables were not normally distributed. Only the data of completion time was normally distributed after transforming. Thus a mixed repeated ANOVA was employed the effects of age group, menu design, and task complexity on completion time. Mann-Whitney test, Friedman test and Wilcoxon signed-ranked test were then employed to compare the differences of navigation performance of correctness rate, number of returns and number of incorrect clicks and subjective evaluation between different levels of menu design and task complexity. Furthermore, a multiple regression analysis was used to ascertain the associations between factors of user characteristics and navigation performance, as well as subjective evaluations under different experimental conditions.

6.3. Results

6.3.1. Description of User Characteristics

Fifteen participants (5 males and 20 females) who aged from 24 to 81 years old were recruited in this study. The group of younger adults was aged from 24 to 38 years old, with an average age of 28.63 years (SD=4.60); and the group of older adults was aged from 52 to 81 years old, with an average age of 69.57 years (SD=11.62). Participants from the younger group had an average education experience of 19.88 years (SD=1.73), and participants from older group indicated a wide range of education levels, from the primary (1-6 years) to the university and above (more than 13 years), with an average education experience of 10.43 years (SD=5.35). The age and education distributions are shown in Table 6.1.

Participants' descriptive data for technology experiences are presented in Table 6.2. Overall, the group of older adults reported less experience with both of the previous and current technologies. Specifically, participants from the younger group reported an average experience of 14.63 years for using computers and 7.50 years for using mobile technologies; and the group of older adults had an average duration of using the computer for 7.07 years and using mobile technologies for 2.55 years. Additionally, the group of younger adults used the mobile technologies for 27.75 hours every week and used 5.13 functions averagely. Simultaneously, participants from the older group used the mobile technologies for 15.50 hours per week and used 4.43 functions averagely. Among the participants from older adults, all of them reported the use of applications related to social connection (100%); 93.3% of them indicated the use of basic functions such as making a phone call, sending and receiving messages, and taking photos; and 73.3% of them claimed the use of applications related to healthcare management such as searching for health-related information and booking an appointment with doctor. Other functions that were widely used also included information searching (73.33%) and entertainment (46.67%). When participants were asked to evaluate their self-efficacy of mobile technologies by 5-point Likert scales, the group of younger adults reported a higher level of self-efficacy at an average rating of 4.00 and the group of older adults reported a medium self-efficacy level at an average rate of 3.00.

Participants' cognitive abilities were measured regarding their working memory, spatial ability and perceptual speed. At the same time, visual abilities were evaluated by their vision acuity, contrast sensitivity and self-reported visual perceptions. Table 6.3 shows the results of these tests and self-reports. In effect, the majority of participants reported a normal level of working memory and spatial ability. No significant cognitive impairment was reported by the participants. The results of SDMT varied a lot from 6 to 74 points, which may be because that the total score of this test were higher than other tests. For the visual abilities, there was no significant decline and impairment indicated by the participants with corrections. Nonetheless, the group of younger adults overall outperformed the group of older adults in all the dimensions of user capabilities.

		Frequency	*Percentage (%)*
	Age (years)		
Younger adults (N=8)	21-25	2	25.0
	26-30	3	37.5
	31-35	2	25.0
	36-40	1	12.5
	Mean	28.63	
	SD	4.60	
Older adults (N=7)	51-55	1	14.3
	56-60	1	14.3
	61-65	1	14.3
	66-70	0	0
	71-75	0	0
	76-80	3	42.9
	81-85	1	14.3
	Mean	69.57	
	SD	11.62	
	Education experience (years)		
Younger adults (N=8)	13-18	2	25.0
	Above 19	6	75.0
	Mean	19.88	
	SD	1.73	
Older adults (N=7)	1-6	1	14.29
	7-12	4	57.14
	13-18	1	14.29
	Above 19	1	14.29
	Mean	10.43	
	SD	5.35	

Table 6.1 Distributions of age and education experience (N=15)

		Minimum	*Maximum*	*Mean*	*SD*
Younger adults (N=8)	Duration of use of computers (years)	9.00	20.00	14.63	3.58
	Duration of use of mobile technology (years)	4.00	13.00	7.50	2.88
	Intensity of use of mobile technology (hours/week)	10.50	42.00	27.75	13.34
	Diversity of use of mobile technology	2.00	7.00	5.13	1.73
	Self-efficacy of mobile technology*	3.00	5.00	4.00	0.76
Older adults (N=7)	Duration of use of computers (years)	0.00	20.00	7.07	8.59
	Duration of use of mobile technology (years)	0.42	5.00	2.55	1.75
	Intensity of use of mobile technology (hours/week)	3.50	56.00	15.50	18.72
	Diversity of use of mobile technology	2.00	6.00	4.43	1.27
	Self-efficacy of mobile technology*	2.00	4.00	3.00	0.82

*Likert scale: 1- very bad; 2- bad; 3- Medium; 4- good; 5- very good.

Table 6.2 Descriptive statistic on technology experience (N=15)

			Minimum	*Maximum*	*Mean*	*SD*
Younger adults (N=8)	Cognitive abilities	MRT	5.00	5.00	5.00	0.00
		CDT	2.00	2.00	2.00	0.00
		SDMT	50.00	74.00	60.38	7.27
	Visual abilities	VA	0.50	1.00	0.84	0.19
		CS	86.00	86.00	86.00	0.00
		VP*	5.00	5.00	5.00	0.00
Older adults (N=7)	Cognitive abilities	MRT	3.00	5.00	4.14	0.69
		CDT	1.00	2.00	1.86	0.38
		SDMT	6.00	49.00	29.71	14.69
	Visual abilities	VA	0.75	2.50	1.43	0.53
		CS	85.00	86.00	85.71	0.49
		VP*	3.00	5.00	4.43	0.79

Table 6.3 Descriptive statistics on capability measurement

6.3.2. Effects of Age, Menu Design and Task Complexity on Navigation Performance

Participants' menu-oriented navigation performances were measured in terms of completion time, correctness rate, the number of incorrect clicks and the number of returns. The description of means and standard deviations of navigation performances are presented in Table 6.4. For the group of the younger group, tasks with a high level of task complexity induced a longer completion time and more times of returns and incorrect clicks overall, as shown in Figure 6.4. When doing the navigation tasks with high level of complexity, the icon-only menu design resulted in longer completion time and more times of returns and incorrect clicks, followed by the menu design of icon-text design. The menu design of text-only resulted in less completion time, returns, and incorrect clicks.

For the group of older adults, the completion time and the number of returns were increased, and the correctness rate was declined when the task complexity level was high (see Figure 6.5). Different from the younger adults, the menu design of text-only didn’t show a dominant advantage for the group of older adults. However, the menu design of icon-text generally resulted in shorter completion time and fewer times of return and incorrect clicks.

Age group	*Interface design*	*Task complexity*	*Completion time (s)*		*Correctness rate (%)*	*Number of incorrect clicks*	*Number of returns*
			Mean (SD)	Mean log (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Younger adults (N=8)	Icon-text	Low	17.00 (5.71)	1.21 (0.15)	100.00 (0.00)	0.00 (0.00)	0.25 (0.46)
		Medium	18.00 (3.93)	1.25 (0.10)	96.88 (8.84)	0.00 (0.00)	0.25 (0.71)
		High	36.88 (6.27)	1.56 (0.07)	100.00 (0.00)	0.13 (0.35)	1.50 (1.69)
	Icon-only	Low	19.00 (5.63)	1.26 (0.14)	96.88 (8.84)	0.13 (0.35)	0.00 (0.00)
		Medium	16.50 (4.31)	1.21 (0.11)	100.00 (0.00)	0.00 (0.00)	0.00 (0.00)
		High	46.00 (15.91)	1.64 (0.13)	100.00 (0.00)	0.63 (1.06)	2.50 (2.33)
	Test-only	Low	18.50 (5.70)	1.25 (0.14)	100.00 (0.00)	0.00 (0.00)	0.00 (0.00)
		Medium	16.63 (3.50)	1.21 (0.09)	100.00 (0.00)	0.00 (0.00)	0.38 (1.06)
		High	37.13 (5.25)	1.57 (0.07)	100.00 (0.00)	0.00 (0.00)	1.13 (1.73)
Older adults (N=7)	Icon-text	Low	44.57 (24.43)	1.60 (0.23)	96.43 (9.45)	0.00 (0.00)	0.29 (0.49)
		Medium	47.57 (23.10)	1.64 (0.20)	85.71 (19.67)	0.00 (0.00)	0.14 (0.38)
		High	77.14 (46.68)	1.82 (0.25)	53.57 (26.73)	0.00 (0.00)	1.00 (1.15)
	Icon-only	Low	37.00 (9.87)	1.55 (0.11)	82.14 (18.90)	0.00 (0.00)	0.29 (0.76)
		Medium	47.71 (28.19)	1.63 (0.20)	89.29 (13.36)	0.14 (0.38)	0.57 (1.13)
		High	94.29 (76.62)	1.87 (0.32)	78.57 (22.49)	0.14 (0.38)	1.00 (1.15)
	Text-only	Low	57.00 (43.44)	1.67 (0.28)	85.71 (19.67)	0.00 (0.00)	0.29 (0.49)
		Medium	44.29 (26.02)	1.60 (0.20)	89.29 (28.35)	0.00 (0.00)	0.14 (0.38)
		High	93.14 (28.37)	1.95 (0.15)	75.00 (28.87)	0.14 (0.38)	1.43 (1.51)

Table 6.4 Participants' menu-oriented navigation performance (N=15)

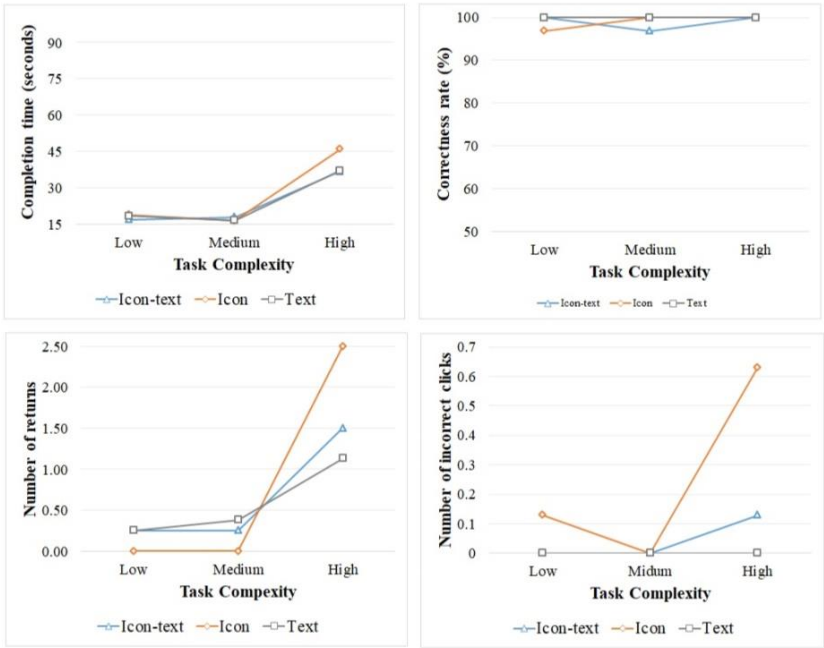


Figure 6.4 Menu-oriented navigation performances of younger adults with different menu design and task complexity

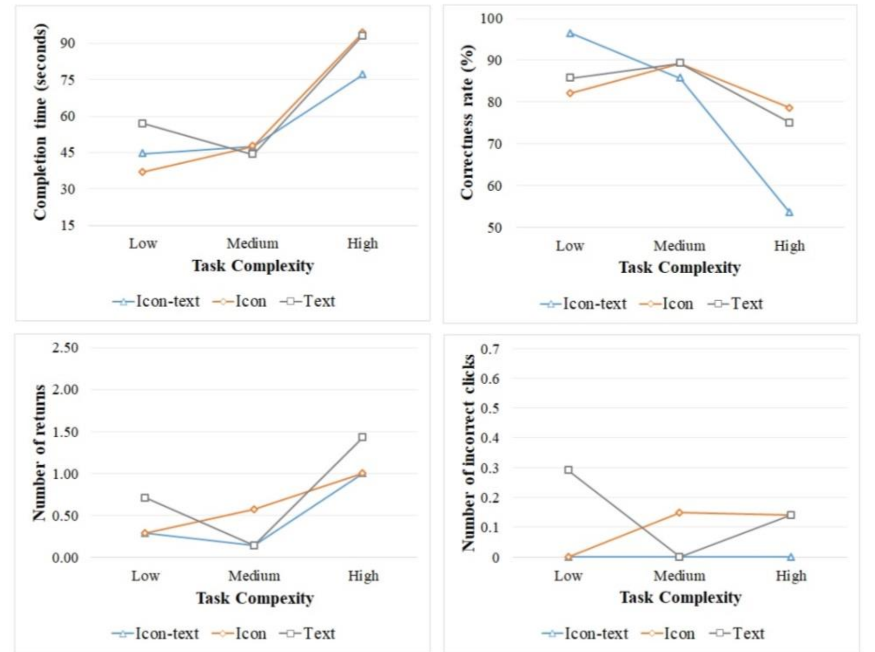


Figure 6.5 Menu-oriented navigation performances of older adults with different menu design and task complexity

6.3.2.1. Completion Time

A mixed 2× 3 × 3 repeated ANOVA was used to examine the influence of age group (younger and older) as a between-subject variable, and menu design (icon-text, icon only and text only) and task complexity (low, medium, and high) as within-subject variables. However, there was no interaction effect found regarding age group, menu design and task complexity. The main effect of task complexity on completion time was reported, $F (2, 26) = 65.22$, $p < 0.001$, partial eta squared 0.834. The Bonferroni corrected post-doc tests showed that there was a significant increase in participants' completion time between the task complexity level of low and high, as well as the level of medium and high respectively; while no significant difference was reported between the task complexity level of low and medium. The influence of age was also significant, $F (1, 13) = 40.87$, $p < 0.001$, partial eta squatted 0.759, showing a significant increase of completion time for the group of older adults than the group of younger adults. However, there was no main effect revealed by the menu design in terms of completion time.

6.3.2.2. Correctness Rate, Number of Incorrect Clicks and Returns

Mann-Whitney test was first conducted to compare the overall differences of correctness rate, number of incorrect clicks and number of returns between the two age groups. No significant difference of correctness rate was reported between age groups for the majority of experimental tasks, except for the task using icon-text menu design with a high level of task complexity ($U = 4.00$, $p = 0.004$). In such a situation, the group of younger adults achieved a significantly higher correctness rate than the group of older adults. Additionally, there was no significant difference reported between various experimental tasks in terms of the number of incorrect clicks and returns.

To investigate the differences between experimental tasks for each group of participants, the Friedman tests were first conducted to analyse the difference of correctness rate, number of incorrect clicks and number of returns between the nine experimental tasks for the group of younger adults. Results indicated there was a marginal statistically significant difference between the nine tasks with different menu design and task complexity in terms of the number of incorrect clicks (χ^2 (8) = 14.800, p = 0.063). In addition, a statistically significant difference was reported in terms of the number of returns depending on tasks with different menu design and task complexity (χ^2 (8) =29.861, p = 0.000).

To further detect where the differences occurred, the Wilcoxon signed-rank test was employed. For the task complexity, the results did not reveal any significant difference in the number of incorrect clicks between tasks with different levels of complexity. Nevertheless, the results indicated that the task with a high level of complexity elicited more times of returns than that with a low level of complexity (Z=-2.207, p=0.027) and that with a medium level of complexity (Z=-2.207, p=0.027) respectively, when using the icon-only menu design. Regarding the menu design, no statistically significant difference was reported in terms of the number of incorrect clicks and returns with different kinds of menu design.

For the group of older adults, statistical differences between tasks with different levels of complexity and menu design were also analysed using the Friedman test. The results reported that significant differences existed in the correctness rate (χ^2 (8) = 16.597, p = 0.035) between tasks. Further analysis of Wilcoxon signed-rank test revealed that the task with a high level of complexity resulted in a significantly lower correctness rate than that with a low level of complexity (Z=-2.220, p=0.026) and that with a medium level of complexity (Z=-2.041, p=0.041) respectively when using the menus with the icon-text design. Nonetheless, there was no significant difference reported between types of menu designs for all the levels of task complexity. In addition, the number of incorrect clicks and returns did not reveal any significant differences depending on the different level of task complexity and menu designs either.

6.3.3. Effects of Age, Menu Design and Task Complexity on Subjective Evaluation

Participants' subjective feelings about the navigation interfaces and tasks were evaluated in terms of ease of use, disorientation, effort needed, helpfulness and satisfaction by 5-point Likert scales. The descriptive data of subjective evaluations were presented in Table 6.5. For the group of younger adults (see Figure 6.6), the menu design of text-only and icon-only induced less disorientation and effort needed than that of icon-text. However, the evaluations of task complexity followed quite a similar pattern between different levels. As for the group of older adults (see Figure 6.7), there was little difference regarding the evaluation of different menu design. As for the evaluation of task complexity, the group of older adults thought the tasks with the high level of complexity was easier to use, less disoriented, and effortless, followed by the tasks with the medium level of complexity and those with the low level of complexity.

The Mann-Whitney test showed that the group of older adults had a higher level of evaluation than the group of younger adults. Older adults thought the interfaces were significantly more helpful than the younger group thought when doing the navigation tasks with low level of complexity (icon-text: U=10.00, p=0.040; text-only: U=6.00, p=0.009), medium level of complexity (icon-only: U =10.50, p=0.040), and high level of complexity (icon-text: U=6.50, p=0.009; icon-only: U=4.00, p=0.004; text-only: U=10.00, p=0.040). Additionally, the group of older adults also had a significant higher satisfaction level than the group of younger adults when doing the navigation tasks with low level of complexity (icon-text: U =10.00, p=0.040; icon-only: U=10.00, p=0.040; text-only: U=5.00, p=0.006), medium level of complexity (icon-only: U=9.50, p=0.029), and high level of complexity (icon-text: U=10.00, p=0.040; icon-only: U=5.00, p=0.006).

To examine the influences of the menu design and task complexity, Friedman tests were further employed to test the differences between the nine tasks in terms of subjective evaluation. However, no statistically significant differences were reported depending on different menu design and task complexity.

Age group	*Interface design*	*Task complexity*	*Ease of use*	*Disorientation*	*Effort needed*	*Helpfulness*	*Satisfaction*
			Mean (SD)	Mean log (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Younger adults (N=8)	Icon- text	Low	4.13 (1.25)	3.75 (1.28)	3.50 (1.20)	2.75 (1.28)	2.87 (1.13)
		Medium	4.38 (1.06)	3.63 (1.19)	3.63 (1.19)	3.13 (1.64)	3.25 (1.49)
		High	3.50 (1.51)	4.13 (0.99)	4.00 (1.07)	2.88 (1.36)	3.25 (0.89)
	Icon-only	Low	4.63 (0.52)	4.38 (0.74)	3.88 (1.55)	3.50 (1.07)	3.13 (0.99)
		Medium	4.00 (1.07)	4.38 (0.92)	3.63 (1.41)	3.13 (1.25)	3.00 (1.31)
		High	4.13 (1.25)	4.38 (0.74)	4.25 (0.71)	2.75 (1.04)	3.00 (0.76)
	Test-only	Low	4.38 (1.06)	4.13 (1.13)	3.63 (1.19)	3.00 (1.20)	3.00 (0.93)
		Medium	4.13 (1.13)	4.38 (0.92)	4.13 (1.36)	3.38 (1.41)	3.38 (1.30)
		High	4.38 (0.92)	4.38 (0.92)	4.25 (1.04)	3.13 (1.36)	3.50 (0.93)
Older adults (N=7)	Icon- text	Low	3.29 (0.76)	3.57 (1.27)	3.29 (1.11)	4.29 (0.95)	4.14 (0.69)
		Medium	4.14 (0.69)	4.29 (0.76)	3.71 (0.95)	4.57 (0.53)	4.43 (0.53)
		High	4.29 (0.49)	4.29 (0.49)	3.71 (0.76)	4.57 (0.53)	4.29 (0.49)
	Icon-only	Low	3.86 (0.69)	3.57 (1.40)	3.29 (0.95)	4.57 (0.53)	4.29 (0.49)
		Medium	4.00 (0.82)	4.14 (0.90)	3.86 (0.90)	4.43 (0.79)	4.43 (0.53)
		High	4.14 (0.69)	4.43 (0.79)	4.00 (0.82)	4.43 (0.53)	4.29 (0.49)
	Test-only	Low	3.57 (0.53)	4.43 (0.79)	3.86 (0.69)	4.57 (0.53)	4.29 (0.49)
		Medium	4.14 (1.07)	3.86 (1.07)	3.57 (1.13)	4.29 (0.76)	4.29 (0.49)
		High	4.29 (0.95)	4.14 (0.90)	3.86 (0.90)	4.43 (0.53)	4.29 (0.49)

Table 6.5 Participants' subjective evaluations of menu-oriented navigation (N=15)

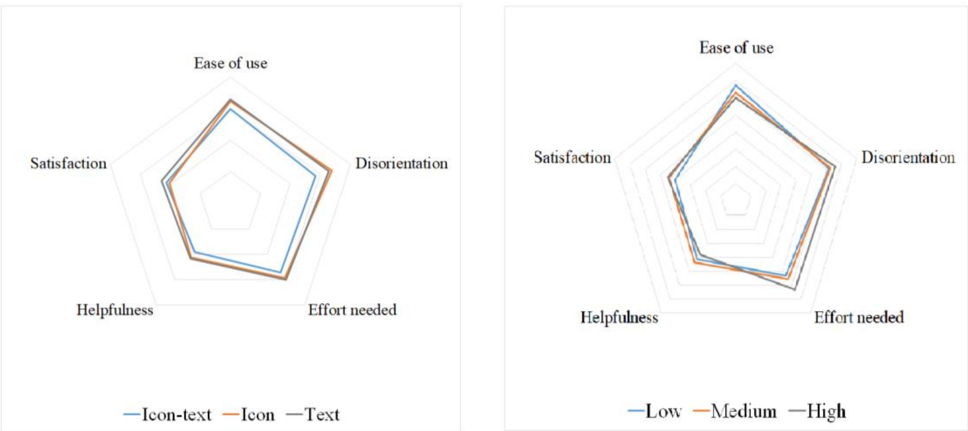


Figure 6.6 Younger adults' subjective evaluation of different menu design (left) and task complexity (right)

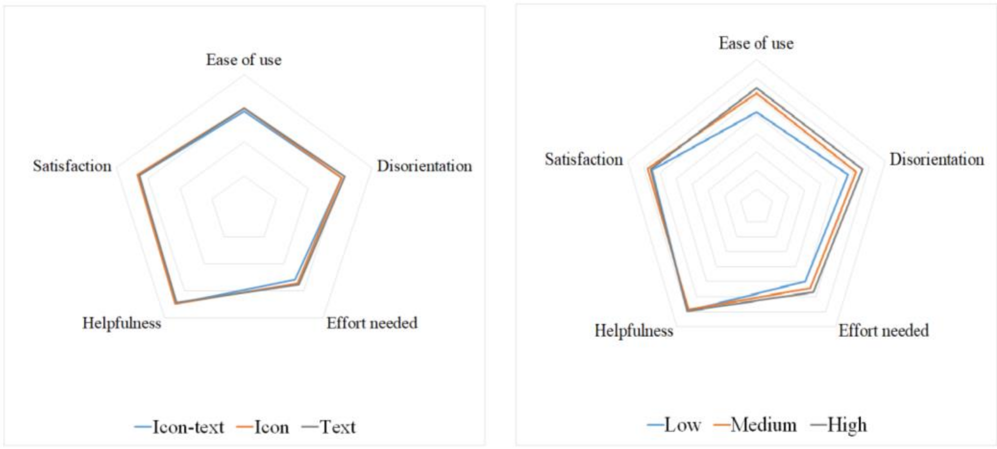


Figure 6.7 Older adults' subjective evaluation of different menu design (left) and task complexity (right)

6.3.4. Relationships between User Characteristics, Navigation Performance and Subjective Evaluation

6.3.4.1. Correlations between User Characteristics, Task Performance and Subjective Evaluation

Spearman test was employed to conduct the correlation analysis between the factors of user characteristics and navigation performance, as well as subjective evaluation. Table 6.6 depicts the significant correlations reported between the user characteristics and dependent variables. For the group of younger adults, the results showed that their navigation performance of the number of returns was significantly correlated with participants' education (p=0.046), duration of use of mobile technologies (p=0.032), and self-efficacy of mobile technologies (p=0.018). Nevertheless, no significant correlation was revealed between the user characteristics and completion time, correctness rate and the number of incorrect clicks.

