ABSTRACT

LIU, SIWEN. Effects of Early Experiences with Interaction Style on Usability and Acceptance of New Technologies by Older Adults: A Generation-Oriented Approach. (Under the direction of Dr. Sharon M. B. Joines).

Most of the previous studies on older adults' usage and acceptance of new technologies were from an aging perspective and focused on older adults' age-related ability declines. However, recent studies have shown that older adults' lack of prerequisite knowledge and experience as an older generation could also influence their technology usage and acceptance.

This study took a technology generation perspective and focused on older adults' generation-specific knowledge and experience, more specifically, their early experiences with the interaction style of consumer products during their formative years (10–25 years old) and their consequent familiarity with and expectations of these products.

A previous study identified that today's older adults typically belong to the electro-mechanical generation (born 1930–1960) and were exposed to the electro-mechanical style during their formative years. The electro-mechanical style featured hardware-based input and output devices with concrete physical manipulation and tangible feedback, 1:1 mapping between control and function, and single-layered operation.

This study experimentally separated two components of the electro-mechanical style (interaction technique and interaction structure) to isolate the influences attributable to each, and investigated the effect of older adults' early experiences with each component of the electro-mechanical style on usability and acceptance of new technologies.

Four interface types with different interaction techniques were assessed in Experiment 1. Three interface types with different interaction structures were assessed in Experiment 2. Participants from two age groups (technology generations) were recruited in each experiment, a younger group (18–33 years) and an older group (65–80 years). The younger group served to establish benchmark comparisons.

Every participant performed tasks on all interface types. The primary measurements of the two experiments were usability and acceptance. Also measured were reaction time and cognitive abilities (processing speed and working memory), technology experience, preferences, and the older adults' perceived relative weights of the two factors attributable to their interaction difficulties (aging factor vs. generation factor).

Results showed that older adults' early experiences with the electro-mechanical style had given them some advantages with respect to task completion time, in that the age group difference was the least pronounced in the interaction technique and the interaction structure belonging to the electro-mechanical style. However, usability and preference for a more recent interaction technique was significantly higher.

Results showed that older adults had negative attitudes toward accepting new technologies employing the interaction technique of the electro-mechanical style, because it seemed old-fashioned. However, they had positive attitudes toward accepting new technologies employing the interaction structure of the electro-mechanical style.

In addition, results showed that older adults' early experiences with the interaction structure of the electro-mechanical style played a greater role in their performance with and acceptance of new technologies. It implied that the essence of the electro-mechanical style was expressed in the features of its interaction structure (1:1 mapping and single-layered operation), which had a great impact on the electro-mechanical generation's future interactions with new technologies in regard to usability, technology acceptance, and preferences.

Results also suggested that the aging factor (age-related ability changes) and the generation factor (generation-specific knowledge and experiences) both played significant roles in older adults' interactions with new technologies with different interaction styles.

Design recommendations on redesigning the electro-mechanical style and designing new interaction styles for today's older adults were provided. A framework of guiding user interface design for older adults was proposed. Finally, theoretical and practical contributions and limitations of this research were discussed, and areas of future work were recommended in this thesis.

Effects of Early Experiences with Interaction Style on Usability and Acceptance of New Technologies by Older Adults: A Generation-Oriented Approach

by
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DEDICATION

For Mom and Tianren.

BIOGRAPHY

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CHAPTER 1

INTRODUCTION

Background

Many industrialized countries are experiencing an increase in the percentage of older populations of ages 65 or older (Lloyd-Sherlock, 2000). In the United States, the older population (ages 65 or older) increased at a faster rate (15.1%) than did the total U.S. population (9.7%) between 2000 and 2010 (Werner, 2011). Since 2011, a substantial increase in the number of U.S. older adults is expected to occur as the Baby Boom generation (people born between 1946 and 1964) begins to cross into this category by turning 65 years old (He, Sengupta, Velkoff, & Debarros, 2005). According to U.S. Census Bureau projections, nearly one in five U.S. residents will be age 65 or older in 2030, and the number of Americans of age 65 and over is projected to be 88.5 million in 2050, more than double its population in 2010 (Vincent & Velkoff, 2010). The growth of the population of age 65 and over presents challenges to policy makers, businesses, families, and health care providers to meet the needs of aging individuals and improve their quality of life (He et al., 2005).

At the same time, we are experiencing and witnessing an increasing proliferation of technologies in almost every aspect of our everyday lives, which could lead to beneficial outcomes for an aging population. Technologies can play important roles and assist older adults in their everyday activities, such as monitoring health, managing health concerns, communicating with friends and family members, learning, shopping, and transportation (Charness & Boot, 2009; Mitzner et al., 2010; Tacken, Marcellini, Mollenkopf, Ruoppila, & Széman, 2005).