For the group of older adults, the navigation performances of completion time was found to be significantly related to the participants' education (p=0.003), duration of use of computers (p=0.013), intensity of use of mobile technologies (p=0.001), self-efficacy of mobile technologies (p=0.016), perceptual speed (p=0.046) and contrast sensitivity (p=0.000); correctness rate was significantly correlated with the participants' education (*p*=0.008), duration of use of computers (*p*=0.003), duration of use of mobile technologies (*p*=0.018), self-efficacy of mobile technologies (*p*=0.016), perceptual speed (*p*=0.031) and visual perception (*p*=0.038); and the number of returns was significantly related with the participants' duration of use of mobile technologies (*p*=0.019), diversity of use of mobile technologies (*p*=0.041), spatial ability (*p*=0.005), and contrast sensitivity (*p*=0.003).

As for the subjective evaluation, the Spearman correlation analysis showed that the group of younger adults' perceived disorientation was significantly related to their duration of use of computers (*p*=0.001), diversity of use of mobile technologies (*p*=0.001), self-efficacy of mobile technologies (*p*=0.000), perceptual speed (*p*=0.006), and vision acuity (*p*=0.007); the participants' perceived effort needed was significantly correlated with their intensity of use of mobile technologies (*p*=0.001), diversity of use of mobile technologies (*p*=0.000), and perceptual speed (*p*=0.000); the participants' perceived helpfulness was significantly related to their intensity of use of mobile technologies (p=0.003); and the participants' satisfaction was significantly related to their intensity of use of mobile technologies (*p*=0.000), as well as their self-efficacy of mobile technologies (*p*=0.036).

Regarding the group of older adults, their perceived ease of use was found to be significantly correlated with the participants' education (*p*=0.042), duration of use of mobile technologies (*p*=0.002), self-efficacy of mobile technologies (*p*=0.004), and perceptual speed (*p*=0.003); their perceived disorientation was significantly related to the participants' education (*p*=0.000), duration of use of computers (*p*=0.008), intensity of use of mobile technologies (*p*=0.000), perceptual speed (*p*=0.001), contrast sensitivity (*p*=0.007) and visual perception (*p*=0.030); their perceived effort needed was significantly correlated with the participants' education (*p*=0.004), duration of use of mobile technologies (*p*=0.031), intensity of use of mobile technologies (*p*=0.005), working memory (*p*=0.028), spatial ability (*p*=0.028) and perceptual speed (*p*=0.000); their perceived helpfulness was significantly related to the participants' education

(p=0.000), duration of use of computers (p=0.000), duration of use of mobile technologies (p=0.000), intensity of use of mobile technologies (p=0.000), diversity of use of mobile technologies (p=0.029), self-efficacy of mobile technologies (p=0.002), spatial ability (p=0.002), perceptual speed (p=0.000), and visual perceptions (p=0.000); and their satisfaction was reported to be significantly correlated with the participants' duration of use of mobile technologies (p=0.000), diversity of use of mobile technologies (p=0.000), self-efficacy of mobile technologies (p=0.003), spatial ability (p=0.000), perceptual speed (p=0.003), vision acuity (p=0.015), and visual perceptions (p=0.000).

		Education	***Duration of use of computers***	***Duration of use of mobile technologies***	***Intensity of use of mobile technologies***	***Diversity of use of mobile technologies***	***Self-efficacy of mobile technologies***	***MRT***	***CDT***	***SDMT***	***VA***	***CS***	***VP***
Younger adults (N=8)	Number of returns	-0.236*		-0.253*			0.279*						
	Disorientation		-0.384**			-0.369**	0.435***			0.320**	-0.317**		
	Effort needed				-0.374**	-0.544***				0.612***			
	Helpfulness				0.344**								
	Satisfaction				0.476***		0.248*						
Older adults (N=7)	Completion time	-0.369**	-0.312*		-0.394**		0.303*			-0.252*		-0.446***	
	Correctness rate	0.331**	0.365**	0.298*			0.303*			0.272*			0.262*
	Number of returns			0.294*		0.258*			-0.347**			-0.369**	

Ease of use	0.257*		0.376*			0.354**			0.363**			
Disorientation	0.478***	0.331**		0.444***					0.407*		0.338**	0.273*
Effort needed	0.360**		0.272*	0.350**			-0.278*	-0.302*	0.507***			
Helpfulness	0.634***	0.432***	0.748***	0.517***	0.275*	0.385**		-0.380**	0.785***			0.486***
Satisfaction			0.684***		0.675***	0.363**		-0.589***	0.364**	-0.304*		0.461***

Note: *$p < 0.05$; **$p < 0.01$; ***$p<0.001$

Table 6.6 Significant correlation coefficients r between user characteristics and dependent variables (N=15)

6.3.4.2. User Characteristics Associated with Menu-oriented Navigation Performance and Subjective Evaluation

A hierarchical regression analysis with a stepwise inclusion specification (backward selection, $p<0.05$) was used to examine the associations between the independent variables of age groups, menu design, task complexity and user characteristics and the dependent variables of navigation performance and subjective evaluations for the group of younger adults and older adults respectively. In total, two regression models were developed for younger adults' navigation performance of completion time and the number of returns, and three regression models were developed for their subjective evaluation of disorientation, helpfulness, and satisfaction. At the same time, three regression equations were developed for the older adults' navigation performance of completion time, correctness rate and the number of returns, and five regression equations were developed for their subjective evaluation of ease of use, disorientation, effort needed, helpfulness and satisfaction. Table 6.7 summarises the results of these multiple regressions.

For the group of younger adults, the navigation performance of completion time was found to be predicted by the level of task complexity (β= 0.698, p=0.000) and their perceptual speed (β= -0.168, p=0.049), resulting in a model with R^2=0.515; and the number of returns was also found to be predicted by the level of task complexity (β= 0.449, p=0.000) and diversity of use of mobile technologies (β= 0.209, p=0.040), resulting in a model with R^2=0.325. In other words, the tasks with the high level of complexity would induce longer completion time and more times of returns; whereas, a higher level of perceptual speed can compensate the declined efficiency caused by the increased task complexity. In addition, the use of more functions would also contribute to longer completion time.

For the group of older adults, the navigation performance of completion time was found to be associated with the level task complexity (β= 0.414, p=0.040), participants' education and duration of use of computers, resulting in a model with R^2=0.464. Specifically, participants with higher level of education could complete the navigation tasks in a short time (*β*= -0.951, *p*=0.040), but those with longer duration of using computers performed worse in terms of the completion time (*β*= 0.560, *p*=0.005). In addition, the older adults' navigation performance of correctness rate was found to be predicted by the level of task complexity (*β*= -0.335, *p*=0.003), participants' duration of use of computers (*β*= 0.262, *p*=0.019), self-efficacy of mobile technologies (*β*= 0.231, *p*=0.041), and visual perceptions (*β*= 0.232, *p*=0.045), resulting in a model with R^2=0.341. Furthermore, the older adults' navigation performance of the number of returns was also significantly and positively associated with the level of task complexity (*β*= 0.279, *p*=0.023) and participants' diversity of use of mobile technologies (*β*= 0.249, *p*=0.042), resulting in a model with R^2=0.140.

Regarding the subjective evaluation of the younger adults, the disorientation was found to be significantly associated with the menu design, and participants' duration of use of computers, diversity of use of mobile technologies, and self-efficacy of mobile technologies, resulting in a model with R^2=0.578. The menu design of text-only resulted in the least disorientation, followed by the menu design of icon-only and icon-text (*β*= 0.193, *p*=0.018). At the same time, participants who had a longer duration of use of computers (*β*= -0.361, *p*=0.000), used more mobile functions (*β*= -0.543, *p*=0.000), and had a lower level of self-efficacy of mobile technologies (β= 0.525, p=0.000) tended to have more possibilities of feeling disorientation. Second, the younger adults' evaluation of the effort needed could be predicted by the participants' diversity of use of mobile technologies and perceptual speed, resulting in a model with R^2=0.438. Participants who used less mobile functions (β= -0.432, p=0.000)) and had a higher level of perceptual speed (β= 0.431, p=0.000) tended to believe the navigation design as less effort needed. Third, the helpfulness was also found to be significantly influenced by the younger adults' user characteristics, resulting in a model with R^2=0.371. Participants with higher level of education (*β*= 0.741, *p*=0.000), higher frequency of mobile technology use (*β*= 0.912, *p*=0.000), higher level of perceptual speed (*β*= 0.369, *p*=0.006) and high vision acuity (*β*=

-0.300, *p*=0.005) tended to evaluate higher in terms of helpfulness. In addition, the participants with higher level of education (*β*= 0.917, *p*=0.000), shorter duration (*β*= 0.201, *p*=0.037) and higher frequency (*β*= 0.794, *p*=0.000), and higher level of self-efficacy of mobile technology use, (*β*= 0.568, *p*=0.000), tended to be satisfied for the navigation tasks, with a model R^2=0.632.

As for the group of older adults, their subjective evaluation of ease of use was found to be predicted by the level of task complexity (*β*= 0.351, *p*=0.002), participants' duration of use of mobile technologies (*β*= 0.532, *p*=0.000) and vision acuity (*β*= 0.283, *p*=0.025), resulting in a model with R^2=0.334. Participants' disorientation was found to be significantly predicted by their education and duration of use of computers, resulting in a model with R^2=0.286. Overall, participants with a higher level of education (*β*= 0.884, *p*=0.000) and less experience with computers (*β*= -0.462, *p*=0.040) tended to feel less disorientation during the navigation tasks. Participants' evaluation of the effort needed was found to be significantly associated with participants' perceptual speed, resulting in a model with R^2=0.247, in which older adults with a higher level of perceptual speed tended to feel effortless (β= 0.497, *p*=0.000). As for the evaluation of helpfulness, it was indicated that participants with lower level of education (*β*= -0.578, *p*=0.001), higher level of self-efficacy of mobile technologies (*β*= 0.318, *p*=0.000), higher level of perceptual speed (*β*= 1.468, *p*=0.000) and worse visual perceptions (*β*= -0.361, *p*=0.000), tended to feel the application as helpful, resulting in a model with R^2=0.789. In addition, it was also reported that the older adults' improved satisfaction could be significantly predicted by a shorter duration of use of computer (*β*= -0.794, *p*=0.000), longer duration of use of mobile technologies (*β*= 1.048, *p*=0.000), higher level of self-efficacy of mobile technologies (*β*= 0.147, *p*=0.021), and higher level of contrast sensitivity (*β*= 0.384, *p*=0.000), which resulted in a model with R^2=0.833.

	Independent variables	***Dependent variables***							
		Navigation performances				Subjective evaluations			
		Completion time	Correctness rate	Number of returns	Ease of use	Disorientation	Effort needed	Helpfulness	Satisfaction
Younger adults (N=8)	Task complexity	0.698***		0.449***					
	Menu design					0.193*			
	Education							0.741***	0.917***
	Duration of use of computers					-0.361**			
	Duration of use of mobile technologies								-0.201*
	Intensity of use of mobile technologies							0.912***	0.794***
	Diversity of use of mobile technologies			0.209*		-0.543***	-0.432***		
	Self-efficacy of mobile technologies					0.525***			0.568***
	SDMT	-0.168*					0.431***	0.369**	
	VA			-0.296**				-0.300**	
	R^2	0.515		0.325		0.578	0.438	0.371	0.632
Older adults (N=7)	Task complexity	0.414**	-0.335**	0.279*	0.351**				
	Education	-0.951**				0.884***		-0.578**	

Duration of use of computers	0.560**	0.262*			-0.462*			-0.794***
Duration of use of mobile technologies				0.532***				1.048***
Diversity of use of mobile technologies			0.249*					
Self-efficacy of mobile technologies		0.231*					0.318***	0.147*
SDMT						0.497***	1.468***	
VA				0.283*				
CS								0.384***
VP		0.232*					-0.361***	
R^2	0.464	0.341	0.140	0.334	0.286	0.247	0.789	0.833

Note: $*p<0.05$; $**p<0.01$; $p<0.001$

Table 6.7 Standardised coefficients Beta of hierarchical regression for navigation performance and subjective evaluations depending on age groups

6.4. Discussion

6.4.1. Comparison of Mobile Interface Navigation between Age Groups

The results of this study can partially support hypothesis H6.1. First, it showed that older adults indicated significantly poorer navigation efficiency than younger adults in terms of completion time, which were consistent with previous literature on information searching (de Barros et al., 2014) and menu navigating (Gatsou et al., 2011). On average, older adults spent twice as long as younger adults. Nevertheless, limited statistically significant differences were reported between the age groups in correctness rate and the number of return and incorrect clicks. A significant decline of correctness rate was indicated for older adults when using the icon-text menu design with a difficult level of task complexity compared to younger adults, who maintained a high and stable correctness rate. In addition, some differences between the age groups were found in terms of their navigation paths. Overall, the younger adults returned more steps and had more incorrect clicks with tasks of high complexity; while, the older adults made fewer steps to return to previous pages. Additionally, the older adults held more positive attitudes about their navigation experiences. They indicated a significantly higher rating of helpfulness and satisfaction for the menu designs and digital tasks. It can be explained by their general positive attitudes toward life (Sayers, 2004).

6.4.2. Effects of Menu Design

Menu-oriented navigation tasks involve several visual exploration and processing actions, thereby emphasising the crucial roles played by menu design. However, the current study did not find any statistically significant effect of the three menu designs on users' navigation performance and subjective evaluations. Hypothesis H6.2 was not supported. This may be because the length of time spent searching for specific menu items accounted for a very small portion of the completion time. Thus the variance of the completion time could not be easily detected. On the other hand, the eight icons used in this study were very distinctive from each other, so fewer difficulties developed and less effort was required when the participants were searching and recognising these menu items.

Though there were limited significant results reported by the present study, a usage pattern of different levels of redundancy design could be found based on the results. Consistent with the previous research of Schröder and Ziefle (2008), for the group of younger adults, the text-only menu design seemed to have better navigation performance, and the icon-only design induced increased completion time, more return steps and more incorrect clicks, especially for the tasks with high level of complexity. For older adults, the icon-text menu design resulted in shorter completion time, fewer steps of returns and fewer incorrect clicks when the complexity level was low. When the complexity level was high, this menu design induced a reduced completion time while simultaneously decreasing the correctness rate. To conclude, although the results were not statistically significant, they still partly support the assumption that a redundancy design facilitates older adults' comprehension of menu-oriented navigation items, which was consistent with previous studies that emphasised the effectiveness of a redundancy design for reducing users' comprehension and memory loads (Wicken and Hollands, 2000; Sweller, 2002; Wicken et al., 2004).

6.4.3. Effects of Task Complexity

This study defined the task requirements as the number of information sources that users need to remember and integrate. As expected, the present study reported that task efficiency was significantly decreased when the task required the integration of multiple information sources for both age groups. At the same time, the navigation effectiveness was considerably decreased when using the icon-text menu design for the group of older adults with a high level of task complexity. Thus, hypothesis H6.3 was partially supported. Nevertheless, younger users maintained a high and stable correctness rate but made more return steps at a high level of task complexity, especially when using the icon-only menu design. No statistically significant difference was found regarding the subjective evaluations between the various task complexity levels, which did not support hypothesis H6.3 in terms of the effects of task complexity on participants' subjective valuations.

Previous studies stated that the number of navigation elements displayed should be determined by users' visual ability of scanning and searching (Juvina and van Oostendorp, 2010). However, in realistic usage scenarios, the task may generate a number of information sources for the user to remember. Users may also need to integrate information from other sources to fulfil the specific functional goals. This study reported that the navigation performance was not influenced by the task that involves low level of memory, for instance, finding the information that was exactly matched with the keyword in task description. Nevertheless, the navigation performance can be significantly decreased if the task demands a number of information sources that needed to be integrated. The results can be explained by previous studies examining task complexity for computers that claimed users need more mental work to compare navigation items against the goal state kept in their working memory and to determine whether the navigation items meet the task criteria (Leuthold et al., 2011).

6.4.4. Role of User Characteristics

Mobile navigating on a limited-size touch-screen is a complicated process. Therefore, understanding target users' capabilities and limitations can assist in decreasing their workload when designing mobile technologies. In addition to task complexity, this study reported that the participants' overall navigation performances were significantly associated with their education, technology experience and user capabilities, supporting hypothesis H6.4. Participants with higher education levels completed the task more quickly, which may be because longer education experience compensates for the relevant loss in cognitive capabilities when performing technological tasks (Habib et al., 2007). Technology experience was found to significantly influence users' navigation strategies. Participants who used more functions of mobile technologies tended to do more returns when navigating. Technology experience also played important roles in predicting users' subjective evaluations of ease of use, disorientation, effort needed, helpfulness and satisfaction. Furthermore, higher levels of working memory and perceptual speed were found to increase users' navigation effectiveness significantly. Together with other capabilities such as spatial ability, visual acuity, contrast sensitivity and visual perceptions, they can also influence users' subjective evaluations such as disorientation, effort needed, helpfulness and satisfaction.

The results showed that the capability of perceptual speed was important for users' mobile navigation behaviour regarding objective performance and subjective preference. Participants with higher levels of perceptual speed navigated more efficiently, especially in the group of younger adults. Perceptual speed was also significantly and positively associated with evaluations of effort needed and helpfulness for both older and younger adults. However, spatial ability was not found to influence users' navigation performance significantly. The results contrasted with previous studies that emphasised the importance of spatial ability on improving web navigation performance (Chen, 2001; Juvina and van Oostendorp 2006; Pak et al., 2006; Puerta Melguizo et al., 2012). When navigating with computerised website, the deep hierarchical information structures need users develop accurate mental models to represent the relationship between pages, which emphasises the role of spatial ability (Juvina and van Oostendorp, 2010). Nevertheless, it is easier to navigate between different pages when using touchscreen-based mobile technologies and the users can get to more information in a shorter time. Thus, it requires a higher level of divided speed and perceptual speed to access more patches of information at the same time.

6.5. Summary

This chapter outlined an experimental study that investigated older adults' mobile-oriented navigation behaviour compared to younger adults. By understanding how older adults navigate menus and quantifying the complex relationships between the predictive variables of user characteristics, task complexity and menu design, this study partly answered the research question Q5. To develop a user model for older adults' menu-oriented navigation behaviour, it is essential to include the factors of task complexity, demographic factors of age and education levels, technology experience of duration of use of computers and duration of use, diversity of use and self-efficacy of mobile technologies, as well as cognitive capabilities of perceptual speed, visual acuity, contrast sensitivity and visual perceptions. Although menu design has no statistically significant influences on older adults’ mobile navigation, it was recommended that the redundancy design of an icon-text menu could improve older adults' understanding of menu items.

This study clarified what variables should be included and how they should be modelled for the user modelling of older adults’ mobile navigation behaviour, focusing on the aspect of menu-oriented navigation. As reported in Chapter 5, content-oriented navigation could be beneficial to facilitate older adults’ navigation behaviour and was also less-evaluated in previous research. Thus, another experimental study is necessary to completely answer the research question Q5 by investigating the predictive variables for older adults’ content-oriented mobile navigation behaviour. Chapter 7 outlines the entire experiment and analyses for content-oriented mobile navigation, and Chapter 8 discusses the research questions proposed in Chapter 1 and finalises the user modelling for older adults’ mobile navigation behaviour.

CHAPTER 7 Study Four: An Experimental Analysis of the Content-oriented Navigation Behaviour

7.1. Introduction

The results of Chapter 5 explicitly summarised the advantages and disadvantages of the two streams of mobile navigation behaviour: menu-oriented navigation and content-oriented navigation. The experiment described in Chapter 6 examined older adults' menu-oriented navigation performance and subjective evaluation and addressed possible relationships among user characteristics, task complexity and menu design. However, content-oriented navigation behaviour has attracted limited attention, since this pattern was more recently proposed with the launch of mobile technologies. Nonetheless, with the development of touchscreen mobile technologies, more mobile applications are depending on content to create hierarchies and focuses. Furthermore, the usability test presented in Chapter 5 proposed content-oriented navigation as a more promising design strategy to guide older adults' mobile navigation behaviour than traditional menu-oriented navigation, which necessitated an investigation of this navigation design.

Therefore, towards the objective of developing a user model for older adults' navigation behaviour with mobile technologies, this study is aimed to investigate older adults' content-oriented navigation behaviour and examine the possible influences of the user characteristics, task complexity and interface design. It is also implemented to examine which kinds of interface design can better guide older adults' content-oriented navigation and induce an improved user experience within different task contexts and information content.

Specifically, the assumptions of this study were developed based on the literatures reviewed in Section 2.5.1.2: that the application of interface metaphor can help in facilitating older adults' cognitive processes when navigation (Zhou et al., 2017), by making a full use of the mobile screen, representing clearer spatial relationships between information patches and enabling a more natural and intuitive way of interaction (Molina et al., 2003).

Two kinds of interface design were implemented depending on the application level of metaphor design: one is an abstract design of 2D list pattern, and one is a metaphor design of 3D card pattern. Also, based on the findings described in Chapter 6 that the perceptual speed was one of the crucial capabilities influencing the older adults' menu-oriented navigation behaviour, this study recruited two groups of older adults with different levels of perceptual speed. In addition, the task complexity was also manipulated according to the difficulty of the information relevance and the information content was designed based on a different level of similarity. Four hypotheses were developed in this study: H7.1. Participants with higher level of perceptual speed will perform better in terms the content-oriented navigation performance and have higher level of subjective evaluations towards the content-oriented navigation design; H7.2. The interface with metaphor design will improve the participants' content-oriented navigation performance and subjective evaluations; H7.3. Participants will have better navigation performance and higher subjective evaluation when completing the tasks with lower level of complexity than those with higher level of complexity; H7.4. Participants will have better navigation performance and higher level of subjective evaluation when navigating the content with lower level of similarity than that with higher level of similarity;.

7.2. Method

7.2.1. Participants

Twenty-Two participants were recruited from three local community elderly centres by leaflet and verbal advertisement. All of them were Hong Kong Chinese adults who aged above 60 years old and had the usage experience with smartphones, tablets and relevant mobile applications. Participants indicated capabilities in reading Chinese characters and were in good physical conditions without any cognitive impairment. Each participant received a 100 Hong Kong dollars supermarket coupon as a reward for participating in the experiments.

7.2.2. Experimental Design and Materials

To study the influences of perceptual speed, interface design, information content, and task complexity on older adults' mobile navigation performance and subjective evaluations, a $2 \times 2 \times 2 \times 2$ factorial design was employed, with the factor of perceptual speed (low and high) as a between-subject variable, and interface design (2D list and 3D card), information content (high similarity and low similarity), and task complexity (low and high) as within-subject variables. Dependent variables were participants' navigation performance of completion time and correctness rate and subjective evaluations of the difficulty of tasks, and ease of use, perceived usefulness, effort needed, disorientation, satisfaction and behavioural intention to use of interfaces.

7.2.2.1. Investigation of User Characteristics

Before the experiment, participants' demographic information, technology experience, and user capabilities were examined by a questionnaire-based interview (see Appendix B). The first section was mainly used to collect participants' demographic factors of age, gender, and education and technology experience of the duration of use of previous generations of technology such as computer, duration of use of mobile technologies, intensity of use of mobile technologies, diversity of use of mobile technologies and self-efficacy of mobile technologies. Duration of use referred to how many years the participants have used computers or mobile technologies such as smartphones and tablets. The frequency of use meant the frequency of mobile technology use per week. The diversity of use referred to how many functions participants have been used, for various purposes including basic functions of calling and sending the message, social networking, entertainment, information searching and learning, health maintaining and so on. Additionally, self-efficacy was assessed by asking the participants to verbally evaluate their competence regarding mobile technologies usage based on a 5-point Likert scale. In the second section, participants' user capabilities, comprising of several cognitive capabilities and visual abilities, were measured by performances tests and self-reporting methods.

Perceptual speed

Perceptual speed was measured by the Symbol Digit Modalities Test (SDMT) (Benedict et al., 2012). During the test, a coding scheme and task sheet were provided for the participants on the same paper. The coding scheme included nine abstract symbols which were pair-wised with nine digital numbers, and the task sheet was comprised of randomly arranged abstract symbols. Participants were then required to fill in as many of the pair-wised numbers as they can in the task sheet, based on the coding scheme sheet presented at the top. The score was calculated accordingly to the number of correctly matched symbols completed by each participant in 90 seconds, which were ranged from 0 to 90. Since the score differences between participants were quite significant, participants were divided into two groups: the first group with low perceptual speed (scored 0-33) and the second group with high perceptual speed (scored 34 and above).

Working memory

Working memory was measured by the auditory number span test (ANST), which was selected from the Kit of Factor referenced cognitive tests (Ekstrom et al., 1976). This test was used to measure the ability to store and retrieve a number of distinct elements in the short-term memory. Since the working memory is reported to be not influenced by the way of presentation, such as visual or auditory, the auditory span test was selected here because of its greater operability. In the test, the experimenter read a series of digits at a speed of one digit per second at first. Until the experimenters have finished the whole series, participants were required to repeat these numbers in the exact order verbally. Participants were given another chance for each length of digits series if they failed in the first try. The length of the digits series would be increased till the participants failed in two attempts. The score was marked as the number of digits that the participant repeated correctly in the exact order.

Spatial Ability

Subsequently, the spatial ability was measured by the card rotation test (CRT), which was also selected from the Kit of Factor referenced cognitive tests (Ekstrom et al., 1976). This test was used to evaluate participants' ability to perceive spatial patterns and maintaining orientation for objects in space. In the test, participants were given a drawing of a card that was cut into an irregular shape. On the right of this card, there were eight drawings of the same card, in which some of the drawings were merely rotated and flipped. Participants needed to indicate whether or not the eight drawings have been turned over. Before the test, the participants were instructed in details and were given sufficient time to familiarise the tests by doing three practices. After that, two parts were included in the formal test. Participants were asked to finish the test as quickly as possible without sacrificing accuracy in three minutes. The score was marked as the number of cards that answered correctly minus the number of cards that answered incorrectly. Thus participants were told there would be no advantages to guess the answers.

Sustained Attention

Participants' sustained attention was examined by the Stroop colour and word test (SCWT), which has been extensively utilised for clinical and experimental purposes. In particular, it can access the participants' ability to inhibit cognitive interference, which occurs when the processing of attributes was affected by the simultaneous processing of another attribute of the same stimulus (Stroop, 1935). It was comprised of three tables with different words printed in seven colours. The first two tables presented the 'congruous condition', in which participants were either required to name different colour patches (C) or read the name of colour-words that printed in black ink (W). Conversely, the third table presented an incongruous condition, in which the colour-words were printed in an inconsistent colour ink (CW). For example, the word 'black' was printed in red ink. For each test, participants were asked to read three tables as fast as they can in 45 seconds. According to the scoring method proposed by Golden (1978), the score was calculated as IG=CW-(W×C)/(W+C).

Visual Perception

Finally, an interface of a tablet, that was comprised of various sizes of texts, pictures and icons, was used to evaluate the participants' visual perceptions in recognising and reading digital displays. Participants were asked to verbally report their perceived difficulties when reading the whole interface based on the 5-point Likert scales, from extremely difficult, very difficult, medium difficult, a little difficult, and not difficult at all.

7.2.2.2. Materials and Tasks

Interface and Navigation Design

A simulated iBook store was implemented by C# programming language on a Samsung phone (Galaxy C7 Pro) with a resolution of 1080×1920 pixels. When navigating the application, participants could access various books by browsing through categories to check the book name, author name, publication time, as well as a content introduction and author biography. As shown in Figure 7.1, there were four pages included in the iBook application: (1) a task description page with a start button, where the participants were informed to find a book that matched the keywords of task instruction; (2) a homepage with twelve books presented in the format of 2D lists or 3D cards navigation design, where the participants could tap the list or card item to enter the page of content introduction. Specially, the book presented in the card format could also be directly selected in this homepage by taping the button of 'adding to favourite', but the book that presented in the list format can only be selected in the detailed content page; (3) a detail content page that introduced about the book category, book name, as well as the content introduction and author biography, where participants could select the book by taping the button of ‘adding to favourite’ on the right-top corner of the interface; (4) an ending page that indicated whether or not the participants have selected the correct book. In addition, once the participants forgot the task instruction, they can click the return button placed on the left-top corner of the homepage to re-check the task description page. However, participants were told that the times of returning would be recorded and may influence their navigation performances.

(a) Task instruction (b) Home pge (card) (c) Home page (list)

(d) Detailed content page (e) Completing

Figure 7.1 Interfaces of the experimental i-Book mobile application

Based on the results of Study Two described in Chapter 5, two kinds of content-oriented navigation design were employed in this study: a 2D list interface and 3D card interface. First, the navigation design of 2D lists was used for the homepage, with the twelve book lists stacked linearly, as shown in Figure 7.2. Each of the list items contained the book category, book name, the name of the author, and publication time. The 2D list interface could be scrolled up and down, with four entire list items and one half-presented list item shown at once maximally. Regarding the 3D card interface, the homepage was designed as book cards stacked one by one, as shown in Figure 7.3. Each of the card items was comprised of the book category, book name, the name of author, publication time, and half a part of the book introduction. When navigating, the card items could be flipped up and down. There was only one card entirely presented on the screen at once, with all the historical cards stacked behind it and one preview card presented below it. In addition, the book categories of the nearest historical card and the preview card were also displayed on the screen at the same time.

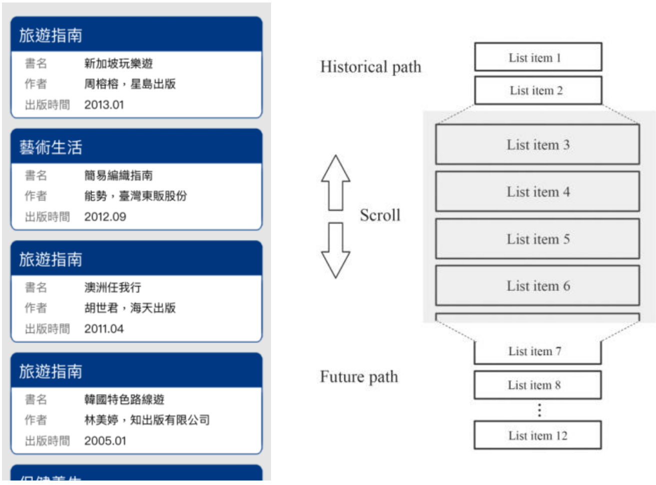


Figure 7.2 Navigation design of the 2D list

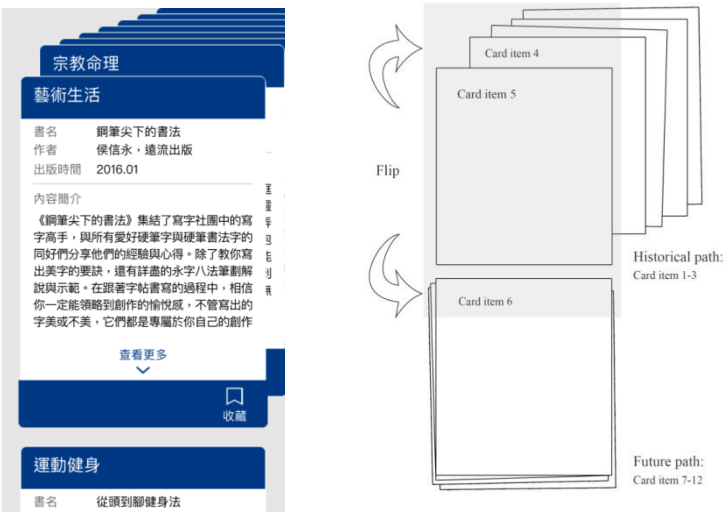


Figure 7.3 Navigation design of the 3D card

Materials and Information Content

In total, 144 pieces of materials were created for the application use, including twelve categories of books with twelve books under each category. All the book materials were selected from Hong Kong Chinese publications of Google books (https://play.google.com/store/books) and Sanmin iBook store (http://www.sanmin.com.tw/Home/Index.html). Two local language experts helped in revising and simplifying the book materials to lessen the possible impacts of various levels in language understanding. At the same time, the book names that included the information cues with the task description were rewritten. The number of words for the book introduction was limited to approximately 210, and the number of words for the author biography was limited to approximately 125. The overview of materials are presented in Table 7.1.

Each time, the application randomly selected twelve books from the pool of materials, including one target book and eleven confounding books without repletion. Two levels of content similarity were implemented for the experiment. For the content with high similarity, there were four books selected from the same category, and there were four categories covered. For the content with low similarity, there was only one book selected from each category, and there were twelve categories covered. Thus, the categories of books used for this task were completely different from each other.

Task Complexity

In this study, navigation tasks were designed with two levels of complexity according to whether there was one criterion or two criteria when searching for the books. Tasks with low level of complexity only had one criterion, that participants were asked to find the book that was exactly matched with the keywords described in the task instruction (e.g. ‘please find the book related to weight-loss diet for your family’, in which the keywords of ‘weight-loss diet’ were highlighted in red). For the tasks with high level of complexity, there were two criteria. First, participants needed to find the books that matched with the keywords described in the task instruction; at the same time, they needed to choose the author who had more experience in relevant area (e.g. ‘please find the book that teaches about home cooking, and select the one whose author had longer cooking experience’, in which the keywords of ‘home cooking’ were highlighted in red). In the tasks with high complexity, there were at least two books that matched with the keywords of the task instruction. Thus the participants had to compare the author details to select the targeted book. After determining the targeted book, they could select the book by adding them to favourite. If they chose the wrong book, the interface would remind them to try on more time. The task would be finished only when the correct book was selected. A complete list of the English translation of task instructions can be found in Table 7.2.

Category	***Number of books***	***Book sample***	
Cooking and food	12	Book category	Travel guide
Exercises and sports	12	Book name	Walking in a passionate country
Arts and entertainment	12	Author name	Mingsheng Xiang
Healthy living	12	Publisher	Wanli Bookstore
Travel guide	12	Publication time	2006.05
Life planning	12	Content introduction	Brazil has three treasures: Samba, beauty and football. Brazil is the only team that won five World Cups and the only national team that has never missed the World Cup finals. Samba Carnival in Brazil is the biggest party across the world. It is crazy that all the people are a carnival for all night long. Brazil also has the world's largest river and tropical rainforest: the Amazon. However, Brazil has everything except monuments. Different from Peru of Inca kingdom and Mexico of the Mayan civilisation, only a handful of primitive tribes lived in the forest when Portuguese navigators came here 500 years ago. Thus, the image of Jesus is the youngest one of the seven wonders of the world.
Religion and Spirituality	12		
Language learning	12		
Business and Investing	12		

Computer and Technology	12	Author biography	Mingsheng Xiang is officially an ordinary white-collar in Tsim Sha Tsui, good at travelling and writing. He travelled in footprint in more than seventy countries around the world. In recent years, he combined the philosophy of art with travelling and published the book《five thousand》, which was the consecutive champion on the ebook list for 13 days.
Fiction and literary collections	12		
History and biography	12		

Table 7.1 Navigation material used in the study, translated by the authors.

Task	*Task description*
Low complexity	If you are an elder who is aged over 65 years old and hope to do some simple exercises, such as practising a front bend. Please find a book related to the forward bending exercise and add it to your favourite.
	Your friend wants to return to work and start a business after retirement. To help him master the rules of entrepreneurship, please find a book introducing about the elderly entrepreneurial experience and add it to the favourite.
	You are planning a long-distance railway journey from Hong Kong recently. Please find a book that suits your journey and add it to your favourite.
	One of your family members has recently been working on a slimming program and wants to make foods that better for slimming. Please find a book related to weight-loss diets and add it to your favourite.
	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 favourite.
High complexity	Recently you are interested in home cooking and want to learn from the chef who has richer culinary experience. Please compare the books about home cooking and choose a book written by the author who has the most extensive cooking experience, and adds it to your favourite.
	One of your family members is currently looking for some simple fitness exercises that are suitable for indoors, such as at home or in the office. Please compare the books about indoor fitness and choose the one whose author has the most extensive fitness experience, and add it to your favourite.
	You are recently planning a European tour. Please compare the books about the European journey and choose one book written by the author with the most extensive travelling experience, and add it to your favourite.
	Your friend has diabetes mellitus, and you want to know more about the treatment and maintenance of diabetes. Please compare the books about diabetes and choose one that is written by the author with the richest experience in diabetes treatment, and add it to your favourite.
	Recently you are very interested in digital photography and want to learn about digital photography in many aspects. Please compare the books on digital photography and choose a book written by the author with the most extensive industry experience, and add it to your favourite.

Table 7.2 Overview of task descriptions, translated by authors.

7.2.2.3. Measures: Navigation Performance and Subjective Evaluations

Navigation performance was measured by the completion time and correctness rate of each task. Completion time was counted in seconds from when participants clicked the 'start' button till they clicked the 'adding to favourite' button for the target book, and correctness rate was calculated by dividing the times of tapping the 'adding to favourite' for the targeted book by the total times of tapping the 'adding to favourite' button. Subjective evaluation was measured in two steps by the 5-point Likert scales from 1 (strongly disagree), 2 (disagree), 3 (medium), 4 (agree) to 5 (strongly agree). First, after each task, participants were asked to evaluate their perceived difficulty towards the task. Second, after finishing the tasks for each kind of interface, the participants needed to further evaluate their preferences regarding the ease of use, perceived usefulness, effort needed, disorientation, satisfaction and behavioural intention to use on these interfaces, as shown in Table 7.3.

Object	***Category***	***Item***	***Questions***
Task	Perceived difficulty	PF	This task is easy for me to complete.
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 needed	EF	I do not need a lot of effort to fulfil 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.
	Behavioural intention to use	BITU	I intend to continue to use this kind of interface if there are opportunities in the future.

Table 7.3 Interview questions on participants' subjective evaluations

7.2.3. Procedure

First, the participants were asked about their demographic information and technology experience before the experiment. Then, the participants were instructed to complete a series of capability tests including SDMT, ANST, CRT, and SCWT, as well as a self-reporting evaluation of their visual perceptions.

Following, participants were introduced to the experimental tasks in details by two experimenters (see Appendix B). Twelve book categories were introduced by the experimenters one by one, to assure an overall familiarity with the materials used for the participants. Two kinds of interfaces were then shown for the participants on the screen. The requirements of tasks with two levels of complexity were also explained respectively. Participants were instructed how to begin and end the task, how to navigate with different interfaces by clicking, tapping, scrolling, flipping, and how to return to previous pages (Figure 7.4). In addition, the participants were informed to take the time in reading the task instructions and searching for the target book, and there would be no benefit to guess the answers because the correctness rate would then be significantly decreased.

Participants were then asked to complete three trial tasks to familiarize themselves with the mobile application. After the trails, participants were free to ask any questions with the experiment. With no questions, they could start the experiment (Figure 7.4). For the experiment, there were 2 (2D lists and 3D cards) ×2 (content with high and low similarity) ×2 (low complexity and high complexity) settings. Each participant needed to complete eight tasks that randomly generated from the task pool presented in Table 7.2. Between each task, the participants had 30 seconds to rest and evaluate their perceived difficulty on each task. After the completion of 4 tasks for each interface, participants were asked to report their subjective evaluations for the interface on the ease of use, usefulness, effort needed, disorientation, satisfaction, and behavioural intention to use.

Figure 7.4 Experimental process: an experimenter was explaining how to use the mobile application (left), and a participant was completing the experimental tasks by himself (right)

7.2.4. Data Analysis

Participants' navigation performance was measured by the completion time and correction rate, and their subjective evaluation was collected by their perceived difficulty towards each task and ease of use, usefulness, effort, disorientation, satisfaction and behavioural intention to use towards each interface. In this study, an alpha level of .05 was used for statistical analysis.

First, a descriptive analysis was conducted for the factors of user characteristics. Then, the Pearson and Spearman correlation analysis were utilised to analyse possible relationships between these factors of user characteristics, and navigation performances and subjective evaluations. Furthermore, the multiple regression analysis was used to ascertain factors of user characteristics that were associated with participants' navigation performance and subjective perceptions overall and for different conditions.

The Shapiro-Wilk test showed that the data of completion time became normally distributed after the log-transformed. Thus, a three-way mixed ANOVA was used to evaluate the interaction effects of experimental variables on completion time. Simultaneously, the Friedman test and Wilcoxon signed-rank test were employed to analyse the differences between various experimental settings for the dependent variables that were not normally distributed such as correctness rate and subjective evaluations.

7.3. Results

7.3.1. Description of User Characteristics

There were twenty-two participants (8 males and 14 females) who aged from 62 to 82 years old attending the experiment, with an average age of 69.7 years old (SD=6.02 years). Participants reported a range of education level, from below the primary school (0 years) to the university level and above (17 years), with an average educational experience of 8.36 years (SD= 4.66). The distribution of the participants' age and education are shown in Table 7.4.

	Frequency	*Percentage (%)*
Age (years)		
61-65	7	31.8
66-70	7	31.8
71-75	4	18.2
76-80	3	13.6
81-85	1	4.5
Mean	69.73	
SD	6.02	
Education (years)		
0	1	4.5

1-7	8	36.4
8-15	11	50.0
16-17	2	0
Mean	8.36	
SD	4.66	

Table 7.4 Age and education distribution (N=22)

The descriptive data of participants' technology experience is presented in Table 7.5. Specifically, 63.6% of the participants reported the usage experience of computers, with an average duration for 6.16 years (SD=7.97). All participants have used mobile technologies: 100.0% of them had the experiences with the smartphone, and 63.6% had the experiences with tablets. Averagely, the participants used the mobile technologies for 4.84 years (SD=2.48), with an average frequency of 2.36 hours per day and an average number of 6.95 advanced mobile applications (SD=2.10). Additionally, it was indicated that 50% of participants thought they were at a medium competence level of using mobile technologies, followed by those who believed they were at a relatively poor level (27.3%), those who thought they were at a relatively good level (18.2%), and those who believed they were at a very poor level (4.5%).

	Minimum	***Maximum***	***Mean***	***SD***
Duration of use of computers (years)	0	25	6.16	7.97
Duration of use of mobile technologies (years)	1	10	4.84	2.48
Intensity of use of mobile technologies (hours/week)	3.50	45.50	16.53	10.71
Diversity of use of mobile technologies	2	11	6.95	2.10
Self-efficacy of mobile technologies*	1	4	2.82	0.80

*Likert scale: 1- very bad; 2- bad; 3- Medium; 4- good; 5- very good..

Table 7.5 Descriptive statistics on technology experience (N=22)

Concerning capability measurements, results of performance tests of SDMT, ANST, CRT, and SCWT, as well as the self-reported VP, are shown in Table 7.6.