However, the expected benefits cannot be realized unless the technologies are actually used. Failure to use and adopt the technologies would not only put older adults at a disadvantage in terms of their ability to remain active and live independently, but also place more burdens on the society and impair the market share and revenue for industry (Czaja et al, 2006a; Mitzner et al., 2010; Renaud & Bilon, 2008). Hence, it is imperative to study how to design modern technologies to increase usability and acceptance by older adults, thereby, ensuring a more fulfilled and independent lifestyle for older adults on social and ethical levels, and also expanding the market share and increasing revenue for industry on organizational and economical levels.

Problem Statement

Studies have shown that older adults typically have more difficulties than do younger adults in operating modern technologies, such as computers (Birdi, Pennington, & Zapf, 1997; Czaja, Sharit, Ownby, Roth, & Nair, 2001), mobile phones (Ziefle & Bay, 2005), PDAs (Arning & Ziefle, 2006), smart phones (Nauman, Wechsung, & Hurtienne, 2004), remote controls (Freudenthal, 1999), digital cameras (Blackler, Popovic, & Mahar, 2010), microwaves (Lewis, Langdon, & Clarkson, 2007), and digital radios (Langdon, Lewis, & Clarkson, 2010). Studies have also revealed that older adults accept and adopt technologies to a lower degree than younger adults do (Duggan & Rainie, 2012; Jones & Fox, 2009; O'Brien, 2010; Ofcom, 2009).

Most of the previous studies in the literature focused on understanding this age group's differences in using and accepting technologies from an aging perspective and provided design recommendations to accommodate older adults' age-related changes (declines) in sensory, physical, and cognitive abilities (Hawthorn, 2000; Morris, 1994; Pattison & Stedmon, 2006; Zajiek, 2001a). These design recommendations were generated from an aging perspective, which were termed as "aging-oriented approach" in this thesis.

It is well known that sensory, physical, and cognitive abilities tend to decline during the process of aging (Fisk, Rogers, Charness, Czaja, & Sharit, 2009; Hawthorn, 2000; Morris, 1994; Pak & McLaughlin, 2011; Pattison & Stedmon, 2006). These age-related ability changes could create accessibility and usability problems. The theory of capacity-demand relationship indicated that "When a user uses any given product, design exclusion takes place when the demands of certain interface features exceed the user's capabilities. If, for example, a user does not possess the required visual acuity, contrast sensitivity and color perception to detect a text level, then design exclusion takes place" (Persad, Langdon, & Clarkson, 2006, p.179).

However, it has been suggested that the age group's differences in using and accepting new technologies may be caused by not only the age-related declines in abilities that are closely associated with interacting with technologies, but also the generation-related differences in knowledge base and previous experiences (Docampo Rama, 2001; Freudenthal, 1998; O'Brien, 2010). Czaja et al. (2006a) wrote that "age differences in adoption and use of technology are probably best viewed as reactions of older generations to historical change rather than age-related declines per se" (Czaja et al., 2006a, p.349). The authors called for taking a generational perspective on older adults' performance and acceptance of new technologies.

Older adults' fundamental knowledge base, regarding interaction with products and interfaces, is different from that of younger adults because older adults grew up with different devices and had different interaction experiences during their formative years (10–25 years old), consequently acquiring different knowledge and skills (Docampo Rama, 2001). However, due to the advancement of technologies over the decades, a great deal of the knowledge and skills that older adults acquired during their formative years is no longer relevant for interacting with today's technologies. Hence, there might be a gap between the established knowledge base of older adults and the knowledge required by the modern technologies. Knowledge gap was defined as "the space between the current knowledge and target knowledge points", where the current knowledge point represents "the amount of knowledge they have when they approach the interface", and the target knowledge point represents "how much knowledge the user needs to know to accomplish their objective" (Spool, 2005, p. 2-3).

Only a few of the previous studies have focused on older adults' prior knowledge and experience, and provided recommendations to leverage their knowledge base (Docampo Rama, 2001; O'Brien, 2010). In this thesis, design recommendations generated from a technology-generation perspective that highlights older adults' generation-specific knowledge and experience were termed as "generation-oriented approach".