It was indicated that the cognitive capabilities varied a lot between participants, especially for the perceptual speed (SDMT) and spatial ability (CRT). To examine the influences of perceptual speed, participants were divided into two groups of 11 participants with low (mean=24.91; SD=6.58), and high (mean=41.27; SD=5.92) level of perceptual speed. The differences between the two groups were significant according to the Mann-Whitney Test (U=0.00, p=0.000)

	N	***Minimum***	***Maximum***	***Mean***	***SD***
SDMT	22	7	55	32.14	11.73
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
VP*	22	3	5	3.95	0.77

*Likert scale: 1- extremely difficult; 2- difficult; 3- medium; 4- easy; 5- extremely easy.

Table 7.6 Descriptive statistics on capability measurement (N=22)

7.3.2. Navigation Performance

Results of the means and standard deviations of completion time and correctness rate for each of the group are shown in Table 7.7.

Task complexity	***Content similarity***	***Interface design***	***Completion time (s)*** Mean (SD)	Mean log (SD)	***Correctness rate (%)*** Mean (SD)
Low	Low	List	51.95 (34.38)	1.62 (0.31)	95.45 (0.15)
		Card	88.36 (85.27)	1.80 (0.36)	93.18 (0.18)
	High	List	78.91 (57.25)	1.82 (0.25)	93.18 (0.18)
		Card	75.68 (45.97)	1.79 (0.30)	95.45 (0.15)
High	Low	List	142.95 (133.66)	2.06 (0.27)	83.32 (0.25)
		Card	124.18 (114.45)	1.94 (0.37)	90.91 (0.20)
	High	List	119.36 (94.42)	1.94 (0.39)	74.23 (0.39)
		Card	155.23 (147.04)	2.02 (0.40)	80.27 (0.27)

Table 7.7 Means and standard deviations of completion time and correctness rate (N=22)

7.3.2.1. Completion Time

For the completion time, a mixed 2×2×2×2 repeated measurement ANOVA's was conducted, with the interface design (2D list and 3D card), task complexity (low and high), and content similarity (high and low) as the within-subject variables, and perceptual speed (low and high) as the between-subject variable.

The result of the Levene's test indicated that variances are homogeneous for all levels of the repeated measures variables ($p>0.05$), which confirmed the accuracy of the F-test for the scores of SDMT. Specifically, the results revealed a significant main effect of the perceptual speed ($F(1, 20) = 10.686$, $p=0.004$), that the participants with a high level of perceptual speed completed faster than those with a low level of perceptual speed. The level of task complexity also had a significant main effect on participants' completion time ($F(1, 20) = 28.634$, $p=0.000$), that participants needed less time when completing the simple navigation tasks than the complex ones.

In addition, a significant interaction influence was reported between the interface design and perceptual speed on participants' completion time, $F(1, 20) = 6.219$ ($p=0.022$), as shown in Figure 7.5. It showed that participants with a high level of perceptual speed performed faster when navigating the 3D card interface than the 2D list interface; whereas, participants with the low level of perceptual speed performed faster when navigating the 2D list interface than the 3D card interface.

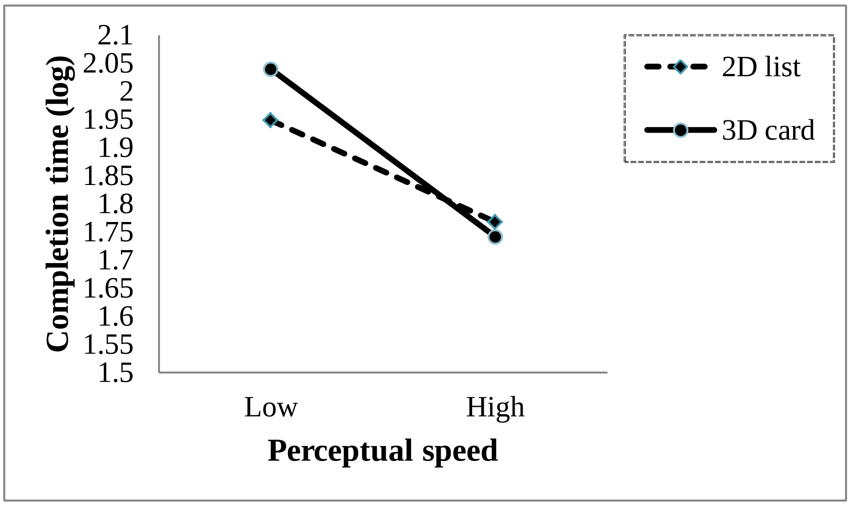


Figure 7.5 Mean completion time (log) needed for 2D list and 3D card interface design for different groups of perceptual speed

The results also revealed a significant interaction between the interface design, content similarity, and task complexity on participants' completion time, F (1, 20) =4.492, *p*=0.047, as shown in Figure 7.6 and Figure 7.7. It was found that, for tasks with low complexity, participants performed faster with the 3D card interface than 2D list interface when navigating content with high similarity (75.68s vs 78.91s), but slower with the 3D card interface than 2D list interface when navigation content with low similarity (88.36s vs 51.95s). However, for tasks with high complexity, participants performed faster with the 2D list interface than 3D card interface when navigation content with high similarity (119.36s vs 155.23s), but slower with the 2D list interface than 3D card interface when navigating content with low similarity (142.95 vs.124.18s).

At the same time, for tasks with low complexity, participants performed faster when navigating content with low similarity than those with high similarity using 2D list interface (51.59s vs 78.91s), but slightly slower when navigating content with low similarity than those with high similarity using the 3D card interface (88.36s vs 75.68s). Nevertheless, for tasks with high complexity, participants performed faster when navigating content with high similarity than those with low similarity using 2D list interface (119.36s vs 142.95s), but slower when navigating content with high similarity than those with low similarity using 3D card interface (155.23s vs 124.18s).

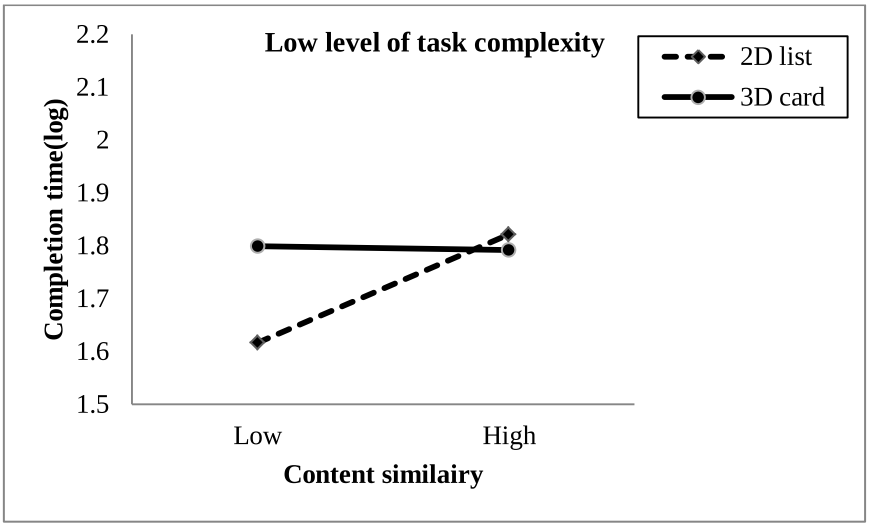


Figure 7.6 Mean completion time (log) needed for 2D list and 3D card interface design to navigate contents with high similarity and low similarity when doing tasks of low complexity

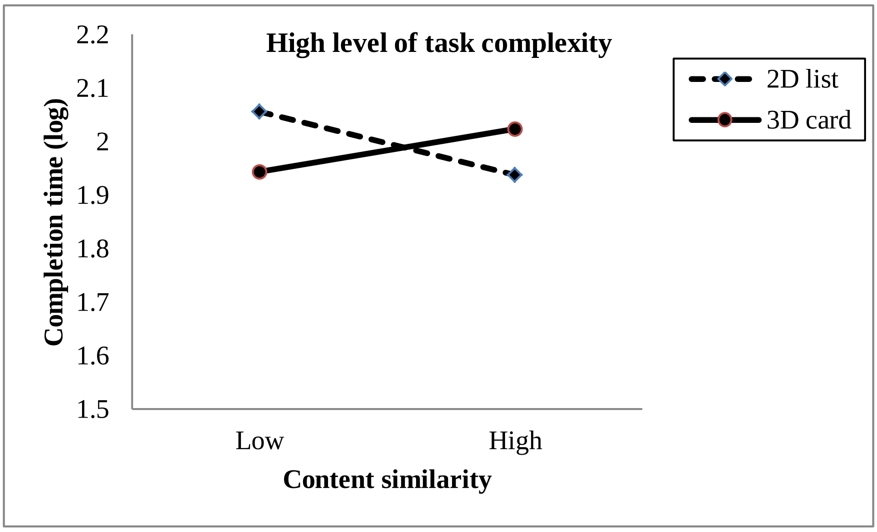


Figure 7.7 Mean completion time (log) needed for 2D list and 3D card interface design to navigate contents with high similarity and low similarity when doing tasks of high complexity

7.3.2.2. Correctness Rate

Friedman test was employed to compare the differences between various experimental settings for the groups of participants with different levels of perceptual speed. Results revealed that for the group with a low level of perceptual speed, there was a statistically significant difference in correctness rate depending on the interface design, content similarity and task complexity ($\chi^2(7) = 27.692$, p=0.000). However, no significant difference was reported in correctness rate between navigation tasks for the group of participants with a high level of perceptual speed. Post hoc analysis of Wilcoxon signed-rank tests with a Bonferroni correction was conducted on the paired comparison for navigation task among the participants with a low level of perceptual speed. It was found that there was a significant reduction of mean correctness rate reported for tasks with high complexity than those with low complexity when navigating content of high similarity using 2D list interface (Z=-2.326, p=0.020). A significant reduction of mean correctness rate was also reported in tasks with high complexity when navigating content with high similarity than those with low similarity using 2D list interface (Z=-2.240, p=0.016). Additionally, the correctness rate for the 3D card interface was found to be significantly higher than the 2D list interface when doing tasks with high complexity and with the content of high similarity (Z=-2.268, p=0.023). Results of the means and standard deviations of correctness rate for each group are also described in Table 7.7.

7.3.3. Subjective Evaluation

7.3.3.1. Perceived Difficulty of Tasks

Participants' perceived difficulties towards the eight experimental tasks were collected using 5-point Likert scales. Analysis using Friedman test revealed that there was a statistically significant difference in perceived difficulty towards tasks among the group of participants with low level of perceptual speed, depending on the interface design, content similarity and task complexity, $\chi^2(7) = 34.391$, *p*=0.000, but there was no significant difference reported among the group of participants with a high level of perceptual speed. Post-hoc analysis of Wilcoxon signed-ranked tests was conducted with a Bonferroni correction. Participants from the group of low level of perceptual speed perceived the tasks with high complexity as more difficult to complete than those with low complexity when navigating the 2D list interface with both of the content of high similarity (Z =-2.754, *p* =0.006) and low similarity (Z=-2.699, *p*=0.007), as well as when navigating the 3D card interface with the content of high similarity (Z=-1.983, p=0.047). Two marginal significant differences were also reported for tasks with the content of high similarity than those of low similarity when navigating the 2D list interface at a low level of task complexity (Z=-1.897, *p*=0.058) and when navigating the 3D card interface at a high level of task complexity (Z=-1.933, *p*=0.053). However, there was no statistically significant difference revealed in the perceived difficulty of tasks depending on various interface designs. The details of the descriptive data are shown in Table 7.8.

Task complexity	*Content similarity*	*Interface design*	*Perceived difficulty** Mean (SD)
Low	Low	List	4.41 (0.59)
		Card	4.18 (0.80)
	High	List	4.00 (0.82)
		Card	3.86 (1.04)
High	Low	List	3.27 (1.08)
		Card	3.64 (0.79)
	High	List	3.32 (1.04)
		Card	3.50 (1.26)

*Likert scale: 1- Extremely difficult; 2- difficult; 3- Neutral; 4- easy; 5- Extremely easy.

Table 7.8 Participants' perceived difficulty towards tasks

7.3.3.2. Subjective Evaluations of Interface Designs

Participants' subjective evaluations of different interfaces designs were measured in terms of the ease of use, perceived usefulness, effort needed, disorientation, satisfaction and behavioural intention of use. The descriptive statistics were reported in Table 7.9 and Figure 7.8. The results showed that the 2D list interface outperformed the 3D card interface in the subjective evaluations for the ease of use, perceived usefulness, and satisfaction. Regarding participants' subjective evaluation of disorientation, the 2D list and 3D card interface achieved a quite similar level. As for the aspects of effort spends and behavioural intention to use, the 3D card interface was preferred more by the participants rather than 2D list interface. However, the analysis of Wilcoxon signed test didn't reveal any statistically significant differences regarding subjective evaluations of interface designs. There was only a significant higher evaluation of the perceived usefulness for the 2D list interface for the group of participants with a low level of perceptual speed that participants believed the 2D list interface could improve their navigation performance rather than the 3D card interface (Z=-2,121, *p*=0.034).

Interface	*PEOU1*	*PEOU2*	*PU1*	*PU2*	*EF*	*DO1*	*DO2*	*ST*	*BITU*
2D List	4.05 (0.58)	4.27 (0.63)	4.45 (0.51)	4.23 (0.69)	3.45 (1.06)	4.05 (0.84)	3.82 (0.59)	4.41 (0.67)	4.23 (0.69)
3D Card	3.73 (0.77)	4.18 (0.73)	4.18 (0.73)	4.14 (0.56)	3.68 (0.99)	4.00 (0.82)	3.82 (0.66)	4.23 (0.69)	4.32 (0.65)

Table 7.9 Participants' subjective evaluations of the interface designs

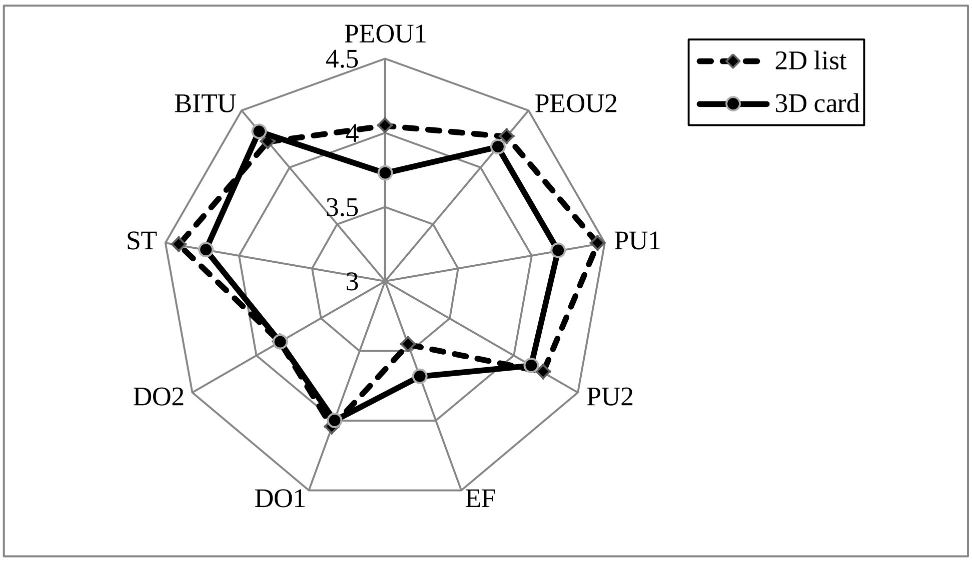


Figure 7.8 Subjective evaluation of interface design

7.3.4. Relationships between User Characteristics, Navigation Performance and Subjective Evaluation

Correlations between User Characteristics, Task Performance and Subjective Evaluation

Correlation analysis was conducted between the factors of user characteristics and dependent variables. Participants' age, education, duration of use of computers, duration of use of mobile technologies, intensity of use of mobile technologies, diversity of use of mobile technologies, and the scores of SDMT, ANST, CRT, and SCWT were found to be normally distributed after log-transforming. Thus the Pearson correlation analysis was conducted for this set of data, and the Spearman correlation analysis was used for the data that was not normally distributed. Significant correlations found between user characteristics and dependent variables are depicted in Table 7.10 and Table 7.11.

Correlations between user characteristics and navigation performance were analysed. Completion time was found to be significantly correlated with the participants' age (*p*=0.000), education (*p*=0.003), duration of use of computers (*p*=0.022), duration of use of mobile technologies (*p*=0.000), sustained attention (*p*=0.000), perceptual speed (*p*=0.000) and visual perceptions (*p*=0.002). Correctness rate was reported to be significantly related to participants' diversity of use (*p*=0.004) and self-efficacy (*p*=0.047) with mobile technologies. In addition, participants' level of perceived difficulty was shown to be significantly correlated with their duration of use of computers (*p*=0.007), self-efficacy of mobile technologies (*p*=0.000), and perceptual speed (*p*=0.005).

	N	***Completion time***	***Correctness rate***	***Perceived difficulty***
Age	22	0.327***		
Education	22	-0.231**		
Duration of use of computers	22	-0.217*		0.203**
Duration of use of mobile technologies	22	-0.261***		
Intensity of use of mobile technologies	22			
Diversity of use of mobile technologies	22		0.215**	
Self-efficacy of mobile technologies	22		0.150*	0.275***
ANST	22			
CRT	22			
SCWT	20	-0.322***		

SDMT	22	-0.384***	0.209**
VP	22	-0.231**	

Note: *p < 0.05; **p < 0.01; ***p < 0.001

Table 7.10 Significant correlations between user characteristics, navigation performance, and subjective evaluation of perceived difficulties towards tasks.

Correlations between the participants' user characteristics and subjective evaluation of each interface design were also analysed. Regarding the use with 2D list interface, it was found that the participants' working memory was significantly correlated with their evaluations of the perceived usefulness (p=0.044) and effort spent (p=0.012). Simultaneous, it was reported that the participants' perceptual speed is also significantly correlated the participants' perceived effort need (p=0.030), as well as two aspects of perceived disorientation (p=0.005; p=0.015). In addition, the participants' age (p=0.036) and education (p=0.042) were also found to be significantly correlated with the two aspects of perceived disorientation respectively.

Regarding the use of 3D card interface, two aspects of the participants' perceived ease of use were significantly correlated with their duration of use of computers (p=0.045) and their duration of use of the mobile technologies (p=0.019) respectively. Different from the use of 2D list interface, it was indicated that the participants' perceived usefulness was significantly correlated with their perceptual speed (p=0.009) when using 3D card interface. Nevertheless, similar to the 2D list interface, participants' perceived disorientation with the 3D card interface was reported to be significantly correlated with their education (p=0.033) and perceptual speed (p=0.001). It was also reported that another aspect in terms of disorientation was significantly correlated with participants' self-efficacy of the mobile technologies (p=0.004). Furthermore, the participants' intention to use the 3D card interface was reported to be significantly but negatively correlated to their self-efficacy (p=0.044).

Interface		*PEOU1*	*PEOU2*	*PU2*	*EF*	*DO1*	*DO2*	*BITU*
2D list	Age						-0.439*	
	Education					0.437*		
	ANST			0.433*	0.527*			
	SDMT				0.464*	0.578**	0.513*	
3D card	Education					0.456*		
	Duration of use of computers	0.431*				0.576**		
	Duration of use of mobile technologies		0.497*					
	Self-efficacy of mobile technologies						0.583**	-0.434*
	SDMT			0.546**		0.678**		

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

Table 7.11 Significant correlations between user characteristics and subjective evaluations of interfaces (N=22).

7.3.4.1. User Characteristics that associated with Content-oriented Navigation Performance and Subjective Evaluations

According to the results of correlation analysis, the hierarchical regression analysis was further conducted to further ascertain the associations between the independent variables of perceptual speed, interface design, task complexity, content similarity and user characteristics, and the dependent variables of navigation performance of completion time and correctness rate and subjective evaluations of perceived difficulty towards tasks, as well as the ease of use, perceived usefulness, effort needed, disorientation, satisfaction, and behavioural intention to use.

Predicting the overall navigation performance and subjective evaluations

A hierarchical regression analysis with a stepwise inclusion specification (backward selection, $p<0.05$) was performed to examine the possibility of hypothetic factors in predicting participants' content-oriented navigation performance and subjective evaluation. The tolerance values of all independent variables were first calculated to access the multicollinearity of predictors. Results showed that all the tolerance values of independent variables were greater than 0.01, together with VIFs less than 5. Thus, the multicollinearity is not a problem. The results of the hierarchical regression are presented in Table 7.12.

Independent variables	***Dependent variables***		
	Navigation performances		Subjective evaluations
	Completion time	Correctness rate	Perceived difficulty
Perceptual speed	-0.238**		
Task complexity	0.306***	-0.272***	-0.340***
Duration of use of computers			0.158*
Diversity of use of mobile technologies		0.205**	
Self-efficacy of mobile technologies		0.145*	0.261***
Visual perception	-0.186*		
R^2	0.222	0.140	0.216

Note: *$p < 0.05$; **$p < 0.01$, ***$p<0.001$

Table 7.12 Standardised coefficients Beta of hierarchical regression for navigation performance and subjective evaluation of perceived difficulty of tasks (N=22).

Three multiple regression equations were developed for the navigation performance of completion time and correctness rate, as well as the subjective evaluation of the perceived difficulty towards each task respectively. The perceptual speed, task complexity, and user characteristics of visual perception explained 22.2% of the variance for navigation performance of completion time. Specifically, participants from the group with a high level of perceptual speed performed faster when doing the content-oriented navigation tasks (β= -0.238, p=0.002). With the improved level of task complexity, the participants needed more time to complete the navigation tasks (β= 0.306, p=0.000). Additionally, participants with a higher level of visual perceptions completed the navigation tasks faster (β= -0.186, p=0.013).

Correctness rate was found to be significantly associated with the task complexity, and participants' diversity of use and self-efficacy of mobile technologies, resulting in a model with R^2=0.140. In other words, the task with a higher level of complexity induced lower correctness rate (β= -0.272, p=0.000). Participants who adopted more functions (β= 0.205, p=0.004) and had a higher level of self-efficacy (β= 0.145, p=0.042) of mobile technologies achieved higher correctness rate.

In addition, the task complexity and participants' duration of use of computers and self-efficacy of mobile technologies predicted their perceived difficulty of tasks, resulting in a model with R^2=0.216. It was reported that participants perceived the tasks with a higher level of complexity as more difficult (β= -0.340, p=0.000); and participants with longer usage experience of computers (β= 0.158, p=0.021) and higher level of self-efficacy of mobile technologies (β= 0.261, p=0.000) perceived the content-oriented navigation tasks as easier.