Most of the existing design recommendations for utilizing users' prior knowledge and experience were generated from a usability perspective and aimed to improve users' performance in their interactions with products. For example, Blackler (2006) recommended that designers use existing features, labels, or icons that users have seen before in similar products and put them in a familiar or expected position to facilitate interaction. O'Brien (2010) suggested that a re-use of the most frequent interaction styles may be particularly helpful for older adults. These recommendations have been empirically proved to be helpful in increasing users' performance in terms of efficiency and effectiveness (Blackler, 2006; Lewis et al., 2007). However, these recommendations did not address the issue of technology acceptance, and it remained unknown whether a re-use of existing features or style would evoke positive or negative attitudes of the users toward accepting the technologies.

Most of the existing design recommendations did not provide guidance on how to develop new features or interaction styles, while highlighting users' prior knowledge and experience. It has been pointed out that recommendations for reusing existing and familiar features may hamper design innovations (Hurtienne, 2004; Raskin, 1994).

In addition, it was unclear how the aging factor (age-related abilities changes) and the generation factor (generation-specific knowledge and experiences) were related in older adults' interactions with new technologies. There are mixed findings on how older adults' cognitive abilities and prior experience came into play in their performance of interacting with new technologies (Blackler, Mahar, & Poovic, 2009; Langdon, Lewis, & Clarkson, 2007; Lewis et al., 2007).

Hence, more studies and design recommendations generated from a generation-oriented approach to leverage older adults' generation-specific prior experiences and knowledge are needed. Design recommendations taking into account both the usability issue and the acceptance issue would be beneficial. In addition, design recommendations with guidance on redesigning the existing features and interactions styles or designing new features and styles, while highlighting older adults' prior knowledge and experiences, would be more desirable. Moreover, more studies are needed to provide further understanding and insights on the issue of how age-related abilities and generation-related knowledge and experiences come into play in older adults' interactions with new technologies.

Focus and Scope

A previous study on technology generations (Docampo Rama, 2001) indentified that today's older adults typically belonged to the electro-mechanical generation (born between 1930 and 1960) and the predominant interaction style of consumer products during their formative years (10–25 years old) was the electro-mechanical style.

By taking a generation-oriented approach, this study focused on investigating the effects of older adults' early experiences with the interaction style of consumer products (the electro-mechanical style) on usability and acceptance of new technologies. Interaction style was chosen as a focus for several reasons.

First, interaction style is a prominent feature of a product and has already been shown to influence users' performance and acceptance (e.g., Lewis et al., 2007; Wiedenbeck & Davis, 1997). For example, Lewis et al. (2007) found that older adults performed better with a product employing the electro-mechanical style (a dial-based model) than they performed with a product with a newer interaction style (a button-display model). However, since an interaction style consists of several components, it was unknown which component produced the usability benefit. Its impact on technology acceptance was also known—whether older adults are more likely to accept a technology employing the electro-mechanical style that they were exposed to during their formative years or that with a newer interaction style.

Second, there is well-documented historical analysis on changes of interaction style between 1930 and 2000 (Docampo Rama, 2001). The analysis has covered the interaction styles that today's older adults were exposed to during their formative years and other newer interaction styles introduced after their formative years. The historical analysis provided detailed information regarding the feature of each main component of all the interaction styles.

Third, early experience with a predominant interaction style of consumer products generally acquired by an entire technology generation of users, hence the results of this research are more likely to benefit a much greater number of older adult users (collective experience) than results from investigating older adults' individually acquired prior experiences with specific products and their design features.

This study was concerned with two main components of the interaction style, namely the interaction technique and the interaction structure. It investigated the effects of older adults' early experiences with these two different components of the electro-mechanical style on usability and acceptance of new technologies.

The scope of this study was limited to (a) today's older adults (the electro-mechanical generation) and their early experiences with the electro-mechanical style; (b) older adults (of ages 65 and over) in the United States; (c) technologies that do not have many functions; (d) technologies that have interactive interfaces; (e) technologies that are intended to be used with little or no assistance the first time; and (f) investigation of the influences on usability and acceptance.

Hence, older adults in other cultures and regions, complex technologies that have many functions, technologies that do not have interactive interfaces, technologies that are intended to be used with instructions and personal assistance, and the issues of emotions and aesthetics that could also be influenced by older adults' early experiences with interaction style of consumer products (e.g., nostalgia) are beyond the scope of this study.

Objectives

This study assessed older adults' performance with and acceptance of new technologies employing different design features of the interaction techniques and the interaction structures belonging to several interaction styles across the historical development. It included the interaction style that today's older adults grew up with (within their technology generation) and newer interaction styles introduced after their formative years (beyond their technology generation). This study focused on understanding the impacts of older adults' early experiences with the predominant interaction style of consumer products during their formative years (10–25 years old) and their consequent familiarity with and expectations of interaction style.

The first objective of this study was to provide understanding and insights on how older adults' early experiences with the interaction technique of the electro-mechanical style influenced usability and acceptance of new technologies by older adults and how that with the interaction structure of the electro-mechanical style influenced usability and acceptance of new technologies by older adults.

The second objective of this study was to compare the impacts of older adults' early experiences with the interaction technique and the interaction style of the electro-mechanical style, to investigate which component of the electro-mechanical style had a greater impact on their future interactions with new technologies. Knowledge of this type was fundamental for reshaping or redesigning the electro-mechanical style.

The third objective of this study was to provide the understanding of how aging factor (age-related abilities) and generation factor (generation-specific knowledge and experience) come into play in older adults' interactions with new technologies.

The fourth objective of this study was to provide design recommendations that could inform designers about redesigning the electro-mechanical style and also designing new interaction styles tailored to the specific technology generation of today's older adults by taking into account their familiarity and expectations that were developed during their early experiences with the electro-mechanical style.

The last objective of this study was to develop a framework for older adults of guiding interface design that systematically combined the aging-oriented approach and the generation-oriented approach.

Significance

This study would contribute to understanding from a generation perspective the role of age difference in using and accepting new technologies, which takes into account the different interaction knowledge and experiences required by the available product interfaces during the formative years of different technology generations. This study would encourage more studies to investigate older adults' generation-specific knowledge and experiences and provide design recommendations on developing user interfaces for new technologies that are consistent with older adults' knowledge bases, representations, and expectations.

The findings of this study would provide design recommendations for user interface design of new technologies for older adults by highlighting their early experiences with the electro-mechanical style. The design recommendations generated from this study would contribute to the existing recommendations in two ways. First, the design recommendations generated in this study would also take into account the issue of technology acceptance rather than the issue of usability alone, which would ensure that older adults are able and also willing to use the new technologies. Second, it would go beyond suggestions for a reuse of existing design features or interaction styles that are familiar to the users; it would provide guidance on how to reshape or redesign the interaction style that today's older adults grew up with and how to design new interaction styles while highlighting their early experiences with the particular interaction style with which they had early experiences.

The findings of this study would improve the understanding of the roles of aging factor (age-related abilities) and generation factor (generation-specific knowledge and experience) in older adults' interactions with new interfaces. It would provide designers a framework of guiding interface design for older adults that takes into account both aging factor and generation factor (by applying both the aging-oriented approach and the generation-oriented approach).

The generated design recommendations and the proposed framework of guiding interface design for older adults would support usability specialists, product designers, interaction designers, product manufacturers, and others involved in the design and development of user interfaces of new technologies for older adults. The findings of this study would be helpful to inform them on how to increase the usability and acceptance of new technologies. The findings of this study would also benefit today's older adult population in providing them new technologies that take into consideration their knowledge bases, past histories of usage, and expectations, in order to assist them to live independently and increase their quality of life. In addition, the results of this study would raise designers' awareness during the user-interface design process for new technologies for older adults so that designers understand and consider older adults' generation-specific knowledge and experiences and their consequent expectations.

Outline of the Thesis

Chapter 2 of this dissertation presents the literature review of for this study, which covered literature on roles of prior knowledge and experiences on usability and acceptance, technology generation, interaction style, and studies comparing the roles of older adults' age-related abilities and prior experiences in their interactions with products. Chapter 3 reviews existing design recommendations for interface design for older adults over the past 20 years and proposes a framework for guiding interface design for older adults by applying both the aging-oriented approach and the generation-oriented approach based on the critical review (this chapter has been previously published). Chapter 4 provides an overview of this research by specifying definitions of key terms, research objectives, research questions, and research design (design of the two experiments). Chapter 5 presents the first experiment of this study which investigated older adults' early experiences with the interaction technique of the electro-mechanical style on usability and acceptance of new technologies. Chapter 6 presents the second experiment of this study which investigated older adults' early experiences with the interaction structure of the electro-mechanical style on usability and acceptance of new technologies. Chapter 7 further discusses the results of the two experiments with an emphasis on their similarities and differences and also presents implications of the results from the two experiments on the proposed framework for guiding interface design for older adults. The last chapter, Chapter 8, summarizes major findings of this study, provides design recommendations for redesigning the electro-mechanical style and designing new interaction styles for today's older adults by highlighting their early experiences, contains discussions on the theoretical and practical contributions and the limitations of this study, and also contains suggestions for areas for future studies.