In terms of participants' subjective evaluations of the interface designs, three regression equations were built for 2D list interface design and five regression equations were developed for the 3D card interface design. The regression models that indicated significant associations are presented in Table 7.13. For the 2D list interface design, working memory was found to be the only significant predictor that could explain 20.8% of variances in participants' perceived effort needed. In particular, participants with better working memory perceived the 2D lists as effortless to use (β= 0.457, p=0.033). Participants' perceptual speed was found to be significantly associated with two aspects of subjective evaluations of disorientation, results in two regression models with R^2=0.398 and R^2=0.187. It was reported that participants with high level of perceptual speed had fewer possibilities of feeling disoriented (β= 0.631, p=0.002), and had a clearer understanding of their current position (β= 0.432, p=0.045). Regarding the 3D card interface design, duration of use of mobile technologies was found to be the only factor that significantly and positively associated with participants' perceived ease of use for navigation tasks (β= 0.449, p=0.036), resulting in a regression model with R^2=0.202. Perceptual speed was also revealed to be a significant predictor for participants' perceived usefulness and disorientation, which could explain 23.2% and 40.4% of variances for the abovementioned dependent variables respectively. Specifically, participants' with a high level of perceptual speed tended to believe the interface design useful for improving their content-orientate navigation performance (β= 0.482, p=0.023) and experience fewer disorientations (β= 0.636, p=0.001). In addition, participants' self-efficacy of mobile technologies was also found to be a significant factor when explaining their evaluations of disorientation, as well as behavioural intention to use the 3D card interface, resulting two regression models with β=0.320 and β=0.192. Participants with a higher level of self-efficacy of mobile technologies could better know their current position between different interfaces (β= 0.565, p=0.006), but they tended to use less of the 3D card interface design in the future (β=-0.438, p=0.041).

	Independent variables	***Dependent variables***					
		PEOU2	PU2	EF1	DO1	DO2	BITU1
2D List	ANST			0.457*			
	SDMT				0.631**	0.432*	
	R^2			0.208	0.398	0.187	
3D Card	Duration of use of mobile technologies	0.449*					
	Self-efficacy of mobile technologies					0.565**	-0.438*
	SDMT		0.482*		0.636**		
	R^2	0.202	0.232		0.404	0.320	0.192

Table 7.13 Standardised coefficients Beta of hierarchical regression for subjective evaluations of interface designs (N=22).

Predicting the navigation performance and perceived difficulties towards tasks between interface designs

The multiple regression analysis was also employed to explore the predictive contribution of user characteristics for the navigation performance and subjective evaluation of perceived difficulties towards tasks depending on different interface design. There were six multiple regression equations developed for the completion time, correctness rate and perceived difficulty for the 2D list and 3D card interfaces. The final models that indicated significant associations are shown in Table 7.14. In total, the proposed factors explained 18.3% of variances for completion time, 18.1% of variances for correctness rate and 30.8% of variances for participants' perceived difficulty towards the navigation tasks when using the 2D list interface; and they also explained 25.8% of variances for completion time, 10.8% of variances for correctness rate and 10.4% of variances for participants' perceived difficulty when doing navigation tasks using the 3D card interface.

Specifically, the regression analysis indicated that the level of perceptual speed was significantly and negatively associated with participants' completion time in terms of the 2D list or 3D card interfaces. Participants from the group with a high level of perceptual speed performed faster in content-oriented navigation tasks whenever using list (β=-0.243, p=0.015) or card (β=-0.288, p=0.007) interfaces. Task complexity was also found to be significantly and positively associated with participants' completion time for the 2D list (β=0.352, p=0.001) and 3D card (β=0.269, p=0.005) interfaces. Additionally, the completion time using 3D card interface was also found to be significantly influenced by the participants' visual perception (β=-0.222, p=0.035).

Task complexity (β=-0.328, p=0.001) and participants' diversity of use of mobile technologies (β=0.270, p=0.007) were found to be significantly influenced the participants' correctness rate when using 2D list interfaces; task complexity (β=-0.211, p=0.042) and participants' self-efficacy of mobile technologies (β=0.252, p=0.016) were reported to be significantly associated with their correctness rate when using 3D card interfaces.

Regarding the participants' perceived difficulty towards the navigation tasks, it was revealed that the task complexity (β=-0.453, p=0.000; β=-0.227, p=0.030) and participants' self-efficacy of mobile technologies (β=0.321, p=0.001; β=0.230, p=0.028) were the significant predictors both for the 2D list and 3D card interfaces.

	Independent variables	Dependent variables		
		Completion time	Correctness rate	Perceived difficulty
2D List	Perceptual speed	-0.243*		
	Task complexity	0.352**	-0.328**	-0.453***
	Diversity of use of mobile technologies		0.270**	
	Self-efficacy of mobile technologies			0.321**
	R^2	0.183	0.181	0.308
3D Card	Perceptual speed	-0.288**		
	Task complexity	0.269**	-0.211*	-0.227*
	Self-efficacy of mobile technologies		0.252*	0.230*
	VP	-0.222*		
	R^2	0.258	0.108	0.104

Note: *p<0.05; **p<0.01; ***p<0.001

Table 7.14 Standardised coefficients Beta of hierarchical regression for navigation performance and subjective evaluation of perceived difficulties with tasks between different interface designs (N=22)

7.4. Discussion

7.4.1. Effects of User Characteristics and Navigation Design

The capability of perceptual speed was reported to influence older adults' efficiency in content-oriented navigation tasks significantly, in support of hypothesis H7.1. Participants with a higher level of perceptual speed completed the navigation task more quickly. In addition, the participants’ level of perceptual speed was also significantly and positively associated with their subjective evaluations of disorientation for the 2D list interface as well as the perceived usefulness and disorientation for the 3D card interface. The results can be explained by previous studies that emphasised the impact of spatial ability on understanding the structural relationship between pages and interfaces within web navigation (Chen, 2001; Pak et al., 2006; Juvina and van Oostendorp, 2006; Puerta Melguizo et al., 2012).

On the one hand, the information hierarchies of mobile applications have become much flatter than web navigation, which may significantly decrease the need to build complete mental models for understanding with spatial ability. On the other hand, due to limited-size screens and direct manipulation, the information content of mobile applications are becoming much broader, which requires quick visual scanning, processing and shifting (Yang et al., 2012; Punchoojit and Hongwarittorrn, 2017). Thus, the ability of perceptual speed becomes more important for older adults' mobile navigation.

7.4.1.1. Navigation Performance

Previous studies on young adults suggested that 2D interfaces could improve navigation performance more than 3D interfaces (Cockburn and McKenzie, 2001; Oulasvirta et al., 2009; Kim et al., 2011). Possible explanations included the lack of visual guidance from the current view to the preview or historical view for the 3D card items (Cockburn and McKenzie, 2001) or difficulty in manipulating the 3D card interface, especially when the menu was broader (Kim et al., 2011). In this study, although content-oriented navigation designs did not produce an independent effect on older adults' navigation performance, an interactive effect of interface design and perception speed was found on participants' navigation performance of completion time, partially supporting hypothesis H7.2. Based on this result, it was believed that the effectiveness of navigation design mainly lies with the demands of certain cognitive capabilities required by different interfaces.

It was suggested that the 2D list interface worked better than the 3D card interface for participants with lower levels of perception speed; for participants with higher levels of perceptual speed, the 3D list interface outperformed the 2D list interface in mobile navigation. The results of this study partly agreed with previous studies that indicated the metaphor design could not effectively work for novice users because they cannot easily understand the additional cues provided by the metaphor itself (Fix et al., 1993; Hsu, 2005). Conversely, the use of metaphor could increase their cognitive load during information navigation (Lee, 2007). Thus, for designers, it is important to decide when to apply the principle of metaphor design based on the level of the user's capabilities, especially perceptual speed.

However, the correctness rate was not found to have significant differences between different interfaces for the majority of experimental settings. This is probably because this experiment tried to control the speed-accuracy trade-off by telling the participants not to risk errors to reduce time. There was only one exception in which the 3D card interface outperformed the 2D list interface in terms of correctness rate when participants were performing tasks with high complexity and with the content of high similarity. Thus, when designing an interface that presents several similar contents (e.g., an online shopping application with products from the same category), a 3D card design is recommended.

7.4.1.2. Subjective Evaluation

Though previous research reported a preference for 3D interfaces in terms of fun (Sebrechts et al., 1999; Kim et al., 2011), this study did not find any statistically significant difference in participants' preferences towards different interfaces. In general, older adults were more satisfied with the 2D list interface. They believed that the 2D list interface was easier to use and more useful than the 3D card interface. This study also examined possible factors associated with older adults' subjective evaluations of the 2D list and 3D card interfaces. For instance, older adults with higher levels of working memory perceived the 2D list as requiring less effort, and those with higher levels of perceptual speed were not easily disoriented or lost.

Overall, older adults preferred the 3D card interface in terms of perceived effort and behavioural intention to use. The level of perceptual speed was also found to be associated with older adults' perceived usefulness and disorientation. In addition, older adults who had longer use experience with mobile technologies tended to perceive the 3D card interface as more useful; those who had lower levels of self-efficacy of mobile technologies were more easily disoriented but expressed higher levels of satisfaction. This may be because the 3D card interface was launched as a new navigation pattern that was not familiar to many users. Therefore, a richer technology experience can assist in the quick development of mental models when using the new interface (Blackwell, 2006). Nonetheless, it is surprising to find that participants with lower self-efficacy tended to adopt the use of the 3D card interface in the future, and this result should be examined in further research.

7.4.2. Effects of Task Complexity and Content Similarity

Mobile navigation is a flow that reflects how users access various information patches between various interfaces and how they can build a proper mental model to process the accessed information for a specific purpose (Lawless and Schrader 2008; Punchoojit and Hongwarittorrn 2017). The difficulty of navigation depends on the length of the navigation path required to find the target information patch (Puerta Melguizo et al., 2006). Consistent with previous studies on web navigation, the results of the current study revealed both independent and interactive effects of task complexity on older adults' navigation performance and subjective perceptions, in support of hypothesis H7.3. It was reported that the longer the navigation path, the more difficulties that may be encountered when searching for information and the worse the navigation performance would be (Puerta Melguizo et al., 2006; Kammerer et al., 2008; van Schaik and Ling 2012).

Another difficulty of mobile navigation lies in information relevance. According to previous studies, the semantic similarity between the target information patch and the information described in the task description could significantly influence users' navigation performance and subjective feelings (Pirolli and Card 1999; Blackmon et al., 2005; Puerta Melguizon et al., 2012). Although this study applied a different way of studying the effect of information relevance by manipulating the semantic similarity between the information patches shown on the same interfaces, the results were partly consistent with these previous studies. Specifically, there was an interactive influence of task complexity, content similarity and interface design on older adults' navigation performance of completion time, partially supporting hypothesis H7.4. For example, for simple tasks using 2D list interfaces and complex tasks using 3D card interfaces, navigating with content of lower similarity was faster than with content of high similarity; however, for simple tasks using 3D card interfaces and complex tasks using 2D list interfaces, navigation with content with high similarity was faster than with content with low similarity.

Regarding correctness rate, effects of task complexity were found when navigating the 2D list interface with the content of high similarity. The impacts of content similarity were also reported for tasks with high complexity using the 2D list interface. This interactive influence can be partly explained by the confounding influence of task complexity and page relevance on navigation efficiency reported by Puerta Melguizo et al. (2012). Older adults were also found to perceive tasks as more difficult when navigating with the content of high similarity than those of low similarity, but only for simple tasks using 2D list interfaces.

7.5. Summary

This chapter presents an experimental study focused on older adults' content-oriented navigation behaviour. By investigating the possible effects of experimental variables including interface design, task complexity and content similarity and user characteristics of perceptual speed, demographic factors, technology experience and other user capabilities, research question Q5 was answered. The results indicated that when developing a user model for older adults' content-oriented navigation behaviour, it is necessary to consider the significant influences of task complexity that depend on the number of integration criteria and the users' level of perceptual speed. Also, interactive impacts on content-oriented navigation were found between the interface design and perceptual speed, as well as between the interface design, task complexity and content similarity. It is vital to notice that the design principle of metaphor design could improve older adults' navigation behaviour but is only suitable for those with higher levels of perceptual speed. For older adults with lower levels of perceptual speed, it is suggested to use the 2D list interface to avoid the additional cognitive loads produced by the metaphor design. Furthermore, the decision to use metaphor design depends on content similarity and task complexity. At the same time, users' technology experience such as duration of use of computers and duration of use, diversity of use and self-efficacy of mobile technologies should also be considered due to their significant influences on older adults' navigation performance and subjective evaluations.

In summary, the results from this study examined the possible factors that influence older adults' menu-oriented navigation behaviour and quantified these relationships, answering research question Q5 by identifying the predictive variables that should be modelled and determining how they should be modelled. The results of this study could greatly help designers choose a content-oriented navigation design for older adults with a wider range of user capabilities and technology experience. Chapter 8 will discuss the findings of each study to answer the research questions outlined in Chapter 1. By addressing the research question Q5, user models for older adults' menu-oriented and content-oriented navigation behaviour were developed based on the results described in Chapter 6 and Chapter 7. Chapter 9 will summarise the findings and indicate significant implications of the research.

CHAPTER 8 Discussion and Finalisation of User Models

This chapter discusses the results of each study to answer the research questions proposed in Chapter 1. By integrating the findings from various methods, the research proposes a theoretical model for older adults' post-adoption usage behaviour and user perceptions towards the mobile technology, a list of design guidelines for elderly-friendly mobile interface navigation design, and two user models to predict older adults' mobile navigation behaviour, which can answer research question Q1- Q5. It then discusses the limitations of the research and proposes possible areas for further study.

8.1. Discussion of Research Questions

8.1.1. Older Adults' Post-Adoption Usage and Perceptions

There has been a stereotype that older adults tend to avoid the use of technologies and have a negative bias towards technologies (Saunders, 2004; Cazja et al., 2006). However, the findings from the semi-structured interview in Study One showed that the majority of participants were in an early adoption stage with less than two years' experience with the mobile technologies, but the older adults were aware of the various ways that mobile technologies could improve their quality of life, for instance in entertainment, communication, information searching and learning. Therefore, we found that overall, older adults held relatively positive attitudes towards mobile technologies and showed considerable interest in learning and using mobile technologies. Some participants claimed that they would like to search for information without assistance from their relatives and that they enjoy sharing photos with their families and friends using social networking applications. Social influences were also found to be important for older adults' adoption of mobile technologies in the objectification stage (Venkatesh et al., 2003; Renaud and Van Biljon, 2008). Persuasion or even pressure from families and friends can easily influence older adults’ attitudes towards mobile technologies. Many participants emphasised that they were persuaded by their sons or daughters to start to use the mobile technologies, and they could be quite frustrated when they encountered difficulties using the mobile technologies, but the families did not provide sufficient assistance or were impatient.

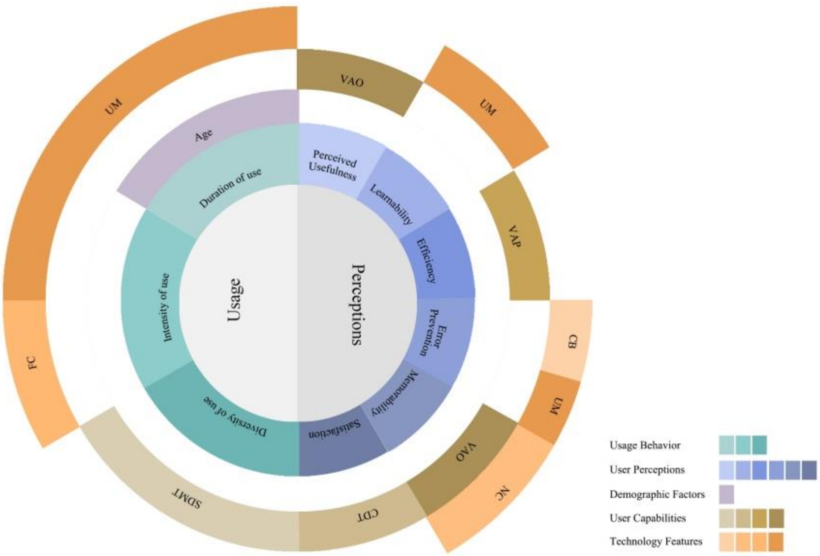
The research also investigated the adoption of mobile technology as a continuous process, specifically emphasising older adults’ post-adoption behaviour in the incorporation and conversion stages (Renaud and Van Biljon, 2008). This perspective is essential when studying mobile technology acceptance and adoption because the essence of mobile technology acceptance and adoption lies in the adoption of more functions. Specifically, this study found that older adults still had many concerns after their initial adoption of mobile technologies. Some participants emphasised that they were too old to learn these technologies and expressed concerns about their declining capabilities and poor literacy when learning and using mobile technologies, new functions and applications. They also reported that some technology features are not suitably designed for their capabilities and limitations, and this aspect is discussed in later sections.

Therefore, there still exists a need to encourage advanced technology adoption behaviour among older adults. The results showed that older adults who perceived mobile technologies as offering high levels of efficiency used the mobile technologies for longer periods. Those who perceived mobile technologies as offering high levels of memorability used mobile technologies more frequently. Those who had a more positive attitude towards mobile technology tended to adopt more diverse mobile functions. In other words, older adults' initial adoption behaviour determines their perceptions of the technologies. In turn, these perceptions can affect how older adults further adopt mobile technologies, such as continuing their current behaviour, upgrading their usage or abandoning the technologies.

8.1.2. Factors Influencing Older Adults' Post-Adoption Behaviour

The research examined how to facilitate older adults' continued and further adoption of mobile technologies by investigating the factors that influence their post-adoption usage and perceptions. The findings indicated that age and perceptual speed ability significantly affect older adults' post-adoption usage behaviour with mobile technologies. Among the older adults, the older the person gets, the less experience with the mobile technologies he or she would have, and those who had lower levels of perceptual speed tended to use fewer kinds of mobile functions. In addition, the technology features of functionality and menus could also significantly influence their post-adoption usage behaviour with mobile technologies. Participants who had higher evaluations on the mobile technology functionality and the use of menus tended to use mobile technologies more frequently and for longer durations, respectively. At the same time, lower evaluations of the use of menus could lead to a more frequent use of mobile technologies.

As for the older adults' post-adoption user perceptions, visual abilities significantly and positively affected their perceived usefulness and perceived usability in terms of efficiency and memorability, and spatial ability could significantly and positively influence their satisfaction with mobile technologies; whereas, spatial ability significantly negatively predicted older adults' satisfaction with mobile technologies. At the same time, evaluations of technology features such as menus, use of colour and background, navigation and controls also significantly and positively influenced several aspects of various aspects of older adults' perceived usability of mobile technologies. Based on the results, a theoretical model for older adults' usage behaviour and user perceptions is proposed, as shown in Figure 8.1.



Note: CDT refers to spatial ability, SDMT refers to perceptual speed, VAP refers to visual ability to read texts on paper, VAO refers to visual ability to do tasks require close observation, VAD refers to visual ability to read texts on digital displays, CB refers to use of colour and background, UM refers use of menus, FC refers to functionality, and NC refers to navigation and controls

Figure 8.1 Factors influencing older adults' post-adoption usage and perceptions

Ten technology feature categories were investigated in the semi-structured interviews in Study One. Rich data were collected from the participants' subjective evaluations and discussions. Overall, participants most frequently reported difficulties related to technology features of navigation. Specifically, 91.4% of participants reported a medium to high level of difficulty regarding the use of menus, 65.7% reported interaction issues in sliding between different interfaces, 60.0% had functionality issues in switching between functions, and 51.4% reported difficulties in navigation and controls such as returning to homepages when using mobile technologies. Many participants claimed that it was quite difficult to find and operate the relevant menus and functions that were sometimes hidden within each other and required additional interaction gestures to manipulate.

As noted above, evaluations of technology features related to navigation significantly influenced older adults' post-adoption usage and perceptions of mobile technologies. The older adults' duration of use of mobile technologies was significantly predicted by their evaluation of the use of menus, and their intensity of use of mobile technologies was significantly influenced by their evaluations of functionality and the use of menus. Additionally, evaluations of the use of menus were also revealed significant influences on the older adults' perceived learnability and error prevention of mobile technologies, and evaluations of navigation and controls significantly predicted perceived memorability of the mobile technologies.

Although studies have extensively investigated older adults' usability problems when using technologies, most of the issues were related to visual and haptic aspects such as size, space and colour. Certain vital aspects that require more cognitive and perceptual processing such as navigation and menus have been less thoroughly explored (Petrovčič et al., 2017). Navigation patterns such as link navigation, content navigation and menu navigation have rarely been explored in mobile UI studies (Punchoojit and Hongwarittorrn, 2017). Therefore, in this study, by answering the first three research questions, technology features related to mobile navigation behaviour were identified as the most significant problem for older adults' further adoption of mobile technologies. The following research questions were thus answered in this specific research scope.

8.1.3. Do Current UI Design Patterns Support Older Adults' Mobile Navigation Behaviour?

Chapter 6 described the results of Study Two, which investigated older adults' use of six state-of-the-art mobile navigation patterns selected from two typical approaches to organise information and functions: menu-oriented navigation and content-oriented navigation. By analysing older adults' usability issues with each of the navigation design patterns, this study provides insights into how current design patterns facilitate or limit older adults' mobile navigation behaviour and develops a set of appropriate design considerations. A list of design guidelines is developed with the aim to support the UI designers by facilitating more intuitive mobile navigation behaviour for older adults as shown in Table 8.1. These guidelines are comprised of two parts: the first part includes the guidelines that extracted from the previous usability principles, which were found to be critical in guiding the older adults' mobile navigation behaviour; and the other part includes the guidelines that were summarised from the results of the current usability study.

Principles	***Items***	***Guidelines***	***Comparing to existing guidelines****
Visual Design	V1	Use visible and large icons and buttons for menu components	O
	V3	Use clear and large titles for content	O
	V6	Provide enough blank space between each of the menu component	O
	V8	Provide obvious distinction between the touchable and non-touchable text and icons	+
Ease of understand ing	E1	Design simple and meaningful icons	O
	E2	Use simple and understandable language for menus	O
	E9	Use distinctive titles for content to prevent confusion with others	+
Navigation and interaction	N1	Place the main menus and assisted navigation buttons in proper positions of the screen that are immediately obvious and can prevent mistaken touching	O
	N6	Use simple interaction gestures that users can easily interact with when navigation	O
	N7	Provide clear and appropriate feedbacks to immediately indicate changes caused by operations, such as interface switching or button tapping	O
	N8	Provide users with indications or cues of her/his exact location of the current interface	O
	N10	Provide sufficient visual cues to inform the user about the interactive mode of menus and content	O
	N11	Reduce the number of dominant menus used in the same application to prevent confusion	+
	N12	Avoid the use of multiple interaction gestures in the same interface	+
Support for habits	H1	Consider the specific using habit among elderly users	O

Note: 'O' donates that the guideline was summarized from previous studies, and '+' donates that the guideline was extracted from the results of current study.

Table 8.1 Final design guidelines for older adults' mobile navigation

Overall, this study found that older adults performed the content-oriented navigation more effectively than the menu-oriented navigation. In regard to the menu-oriented navigation, older adults preferred vertical menus such as springboards and sider drawers over tab menus because they can display more menu items at one time. However, they experienced great usability challenges in directing their attention to the menu-oriented navigation items, comprehending the meanings of icons and interacting with these menu items. Thus, to compensate for the possible drawbacks of menu-oriented navigation, this study suggests that designers should use vertical menus rather than the horizontal menus if possible, use top-placed and larger text buttons for the tab menus, provide sufficient visual cues if the menus require scrolling, minimise the use of icons on the screen and use simple, semantically closed, distinctive and text-remarked icons if possible.

As for content-oriented navigation, the older adults preferred vertical presented patterns such as lists and galleries, and the list pattern was more effective than the other design patterns in that it resulted in fewer failures and breakdowns. As a result, several design considerations were proposed for the use of list and gallery patterns, including designing the lists with enough height and simple manipulation, providing obvious interaction indications and using larger and more unique titles for each list and gallery. In addition, the results revealed that the card pattern is a promising design direction to facilitate older adults' mobile navigation behaviour. Generally, older adults found it quite easy and convenient to learn and execute card pattern navigation because it involves simple interaction techniques and allows for larger interactive areas. However, usability problems still existed for older adults in terms of the high requirements for interaction gestures, the lack of overviews of whole content lists and difficulties in establishing one's current position during navigation. Thus, this study suggested that card patterns should involve easier flipping gestures, use sufficient cues to inform users about their current location, provide visible and clear feedback for changes in interfaces and limit the use of simultaneous existing interactive areas in the same interface.

8.1.4. User Modelling for Older Adults' Mobile Navigation Behaviour

Two experimental methods were conducted in Chapter 6 and Chapter 7. These addressed research question Q5 by distinguishing two aspects of mobile navigation behaviour, menu-oriented navigation and content-oriented navigation. These two perspectives were studied based on the usability testing of older adults' realistic navigation behaviour outlined in Chapter 5. Thus, the integration of findings from the two experimental studies identified which factors and how these factors and in which way they can influence older adults' mobile navigation behaviour. Accordingly, the variables that should be modelled and the way they should be modelled are further defined, as shown in Figure 8.2 and Figure 8.3.

Based on the findings of Study Three (Chapter 6), the user group of younger adults performed significantly better than the user group of older adults in the mobile navigation tasks. As the level of task complexity increased, older adults' menu-oriented navigation performance and subject feelings deteriorated accordingly. The influential variables are highlighted in Figure 8.2. In addition, factors of education, technology experience in terms of duration of use of computers, duration of use of mobile technologies, diversity of use of mobile technologies and self-efficacy with mobile technologies, as well as their user capabilities of perceptual speed, vision acuity, contrast sensitivity and visual perceptions significantly influenced older adults' menu-oriented navigation performance and perceptions.

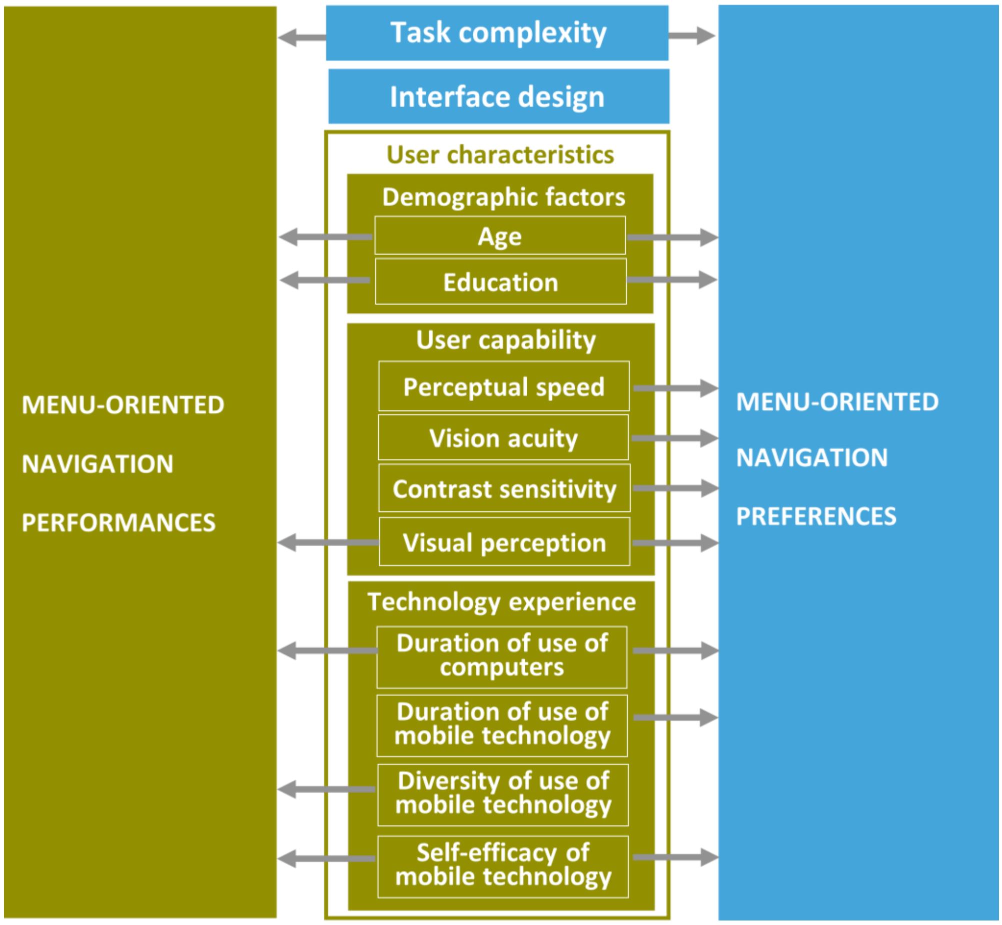


Figure 8.2 User modelling for the menu-oriented mobile navigation

According to the findings addressed in Study Four (Chapter 7), the older adults' content-oriented navigation performance and perceptions were significantly influenced by users' perceptual speed and the task complexity. Spatial ability has been extensively addressed in studies on web navigation (Chen, 2001; Juvina and van Oostendorp, 2006; Pak et al., 2006; Puerta Melguizo et al., 2012), but in this study perceptual speed was found to be the major user capability that influencing older adults'mobile navigation. Navigation task complexity can also affect older adults' mobile navigation behaviour, which can be explained by assessing the effect of the number of selection criteria.

Furthermore, researchers and designers should also pay attention to the interactive effects of these variables. First, older adults' perceptual speed and metaphor design had an interactive effect on navigation performance. The metaphor design of the 3D card interface can improve the navigation performance for older adults with a higher level of perceptual speed; whereas, the 2D list interface without metaphor design is more helpful in improving the performance of older adults with lower perceptual speed. This accords with the analytical framework for quantification of the capability-demand relationship proposed by Langdon et al. (2010), that the failure and difficulty of product interaction mainly occur when product demands exceed the users' capability. Moreover, the empirical findings of the research also identified the predictive variables and quantified the relationship between content-oriented navigation design and users' cognitive capabilities.

Second, there was an interactive effect of navigation design, content similarity and task complexity on older adults' navigation performance. When there was only one criterion for the task requirement, the 3D card interface was more suitable for content with high similarity, and the 2D list interface was more useful for content with low similarity. However, when the task involved multiple selection criteria, the 2D list interface was more effective for content with high similarity, and the 3D card interface was more helpful for content with lower similarity. Hence, content-oriented navigation design is not simple and straightforward. Researchers and designers should also consider the match between variables such as interface design, information content and task complexity.

In addition, during the navigation process, older adults' performance and perceptions were also influenced by their technology experience, for instance, their duration of use of computers, duration of use of mobile technologies and self-efficacy with mobile technology, as well as the user capability of visual perception.

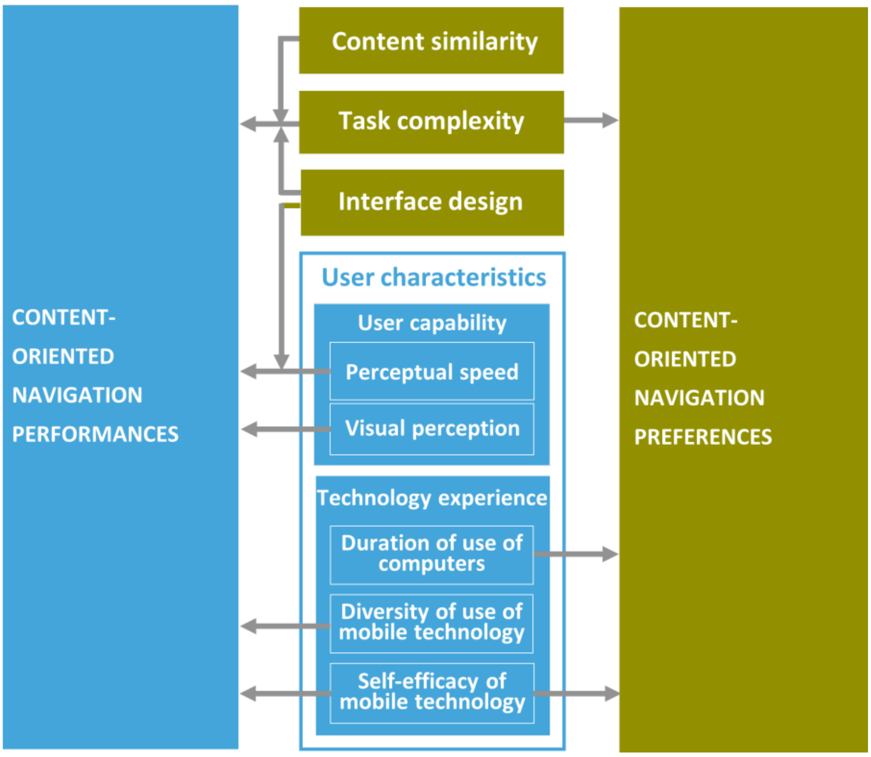


Figure 8.3 User modelling for the content-oriented mobile navigation

8.2. Limitations and Future Work

This study investigated older adults' post-adoption usage and perceptions of mobile technologies using a combination of qualitative and quantitative methods. Nevertheless, some limitations remain because of the time limit and research scope.

First, the research focused on older adults' post-adoption behaviour due to the high penetration rate of mobile technologies in Hong Kong. It mainly investigated the factors influencing older adults' continued use of mobile technologies and applications after their initial adoption. The participants recruited in this study comprised a group of senior citizens who had an average education level from primary school to middle school and possessed certain level of digital literacy. Although the interview questions, capability tests, and experimental interfaces and materials used in the research are understandable and applicable across various culture backgrounds, we should be cautious to extend the findings of the research to seniors with various levels of education and technology experience. Future studies can further investigate mobile navigation behaviour using similar methods for the novice or low-literacy senior users.

Second, this study used a series of capability tests to evaluate older adults' perceptual and cognitive abilities. These tests were mainly selected from the field of psychology. Although the reliability and validity of these tests have been proved in psychological experiments, they have not been widely used to evaluate older adults' user capabilities in human-computer interaction. In addition, the detailed objective performance measurements used in this study are more suitable for a smaller sample of participants. When recruiting a larger sample of users, greater time and resources will be needed. Thus future studies can be conducted to develop a set of objective capability tests that are accurate and quick to administer with older adults.

The research also provides possible directions for future studies. First, the modelling of interaction behaviour is a complex process that involves investigating the underlying mechanism of technology interaction, identifying predictive variables for modelling, quantifying the relationships between variables and validating and improving the model based on a vast amount of data. Even to estimate one parameter, numerous data are needed. Thus, considering time limits, the research focused on a specific interaction feature, goal-directed mobile navigation, which was defined based on the results of Study One. Other aspects related to technology interaction require further investigation to build a more integrated predictive user model. Further studies that investigated voice user interfaces or cognitive user interfaces can evaluate more predictive parameters and quantify user models for more technology features such as interface feedback or interaction techniques following a similar methodology.

Second, the research addressed the lack of investigation of factors such as interface features in predictive model development. The main contributions are in the stages of identification of predictive variables and the quantification of the relationships between these variables for user modelling. Nevertheless, future studies with a larger sample size and more kinds of interfaces need to further validate and improve the user model to support a wider range of design evaluations. In addition, this study mainly focused on several factors of perceptual and cognitive capabilities, considering the essence of navigation behaviour, which demands greater perceptual and cognitive information processing. Future studies could cover a wider range of user capabilities for sensory and motor parameters, especially when designing for the group of old-old adults with significantly impaired motor capabilities. Furthermore, the methods of user modelling and artificial intelligence can be combined to detect the patters of older adults' interaction behaviour in the future.

CHAPTER 9 Conclusion

This chapter summarises the major findings of the research and outlines its contributions and implications.

9.1. Major Findings

The research provides several important findings:

- Hong Kong Chinese older adults' usage and perceptions of mobile technologies were investigated in the post-adoption stages. They generally hold positive attitudes towards mobile technologies. However, the technology was not suitably designed for their capabilities and limitations, so it did not support older adults' use and further adoption of these mobile technologies.
- After initial adoption, older adults' use of mobile technologies was significantly influenced by their age, perceptual speed and technology features of menu and functionality. At the same time, older adults' post-adoption perceptions of mobile technologies were significantly predicted by their visual perception and spatial abilities, as well as the technology features of menus, colour and background, navigation and controls. Accordingly, a theoretical model for older adults' post-adoption usage behaviour and user perceptions was developed.
- In particular, due to the complex perceptual and cognitive processes, the features that related to mobile navigation were the most problematic issues that limited older adults' post-adoption usage and perceptions of mobile technologies, which have been rarely explored in previous studies.
- Older adults' navigation behaviour with mobile technologies can be

categorised into two ways: menu-oriented navigation and content-oriented navigation. Overall, older adults performed better when navigating content rather than menus. Usability issues were detected for six state-of-the-art design patterns including tabs, sider drawers, springboards, lists, galleries and cards. The study obtained key insights into how different design patterns support or limit older adults' mobile navigation behaviour and developed a set of design guidelines accordingly.

- A user model for older adults' menu-oriented navigation behaviour was developed. In this model, navigation performance and evaluations are predicted by the level of task complexity and user characteristics (specifically the factors of age and education, technology experience in terms of duration of use of computers, duration of use of mobile technologies and self-efficacy with mobile technologies and user capabilities of perceptual speed, visual acuity, contrast sensitivity and visual perception). The effect of redundancy design was not statistically significant, but it is still recommended as a superior menu design solution for older adults.
- A user model for older adults' content-oriented navigation behaviour was also built. In this model, the navigation performance and perceptions were significantly influenced by user capabilities of perceptual speed and task complexity, by the interaction between perceptual speed and navigation design and by the interaction between navigation design, content similarity and task complexity. In addition, the user's technology experience such as duration of use of computers and mobile technologies and self-efficacy of mobile technologies can also predict the older adults' performance and perceptions in content-oriented navigation behaviour. The metaphor design can help to facilitate older adults' content-oriented navigation behaviour,

but it should be carefully applied by considering older adults' varying levels of perceptual speed.

9.2. Contributions

The findings presented in this thesis have important implications for the research field and for design practice.

First, the research advances our knowledge of human-computer interaction and universal design:

- The interview investigation of older adults' post-adoption usage and perception regarding mobile technologies refines the theories of technology acceptance and adoption by emphasising that the essence of mobile technology acceptance lies in the process of continued adoption of functions.
- By examining usability problems that older adults face when navigating different interfaces and analysing the underlying reasons for these usability issues on the basis of older adults' objective limitations and subjective preferences, the research provides rich and deep empirical evidence by proposing a list of guidelines for designing elderly-friendly mobile navigation interfaces, which can compensate the lack of understanding of older adults' behaviour challenges when navigating rapidly evolving mobile interfaces.
- The user models proposed by the experiments provide an effective way to predict older adults' mobile navigation behaviour, which can advance the development of analytical usability evaluation methods for future elderly-friendly user interface design. By comparing various aspects of user

characteristics such as technology experience and user capabilities to the corresponding interface and task demands that determined in the user models, it can help to assess and improve the degree of fit between the user, technology and task. In this way, the results can compensate for previous studies of user models that depend on the concepts of information scent and label-following.

Second, the research has generated a number of findings that can be applied to design practice, which is especially instructive and helpful for mobile technology designers and developers. The implications are summarised as follows:

- The assessment of user characteristics and technology features that influence older adults' post-adoption behaviour can provide a theoretical basis for designers to develop guidelines that can encourage older adults' continued and upgraded adoption behaviour.
- By investigating older adults' mobile navigation behaviour, design guidelines were specifically developed for each kind of navigation pattern. These guidelines address the lack of usability standards in mobile navigation design and can better fit into specified design scenarios because they follow style guides in the contemporary mobile industry.
- The user models for older adults' navigation behaviour can help designers to analytically evaluate a large amount of proposed mobile interface designs. It can also inform designers by identifying possible causes of poor navigation performance. With future iterative improvement and validation of the model, the advantages of this prediction tool will be further enhanced, and less time and fewer resources will be required.

- By evaluating the effectiveness of two design principles, redundancy design and metaphor design, the results can help designers to decide how to use these principles by considering the target users' level of cognitive capabilities.

Appendix A. Questionnaire for Study One (Chinese Version)

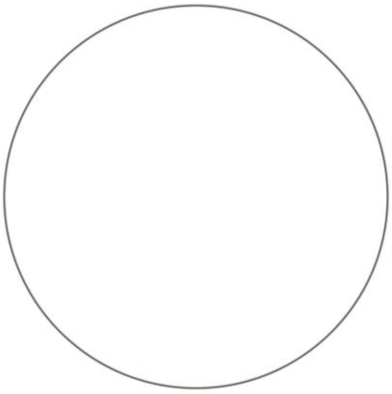
一、能力評估

1. 請選擇下列三樣項目注記：

   黑色☐　紅磡☐　葡萄☐
   紅色☐　西環☐　蜂蜜☐
   藍色☐　觀塘☐　蘋果☐
   綠色☐　屯門☐　餅乾☐

2. 時鐘繪畫測試

   (1) 請在下圖圓圈中畫出鐘錶盤上的數字
   (2) 請畫出 11：10 時的指針方向



3．視知覺速度

(	#	>	┌	├	┤	)	+	&
1	2	3	4	5	6	7	8	9

根據以上圖表，請在 90 秒中儘快找出下列符號對應的數字:

#	>	+	&	├	┌	├	)	├	(
┤	)	#	├	┌	&	(	+	┤	>
#	├	┤	├	+	┌	)	>	┤	┌
(	├	#	(	├	+	>	#	┌	)
#	&	┤	>	┌	)	#	┤	(	├
+	>	├	)	#	>	(	┤	+	┌
┤	)	#	>	+	├	(	&	┌	┤

4．視覺感知評估

以下三個問題將會涉及到您在日常生活中使用視力(包括矯正後視力)的情況，請您根據您在日常生活中從事以下活動時的真實感受和經驗選擇其中您認為最為接近的選項：

(1)您在閱讀普通報紙時是否感覺到困難？

因為視力問題根本無法閱讀報紙 ☐　非常困難 ☐　中等困難 ☐　有一點困 ☐　一點也不困難 ☐

(2)您在從事要求清楚地進行近距離觀察的活動時（例如縫紉，修理東西或者使用手動工具等）是否感覺到困難？

因為視力問題根本無法閱讀報紙 ☐　非常困難 ☐　中等困難 ☐　有一點困 ☐　一點也不困難 ☐

(3)請您閱讀 iPad 上的文字，是否感覺到困難？

因為視力問題根本無法閱讀報 ☐　非常困難 ☐　中等困難 ☐　有一點困難 ☐　一點也不困難 ☐

二、智能產品的用戶感知與使用習慣問卷

1. 性別： 男 ☐ 女 ☐
2. 年齡： ______ 歲
3. 教育程度： ______ 年
   小學以下 ☐ 小學 ☐ 中學 ☐ 專上學院 ☐
   大學及以上 ☐
4. 您對智能產品的態度：
   (1)我認為使用智能產品讓我感到厭煩：
非常同意□ 同意□ 我不知道□ 不同意□ 非常不同意□
   (2)我認為使用智能產品會對我的生活帶來方便：
非常同意□ 同意□ 我不知道□ 不同意□ 非常不同意□
   (3)我有信心去學習使用一個新的智能產品或其應用程式：
非常同意□ 同意□ 我不知道□ 不同意□ 非常不同意□
5. 若您對智能產品感到厭煩，請闡述原因 (多選)：
   ☐ 我壓根不喜歡接觸科技型產品
   ☐ 我沒有信心去學習使用這類產品
   ☐ 智能產品使用起來太過複雜
   ☐ 我沒有經濟能力購買這些產品
   ☐ 沒有人給我幫助和指導
   ☐ 其他________________
6. 您有______年的智能產品使用經驗(智能手機☐ iPad 或其他平板電腦☐ 智能手錶等☐)
7. 您平均每天/每週使用智能產品_______小時
8. 您經常使用的應用程式和功能包括？(多選)
   ☐ 基本功能：電話，短信，計算器，日曆，鬧鐘，照相
   ☐ 社交目的：社交軟體
   ☐ 線上購物
   ☐ 獲取健康資訊
   ☐ 獲取新聞資訊，線上學習及其他教育目的
   ☐ 娛樂，如看電影，遊戲等
   ☐ 其他 ______
9. 您對智能產品及其應用程式的可用性評價：
   (1)我在學習使用智能產品或其應用程式時，感覺到非常困難：
   非常不同意□ 同意□ 我不知道□ 不同意□ 非常同意□
   (2)在使用我常用的智能產品或其應用程式時，我能夠非常高效的完成任務。例如，我可以快速且正確地找到我需要的資訊：
   非常不同意□ 同意□ 我不知道□ 不同意□ 非常同意□
   (3)在使用智能產品及其應用程式時，我經常操作錯誤，並不知道如何從錯誤中恢復。例如，我經常點錯螢幕上的圖示，並不知道如何撤銷我的錯誤操作：
   非常不同意□ 同意□ 我不知道□ 不同意□ 非常同意□

(4)如果我有很長一段時間不使用智能產品，當我再次使用它時，我常常忘記該怎樣操作而不得不重新學習如何使用：

非常不同意☐　同意☐　我不知道☐　不同意☐　非常同意☐

(5)在使用智能產品及其應用程式時，我感到愉悅而滿足：

非常不同意☐　同意☐　我不知道☐　不同意☐　非常同意☐

(6)若您曾在學習或使用中感覺到困難，請回憶您當時所遇到的困難並回答以下問題：

目標設計	目標按鍵太小或不夠突出，我不知道該點擊哪裡	非常同意☐ 同意☐ 我不知道☐ 不同意☐ 非常不同意☐
圖片設計	過多的圖片和動畫讓我眼花繚亂	非常同意☐ 同意☐ 我不知道☐ 不同意☐ 非常不同意☐
圖标設計	應用程式中的圖标太過複雜或毫無意義，我無法看懂	非常同意☐ 同意☐ 我不知道☐ 不同意☐ 非常不同意☐
操作交互	我經常不知道如何滑動或者滾動介面	非常同意☐ 同意☐ 我不知道☐ 不同意☐ 非常不同意☐
功能設計	我經常找不到隱藏的菜單	非常同意☐ 同意☐ 我不知道☐ 不同意☐ 非常不同意☐
導航設計	我不知道如何在各個功能或介面中轉換	非常同意☐ 同意☐ 我不知道☐ 不同意☐ 非常不同意☐
功能轉換	我不知道如何返回我之前的操作介面	非常同意☐ 同意☐ 我不知道☐ 不同意☐ 非常不同意☐
指示語言	指示語言太過複雜，我看不懂	非常同意☐ 同意☐ 我不知道☐ 不同意☐ 非常不同意☐
介面設計	操作介面的整體佈局，包括文字，圖片，巡覽列等太過複雜，讓我在尋找資訊的過程中感到疲憊	非常同意☐ 同意☐ 我不知道☐ 不同意☐ 非常不同意☐
顏色設計	介面的顏色讓我在尋找資訊的過程中感到疲憊	非常同意☐ 同意☐ 我不知道☐ 不同意☐ 非常不同意☐

Appendix B. Questionnaire for Study One (English Version)

Ⅰ. Capability Assessment

1. Please remember the words as following:

   Black□ Hung Hom□ Grape□

   Red□ Sai Wan□ Honey□

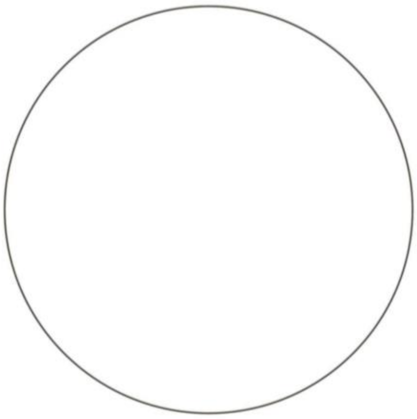
   Blue□ Kwun Tong□ Apple□

   Green□ Tuen Mun□ Cookie□

2. Clock Drawing Test (CDT)

   (1) Please draw a clock face with numbers displayed on it.

   (2) Please draw the clock hands to read time of 11:10.



3. Spatial Digit Modalities Test (SDMT)

(	#	>	┌	├	┤	)	+	&
1	2	3	4	5	6	7	8	9

Please pair the abstract symbols with corresponding numbers based on the above chart as many as possible within 90 seconds.

#	>	+	&	├	┌	├	)	├	(
┤	)	#	├	┌	&	(	+	┤	>
#	├	┤	├	+	┌	)	>	┤	┌
(	├	#	(	├	+	>	#	┌	)
#	&	┤	>	┌	)	#	┤	(	├
+	>	├	)	#	>	(	┤	+	┌
┤	)	#	>	+	├	(	&	┌	┤

4. Visual Ability Self-evaluation:

Please evaluate your daily visual perception abilities (with corrections) according to your experience when reading texts or detecting targets:

(1) Visual ability to read texts on paper:

Very difficult☐ Difficult☐ Medium☐ A little difficult☐ Not difficult at all☐

(2) Visual ability to complete tasks that require close observation

Very difficult☐ Difficult☐ Medium☐ A little difficult☐ Not difficult at all☐

(3) Visual ability to read texts on digital displays

Very difficult☐ Difficult☐ Medium☐ A little difficult☐ Not difficult at all☐

Ⅱ. Interview Questionnaire on User Perception and Usage Behaviour

1. Gender: Male☐ Female☐
2. Age:_______
3. Education Level: _____
   Below the primary school☐ Primary school☐ Secondary school☐ Post-secondary school☐ University and above☐
4. Attitudes towards mobile technologies:
   (1) I do not like to use mobile technologies:
   Strongly agree☐ Agree☐ I don't know☐ Disagree☐ Strongly disagree☐
   (2) Mobile technologies bring some convenience to your life:
   Strongly agree☐ Agree☐ I don't know☐ Disagree☐ Strongly disagree☐
   (3) I'm capable to learn a new kind of mobile technology or related application:
   Strongly agree☐ Agree☐ I don't know☐ Disagree☐ Strongly disagree☐
5. Please indicate why you dislike mobile technologies:
   ☐ I don't like technological products
   ☐ I don't have confidence to learn the technological products
   ☐ It's too complicated to use technologies
   ☐ I cannot afford these technologies.
   ☐ Nobody provides instructions or help
   ☐ Others_________________
6. I have used the mobile technologies for __ years (smartphone☐/iPad or tablets☐/smart-watch☐)
7. I used mobile technologies __for hours/day
8. I used the following mobile applications:
   ☐ Basic functions: calling, message, calculator, calendar, clock, camera
   ☐Social communication and connection
   ☐On-line shopping
   ☐Health-care information
   ☐Information searching and learning
   ☐Entertainment and games
   Others________
9. Please evaluate the mobile technologies' usability based on the following aspects:
   (1) I feel it easy to learn a new mobile technology or related application:
   Strongly disagree☐ Disagree☐ I don't know☐ Agree☐ Strongly agree☐
   (2) I can complete most of the tasks efficiently using my familiar mobile technology:
   Strongly disagree☐ Disagree☐ I don't know☐ Agree☐ Strongly agree☐
   (3) I can easily recover from the mistakes using my mobile technologies:

Strongly disagree□ Disagree□ I don't know□ Agree□ Strongly agree□

(4) I can easily remember how to use the technologies or applications when there has been a long time since I haven't used them:

Strongly disagree□ Disagree□ I don't know□ Agree□ Strongly agree□

(5) I feel pleasured and satisfied when using mobile technologies and related functions:

Strongly disagree□ Disagree□ I don't know□ Agree□ Strongly agree□

(6) Please recall the difficulties you have encountered when using mobile technologies:

Target design (TD)	The target is clear and visible for me, such as text and buttons.	Strongly agree□ Agree□ I don't know□ Disagree□ Strongly disagree□
Use of graphics (UG)	The number of graphics and animations is appropriate on the screen? They make me feel comfortable and clear?	Strongly agree□ Agree□ I don't know□ Disagree□ Strongly disagree□
Icon design (ID)	The icon is simple and meaningful enough to me.	Strongly agree□ Agree□ I don't know□ Disagree□ Strongly disagree□
Interaction (IT)	I know how to slide between different interfaces by tapping, swiping, dragging or dropping.	Strongly agree□ Agree□ I don't know□ Disagree□ Strongly disagree□
Functionality (FC)	I know how to switch between different functions.	Strongly agree□ Agree□ I don't know□ Disagree□ Strongly disagree□
Use of menus (UM)	I can easily find the pull-down menu or sider drawer.	Strongly agree□ Agree□ I don't know□ Disagree□ Strongly disagree□
Navigation and controls (NC)	I know how to return to the previous interface or homepage.	Strongly agree□ Agree□ I don't know□ Disagree□ Strongly disagree□
Instruction and language (IL)	I can understand the language or instruction used.	Strongly agree□ Agree□ I don't know□ Disagree□ Strongly disagree□
Layout design (LD)	All the displayed information is relevant and the interface is simple and clear for me.	Strongly agree□ Agree□ I don't know□ Disagree□ Strongly disagree□
Use of colour & background (CB)	The colours and background used are properly for me.	Strongly agree□ Agree□ I don't know□ Disagree□ Strongly disagree□

Appendix C. Questionnaire for Study Four (Chinese Version)

第一部分：個人資料

1. 性別： ☐ 男 ☐ 女
2. 年齡： _______ 歲
3. 教育程度：接受正规教育的时间 ______ 年
   ☐ 小學以下 ☐ 小學 ☐ 中學 ☐ 專上學院
   ☐ 大學及以上
4. 智能產品使用經驗：
   (1) 您有______年的電腦使用經驗。
   (2) 您的智能產品使用經驗: ☐ 智能手機___年; ☐ 平板電腦___年; ☐ 智能手錶___年。
   (3) 您平均☐ 每天/ ☐ 每週使用智能產品_______小時。
   (4) 您的智能產品使用水準是？

非常差	比較差	中等水準	比較好	非常好
☐	☐	☐	☐	☐

   (5) 您經常使用的應用程式和功能包括？（多選）

基本功能		☐ 電話 ☐ 短信 ☐ 計算器 ☐ 日曆 ☐ 鬧鐘 ☐ 相機	其他 ______
社交功能		☐ WhatsApp ☐ 微信 WeChat ☐ Facebook ☐ E-mail ☐ Line	其他 ______
影音娛樂	電影、電視節目等	☐ YouTube ☐ myTV SUPER ☐ 騰訊視頻	其他 ______
	音樂、唱歌	☐ JOOX ☐ 經典老歌 ☐ K歌	其他 ______
獲取資訊	閱讀新聞	☐ 蘋果動新聞 ☐ 頭條日報 ☐ 東網/東方日報 ☐ 長青網	其他 ______
	查找資料	☐ Google Chrome ☐ 其他瀏覽器	其他 ______
	財經股票	☐ Now財經 ☐ 港股360 ☐ 銀行類 ☐ 賽馬會 ☐ 其他股票證券	其他 ______
教育目的	線上學習/查字典	☐ google翻譯 ☐ 聖經 ☐ 成語/歇後語 ☐ 其他翻譯軟件	其他 ______
日常生活	交通資訊	☐ 九巴 ☐ KMB城巴 ☐ MTR港鐵 ☐ google地圖	其他 ______
	其他生活	☐ 天文臺 ☐ 電訊盈科 ☐ 六合彩	其他 ______
健康管理		☐ 健康資訊 ☐ 健康管理 ☐ 營養食譜	其他 ______
娱乐游戏		☐ 麻将 ☐ Candy Crash	其他 ______

第二部分 認知能力測試

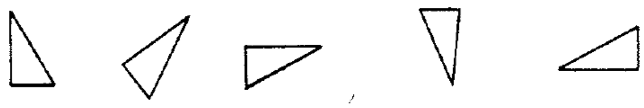
1. 順序記憶力廣度測試

順背數字廣度測驗是由 2 位數直到 13 位數組成的數位表，共兩套。測驗時以每秒鐘一個數字的速度，從第一套數位表的 2 位數開始，逐行念給被測試者聽，要求被測試者照樣背下來 (每秒一數，不能分組)。如果被測試者通過了 2 位數，再測 3 位數，以此類推。如果被測者沒有通過 8 位數，則念第二套測試表的 8 位數，通過了再繼續念第一套測試表的 9 位數。按通過的數字位數計分。

2	6-4
	9-1
3	5-8-2
	6-9-4
4	6-4-3-9
	7-2-8-6
5	4-2-7-3-1
	7-5-8-3-6
6	6-1-9-4-7-3
	3-9-2-4-8-7
7	5-9-1-7-4-2-8
	4-1-7-9-3-8-6
8	5-8-1-9-2-6-4-7
	3-8-2-9-5-1-7-4
9	2-7-5-8-6-2-5-8-4
	7-1-3-9-4-2-5-6-8
10	5-2-7-4-9-1-3-7-4-6
	4-7-2-5-9-1-6-2-5-3
11	4-1-6-3-8-2-4-6-3-5-9
	3-6-1-4-9-7-5-1-4-2-7
12	7-4-9-6-1-3-5-9-6-8-2-5
	6-9-4-7-1-9-7-4-2-5-9-2

2. 旋轉圖片測試

請看下面這五個三角形。



你可以發現所有的這些三角形都是由同一個三角形旋轉到不同位置行成的。

現在，請看下面這兩個三角形：

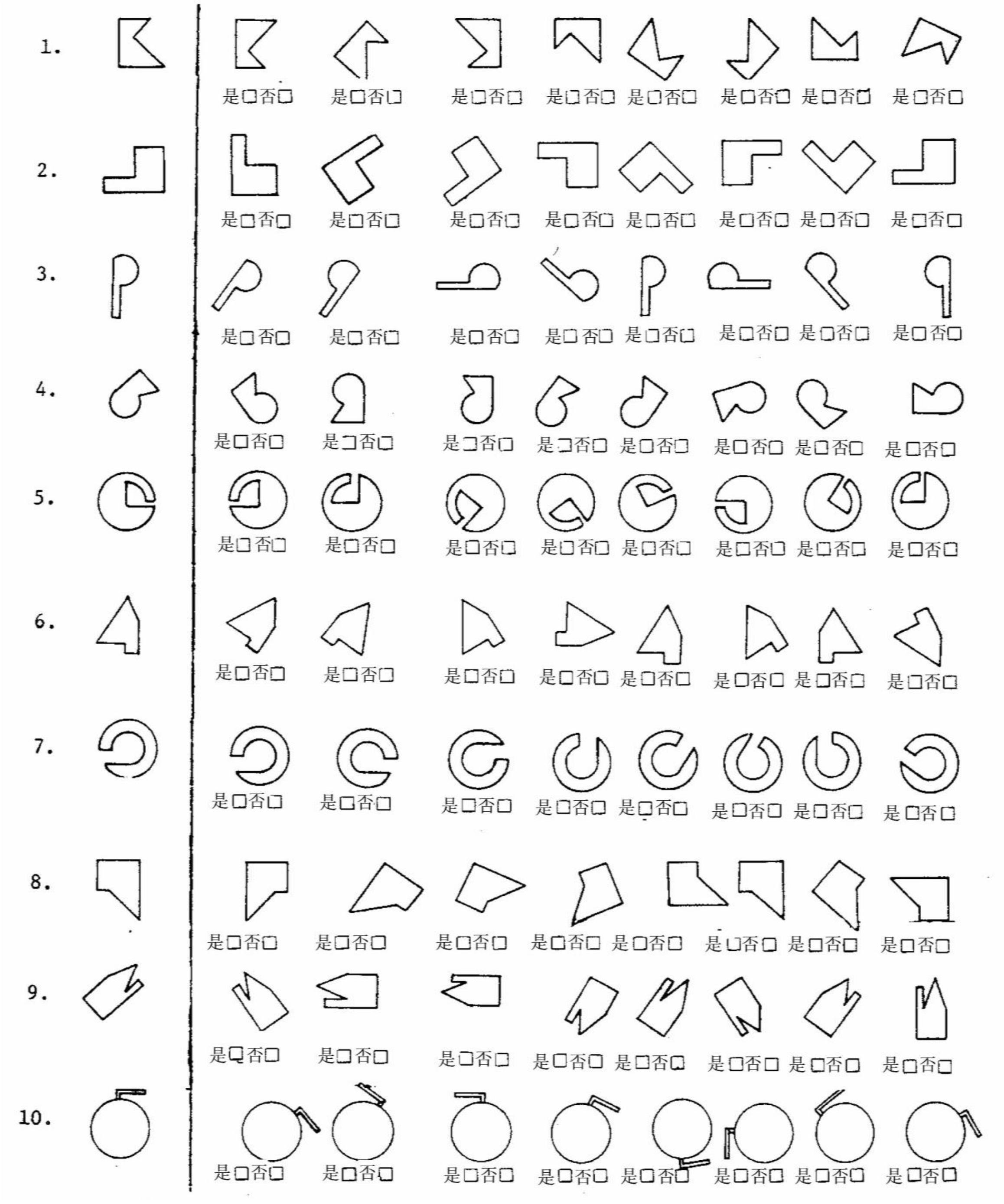
這兩個三角形是不一樣的。第一個三角形無論如何也無法旋轉到同第二個三角形一模一樣的位置，它將會旋轉到不同的形狀。

在這個測試的所有問題中，豎線左邊有 1 個圖形，豎線右邊有 8 個圖形。你需要判斷豎線右側的八個圖形和豎線左邊的圖形是否相同。如果相同，請在圖形下方勾選“是”，如果不相同，請在圖形下方勾選“否”。

請首先嘗試下面的練習，請參考第一行的例子。

下面的問題共分為兩個部分，每一部分你都有三分鐘的時間作答，每個問題難度不一，如果你無法完成其中的某道問題，請先跳過並繼續後面的問題。

---第一部分 (3 分钟)---


1.
是□否□ 是□否□ 是□否□ 是□否□ 是□否□ 是□否□ 是□否□ 是□否□
2.
是□否□ 是□否□ 是□否□ 是□否□ 是□否□ 是□否□ 是□否□ 是□否□
3.
是□否□ 是□否□ 是□否□ 是□否□ 是□否□ 是□否□ 是□否□ 是□否□
4.
是□否□ 是□否□ 是□否□ 是□否□ 是□否□ 是□否□ 是□否□ 是□否□
5.
是□否□ 是□否□ 是□否□ 是□否□ 是□否□ 是□否□ 是□否□ 是□否□
6.
是□否□ 是□否□ 是□否□ 是□否□ 是□否□ 是□否□ 是□否□ 是□否□
7.
是□否□ 是□否□ 是□否□ 是□否□ 是□否□ 是□否□ 是□否□ 是□否□
8.
是□否□ 是□否□ 是□否□ 是□否□ 是□否□ 是□否□ 是□否□ 是□否□
9.
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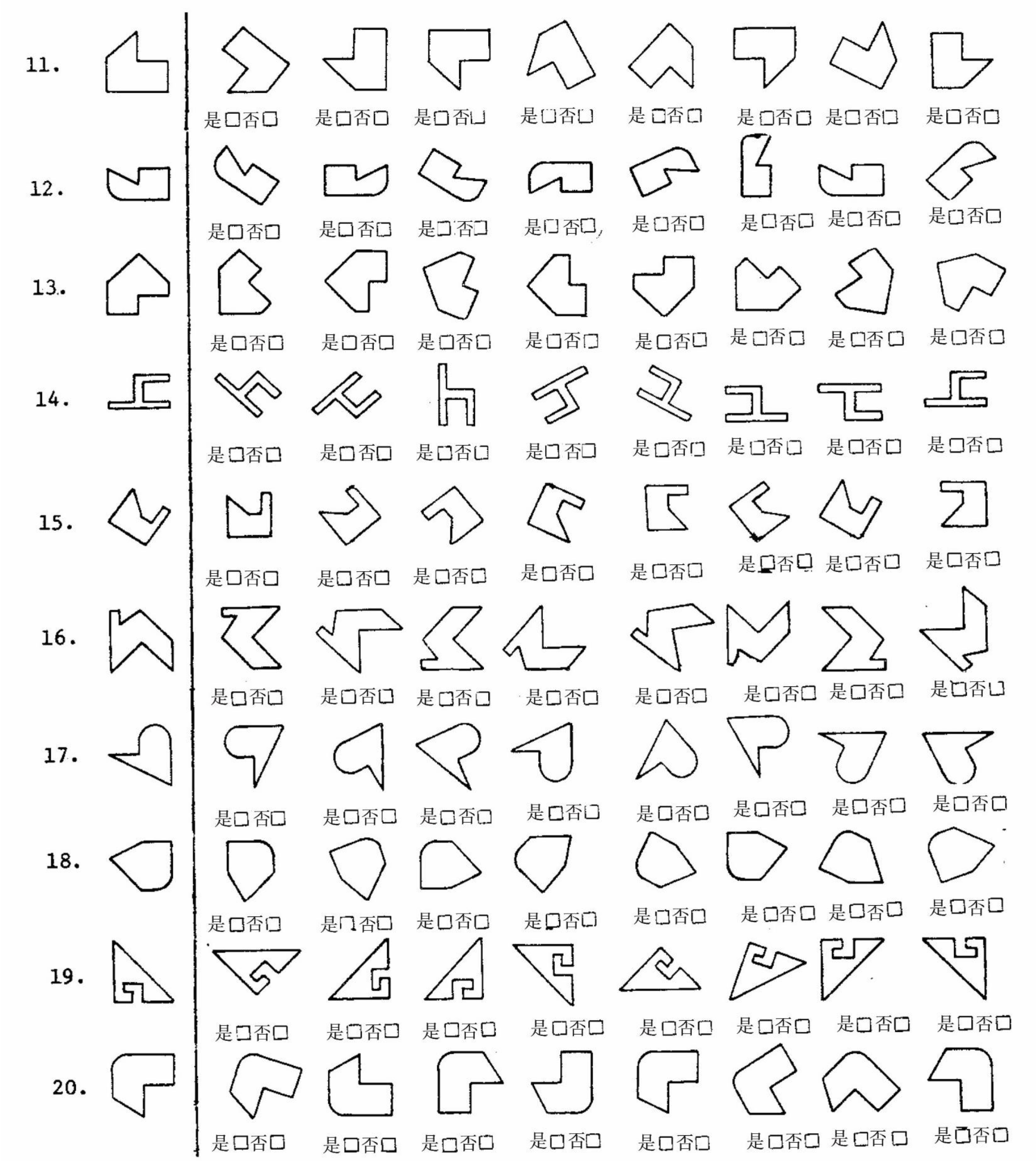
---第二部分 (3 分钟) ---


11.
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12.
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17.
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18.
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19.
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20.
是□否□ 是□否□ 是□否□ 是□否□ 是□否□ 是□否□ 是□否□ 是□否□

3. 數位記號模式試驗

(	#	>	┌	├	┤	)	+	&
1	2	3	4	5	6	7	8	9

根據以上圖表，請在 90 秒中儘快找出下列符號對應的數字：

#	>	+	&	├	┌	├	)	├	(
┤	)	#	├	┌	&	(	+	┤	>
#	├	┤	├	+	┌	)	>	┤	┌
(	├	#	(	├	+	>	#	┌	)
#	&	┤	>	┌	)	#	┤	(	├
+	>	├	)	#	>	(	┤	+	┌
┤	)	#	>	+	├	(	&	┌	┤
#	)	+	>	&	┤	┌	(	>	+

4. 斯特鲁普色词测验

请分别在 45s 内完成以下任务：

a．请尽可能正确地读出下列描述颜色的词语 ______。

黑色	红色	橙色	蓝色	绿色
蓝色	粉色	黄色	蓝色	绿色
黑色	粉色	蓝色	黑色	橙色
红色	绿色	黑色	红色	粉色
橙色	绿色	红色	蓝色	粉色
红色	黑色	蓝色	黄色	绿色
绿色	黑色	蓝色	粉色	红色
黄色	蓝色	绿色	黑色	橙色
粉色	蓝色	红色	粉色	绿色
黄色	黑色	橙色	蓝色	绿色
橙色	黑色	蓝色	粉色	绿色
黑色	红色	黄色	橙色	蓝色
粉色	黑色	蓝色	红色	绿色
橙色	红色	黄色	蓝色	绿色
黑色	粉色	绿色	红色	橙色
黄色	粉色	黑色	红色	蓝色

b．请尽可能正确的读出下列词语的字体颜色 ______。

香港	香港	香港	香港	香港
香港	香港	香港	香港	香港
香港	香港	香港	香港	香港
香港	香港	香港	香港	香港
香港	香港	香港	香港	香港
香港	香港	香港	香港	香港
香港	香港	香港	香港	香港
香港	香港	香港	香港	香港
香港	香港	香港	香港	香港
香港	香港	香港	香港	香港
香港	香港	香港	香港	香港
香港	香港	香港	香港	香港

c．请尽可能正确的说出下列词语的字体颜色 (注意：不是读出词语本身)______。

蓝色	橙色	黄色	红色	粉色
黑色	粉色	绿色	蓝色	黄色
黑色	绿色	橙色	黑色	蓝色
黑色	黄色	粉色	蓝色	红色
橙色	黑色	黄色	粉色	绿色

红色	蓝色	黑色	橙色	粉色
绿色	橙色	粉色	红色	黄色
绿色	红色	黑色	黄色	红色
红色	蓝色	粉色	橙色	绿色
黑色	蓝色	黄色	红色	粉色
蓝色	黑色	黄色	绿色	蓝色
粉色	蓝色	绿色	蓝色	橙色

5. 請您閱讀 iPad 上的文字，是否感覺到困難？

因為視力問題根本無法閱讀報紙 □　非常困難 □　中等困難 □　有一點困 □　一點也不困難 □

第三部分　實驗說明

本次實驗需要您在手機上使用兩種界面來完成一些任務，共有 8 個任務，每個任務將會要求您在 4 種類別的共 12 本書籍中選擇符合任務描述要求的書籍，請儘快並且正確地完成實驗任務，我們將記錄您完成每項任務的時間和正確率。在每個任務後我們將邀請您對這個任務或界面進行評價。整個實驗流程將大約為一個小時。實驗結束後，我們將支付您 50 港幣作為報酬。

1. 試驗環節：

   現在，您將進行試驗環節。本環節將會有三個任務，請您按照介面要求進行。任務結束後，如您有任何問題，請向實驗人員詢問。如沒有問題，請您進入正式實驗環節。

2. 實驗環節：

   實驗正式開始，請按照介面要求完成 8 個任務。

第四部分 客觀評價量表

1. 請對剛才的任務進行評價：

a. 完成刚才這個任務对我来说非常簡單：

非常困难				非常简单
1	2	3	4	5
☐	☐	☐	☐	☐

b. 請描述你是否在任務中間是否遇到了任何問題或者困難

____

2. 請對剛才的界面進行評價，當你使用這個界面時：

易用性	使用這個界面完成任務對我來說非常簡單。	界面	非常不同意　　　非常同意
		(1)	1　2　3　4　5
		(2)	1　2　3　4　5
		(3)	1　2　3　4　5
	使用這個界面完成的各種操作(例如翻頁，點擊，瀏覽等動作) 對我來說都非常簡單。	界面	非常不同意　　　非常同意
		(1)	1　2　3　4　5
		(2)	1　2　3　4　5
		(3)	1　2　3　4　5
有用性	這個界面能夠幫助我很快完成任務。	界面	非常不同意　　　非常同意
		(1)	1　2　3　4　5
		(2)	1　2　3　4　5
		(3)	1　2　3　4　5
	這個界面可以幫助我更好地尋找需要	界	非常不　　　非常

	的信息。	面	同意　　　　　　同意
		(1)	1　2　3　4　5
		(2)	1　2　3　4　5
		(3)	1　2　3　4　5
精力	我不需要投入很多精力來完成這個任務。	界面	非常不同意　　　　非常同意
		(1)	1　2　3　4　5
		(2)	1　2　3　4　5
		(3)	1　2　3　4　5
方向感	我不会感到迷茫或找不到方向。	界面	非常不同意　　　　非常同意
		(1)	1　2　3　4　5
		(2)	1　2　3　4　5
		(3)	1　2　3　4　5
	我非常清楚自己浏覽時候的位置，例如前後的資訊，已經流覽的路徑和計畫路徑。	界面	非常不同意　　　　非常同意
		(1)	1　2　3　4　5
		(2)	1　2　3　4　5
		(3)	1　2　3　4　5
滿意度	就這個界面的使用體驗，我覺得非常滿意。	界面	非常不同意　　　　非常同意
		(1)	1　2　3　4　5
		(2)	1　2　3　4　5
		(3)	1　2　3　4　5
行為意圖	如果有机会，我有意愿在将来继续使用这种界面。	界面	非常不同意　　　　非常同意
		(1)	1　2　3　4　5
		(2)	1　2　3　4　5
		(3)	1　2　3　4　5

Appendix D. Questionnaire for Study Four (English Version)

Ⅰ Personal Information

1. Gender: Male☐ Female☐
2. Age:____
3. Education experience: ______years
   Below the primary school☐ Primary school☐ Secondary school☐ Post-secondary school☐ University and above☐
4. Mobile technology experience:
   (1) I have used computers for ___ years.
   (2) I have used ☐smartphone ☐tablets ☐smart-watch for ___years.
   (3) I use the mobile technologies for ___hours per day.
   (4) Self-evaluated competence in mobile technology usage:
   Very bad☐ Bad☐ Medium☐ Good☐ Very good☐
   (5) I have used the following mobile applications:

Basic functions		☐ call ☐ message ☐ calculator ☐ canlendar ☐ clock ☐ camera	others ______
Social communication		☐ WhatsApp ☐ WeChat ☐ Facebook ☐ E-mail ☐ Line	others ______
Entertainment	Movie and TV	☐ YouTube ☐ myTV SUPER ☐ Tengxun TV	others ______
	Music	☐ JOOX ☐ Classic Songs ☐ Karaoke	others______
Information Searching	News	☐ Apple Daily ☐ Headline Daily ☐ Oriental Daily ☐ 長青網	others ______
	Information Searching	☐ Google Chrome ☐ other browser	others______
	Finance and Stock	☐ Now Financial News ☐ Hong Kong stock 360 ☐ E-bank ☐ Jockey club	others ______
Education	On-line learning	☐ Google translation ☐ bible ☐ idiom	others ______
Daily Life	Traffic information	☐ KMB.LWB ☐ MTR ☐ Google map	others ______
	Others	☐ Hong Kong Observatory ☐ PCCW ☐ Six legend	others ______
Healthcare Management		☐ Healthcare information ☐ Healthcare management ☐ Diet	others ______
Games		☐ Mahjong ☐ Candy Crash	others

		______

Ⅱ **Capability Assessment**

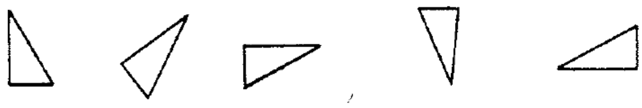
1. Auditory number span test (ANST)

   The experimenter will read a series of digits at a speed of one digit per second at first. Until the experimenters have finished the whole series, you are required to repeat these numbers in the exact order verbally. We will give you another chance for each length of digits series if you failed in the first try. The length of the digits series would be increased till you fail in two attempts. The score will be marked as the number of digits that you can repeat correctly in the exact order.

2	6-4
	9-1
3	5-8-2
	6-9-4
4	6-4-3-9
	7-2-8-6
5	4-2-7-3-1
	7-5-8-3-6
6	6-1-9-4-7-3
	3-9-2-4-8-7
7	5-9-1-7-4-2-8
	4-1-7-9-3-8-6
8	5-8-1-9-2-6-4-7
	3-8-2-9-5-1-7-4
9	2-7-5-8-6-2-5-8-4
	7-1-3-9-4-2-5-6-8
10	5-2-7-4-9-1-3-7-4-6
	4-7-2-5-9-1-6-2-5-3
11	4-1-6-3-8-2-4-6-3-5-9
	3-6-1-4-9-7-5-1-4-2-7
12	7-4-9-6-1-3-5-9-6-8-2-5
	6-9-4-7-1-9-7-4-2-5-9-2

2. Card rotation test (CRT)

Please look at the five triangles as following and you will find that all these triangles can be rotated or flipped to the same shape:

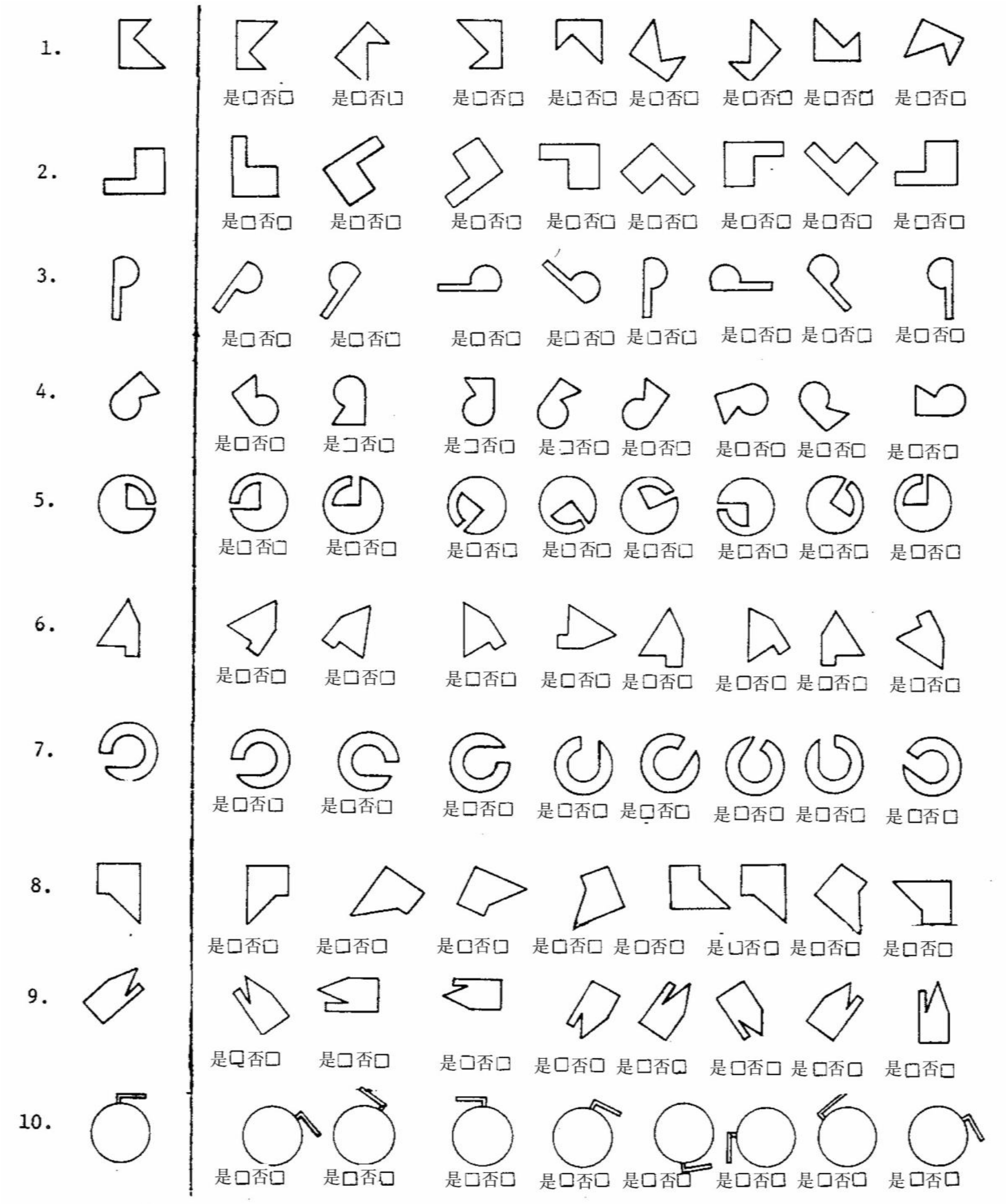


Nevertheless, the below two triangles are different because they cannot be rotated or flipped to the same shape:

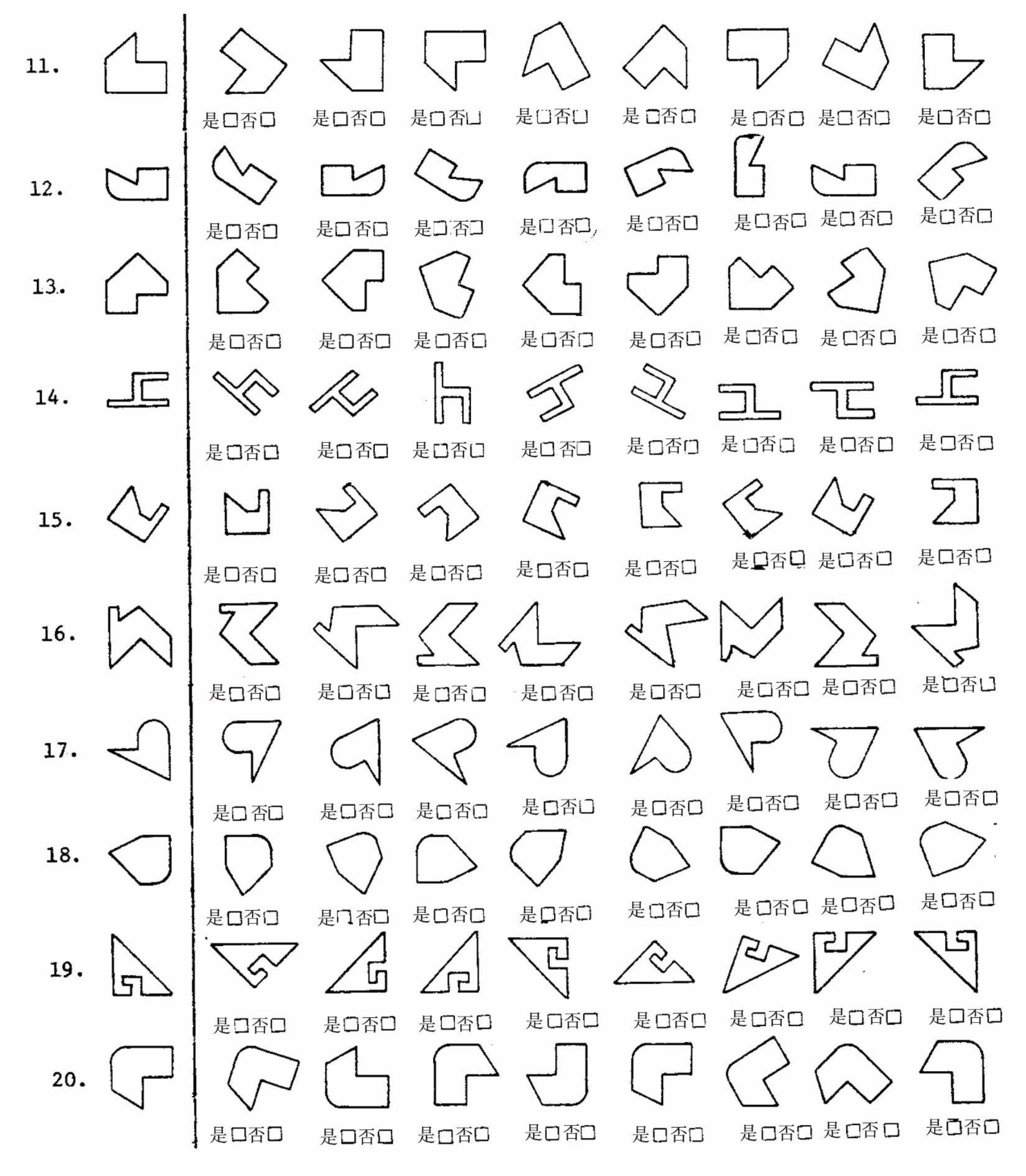
You are given a drawing of a card that was cut into an irregular shape. On the right side of this card, there are eight drawings of the same card, in which some of the drawings are merely rotated and flipped.

In the test, you need to indicate whether or not the eight drawings have been turned over. Before the test, please take your time to familiarise the tests by doing three practices. After that, you need to finish the test as quickly as possible without sacrificing accuracy in three minutes.

Part 1—3 minutes



Part 2—3 minutes



3. Spatial Digit Modalities Test (SDMT)

(	#	>	┌	├	┤	)	+	&
1	2	3	4	5	6	7	8	9

Please pair the abstract symbols with corresponding numbers based on the above chart as many as possible within 90 seconds.

#	>	+	&	├	┌	├	)	├	(
┤	)	#	├	┌	&	(	+	┤	>
#	├	┤	├	+	┌	)	>	┤	┌
(	├	#	(	├	+	>	#	┌	)
#	&	┤	>	┌	)	#	┤	(	├
+	>	├	)	#	>	(	┤	+	┌
┤	)	#	>	+	├	(	&	┌	┤

4. Stroop colour and word test (SCWT)

Please complete each task in 45 seconds:

a. Please read the following words as soon as possible:

黑色	红色	橙色	蓝色	绿色
蓝色	粉色	黄色	蓝色	绿色
黑色	粉色	蓝色	黑色	橙色
红色	绿色	黑色	红色	粉色
橙色	绿色	红色	蓝色	粉色
红色	黑色	蓝色	黄色	绿色
绿色	黑色	蓝色	粉色	红色
黄色	蓝色	绿色	黑色	橙色
粉色	蓝色	红色	粉色	绿色
黄色	黑色	橙色	蓝色	绿色
橙色	黑色	蓝色	粉色	绿色
黑色	红色	黄色	橙色	蓝色
粉色	黑色	蓝色	红色	绿色
橙色	红色	黄色	蓝色	绿色
黑色	粉色	绿色	红色	橙色
黄色	粉色	黑色	红色	蓝色

b. Please tell the colour of the following words as soon as possible:

香港	香港	香港	香港	香港
香港	香港	香港	香港	香港
香港	香港	香港	香港	香港
香港	香港	香港	香港	香港
香港	香港	香港	香港	香港
香港	香港	香港	香港	香港
香港	香港	香港	香港	香港
香港	香港	香港	香港	香港
香港	香港	香港	香港	香港
香港	香港	香港	香港	香港
香港	香港	香港	香港	香港
香港	香港	香港	香港	香港

c. Please tell the colour of the following words as soon as possible:

蓝色	橙色	黄色	红色	粉色
黑色	粉色	绿色	蓝色	黄色
黑色	绿色	橙色	黑色	蓝色
黑色	黄色	粉色	蓝色	红色
橙色	黑色	黄色	粉色	绿色
红色	蓝色	黑色	橙色	粉色
绿色	橙色	粉色	红色	黄色
绿色	红色	黑色	黄色	红色
红色	蓝色	粉色	橙色	绿色
黑色	蓝色	黄色	红色	粉色
蓝色	黑色	黄色	绿色	蓝色
粉色	蓝色	绿色	蓝色	橙色

5. Please read the texts on the iPad. Do you feel difficult when recognizing the targets?

   Very difficult☐ Difficult☐ Medium☐ A little difficult☐ Not difficult at all☐

Ⅲ Task Description

You are asked to complete 8 tasks using two interfaces in the experiment. In each task, you need to select one targeted book from the twelve books under four categories. Please complete the task as soon as possible. The completion time and correctness rate will be recorded as your task performance. After the completion of 4 tasks for each interface, you are asked to report your subjective evaluations for the interface on the ease of use, usefulness, effort needed, disorientation, satisfaction, and behavioural intention to use. The whole experiment will last for one hour and we will pay 100 dollars to you as a reward.

1. Trial tasks:
   Before the experiments, you need to complete three trial tasks to familiarize yourself with the mobile application. After the trails, you are free to ask any questions about the experiment. Without questions, you can start the experiment.
2. Experiment:
   You need to conduct 8 experimental tasks in total. Please conduct the tasks according to the experimental distributions.

Ⅳ **Subjective Evaluation**

1. Please evaluate the difficulty level for the previous task:

a. This task is easy for me to complete:

Strongly disagree				Strongly agree
1	2	3	4	5
☐	☐	☐	☐	☐

b. Please describe the difficulties during your last task:

____

2. Please evaluate this interface:

Perceived ease of use	In this version of the interface, it is easy for me to complete the tasks.	Interface	Strongly disagree				Strongly agree
		(1)	1	2	3	4	5
		(2)	1	2	3	4	5
		(3)	1	2	3	4	5
	The interaction with this interface is clear and understandable.	Interface	Strongly disagree				Strongly agree
		(1)	1	2	3	4	5
		(2)	1	2	3	4	5
		(3)	1	2	3	4	5
Perceived usefulness	The interface can help me in completing my tasks.	Interface	Strongly disagree				Strongly agree
		(1)	1	2	3	4	5
		(2)	1	2	3	4	5
		(3)	1	2	3	4	5
	I believe this interface could improve my information searching performance.	Interface	Strongly disagree				Strongly agree
		(1)	1	2	3	4	5
		(2)	1	2	3	4	5
		(3)	1	2	3	4	5

Effort	I do not need a lot of effort to fulfil these tasks.	Interface	Strongly disagree				Strongly agree
		(1)	1	2	3	4	5
		(2)	1	2	3	4	5
		(3)	1	2	3	4	5
Disorientation	I do not feel lost or disoriented.	Interface	Strongly disagree				Strongly agree
		(1)	1	2	3	4	5
		(2)	1	2	3	4	5
		(3)	1	2	3	4	5
	I know my current position in the interface.	Interface	Strongly disagree				Strongly agree
		(1)	1	2	3	4	5
		(2)	1	2	3	4	5
		(3)	1	2	3	4	5
Satisfaction	I feel very satisfied with the overall experience.	Interface	Strongly disagree				Strongly agree
		(1)	1	2	3	4	5
		(2)	1	2	3	4	5
		(3)	1	2	3	4	5
Behavioural intention to use	I intend to continue to use this kind of interface if there are opportunities in the future.	Interface	Strongly disagree				Strongly agree
		(1)	1	2	3	4	5
		(2)	1	2	3	4	5
		(3)	1	2	3	4	5

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