CHAPTER 2

LITERATURE REVIEW

Prior Knowledge and Experiences

User characteristics—prior knowledge and experiences. ISO 20282-1: 2006 (E) entitled *Ease of Operation of Everyday Products* suggested that the design of an everyday product should take into account all user characteristics. Three main groupings of user characteristics were defined as follows: (a) demographics, (b) physical and sensory characteristics; and (c) psychological and social characteristics.

Users' knowledge and experiences were identified within the psychological and social characteristics group. Prior knowledge and experiences of the users are important aspects of user characteristics and should be taken into account when designing products and interfaces. Otherwise, usability problems would result from failure to study and understand the knowledge base and experience of the target user group.

Classification of prior knowledge and experiences. Prior knowledge associated with product interaction may originate from different sources. Hurtienne and Israel (2007) classified the sources of prior knowledge along a continuum. As shown in Figure 2.1, the lowest level is the innate knowledge acquired through genes. The next level is the sensorimotor knowledge acquired very early in childhood and repeatedly used during interactions with the world. The next level is the knowledge specific to a culture. The highest level of knowledge is the expertise that is acquired in one's specialization and profession. Knowledge about tools was presented across the sensorimotor, culture, and expertise levels of knowledge.

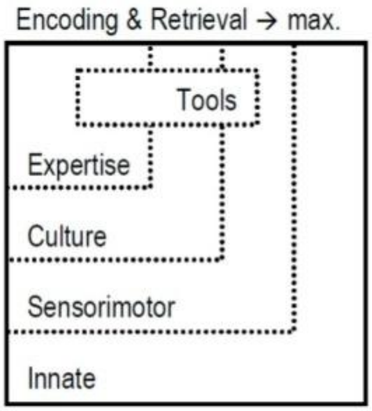

Figure 2.1. Continuum of Knowledge in Intuitive Interaction (Hurtienne & Israel, 2007).

Blackler (2006) proposed a continuum of knowledge in users' heads that could be leveraged by designers, including body reflector, population stereotype, familiar features from the same domain, familiar features from other domain, and metaphor from other domain (Figure 2.2).

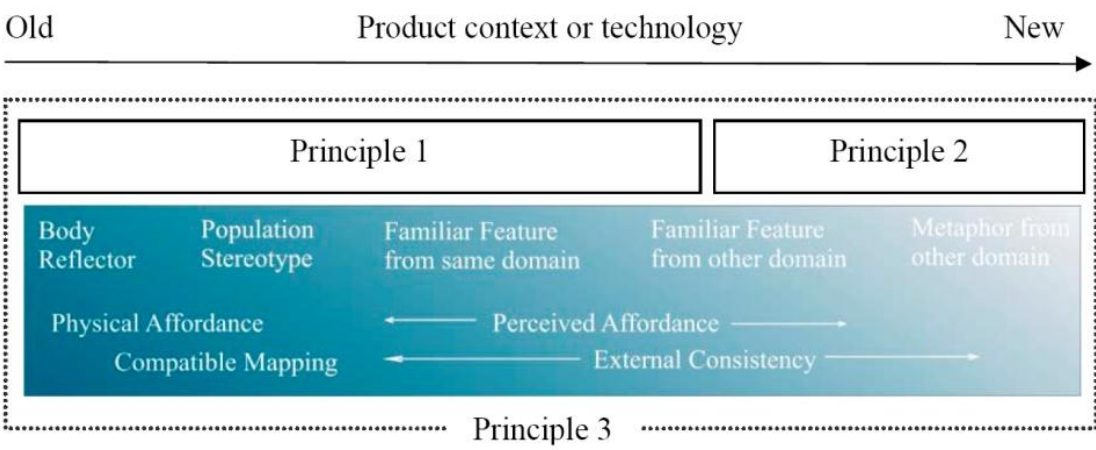

Figure 2.2. The Intuitive Interaction Continuum (Blackler, 2006).

Blacker and Hurtienne (2007) suggested how the Intuitive Interaction Continuum (Figure 2.2) and the Continuum of Knowledge in Intuitive Interaction (Figure 2.1) were connected to each other. Body reflector is linked to the sensorimotor level, population stereotype is linked to the both body sensorimotor level and the cultural level, familiar features from the same domain and familiar features from other domain are linked to the tools level, and the metaphor from other domains is linked to all levels except the innate level.

There are also other ways to classify the knowledge associated with product interaction. For example, Dixon and Gabrys (1991) distinguished two kinds of knowledge that might contribute to one's ability to learn a new task: conceptual knowledge and operational knowledge. "Conceptual knowledge refers to the device and how it works, whereas operational knowledge refers to the operating procedure for the device at a purely formal structural level" (Dixon & Gabrys, 1991, p.103). Anderson (1983) distinguished two types of knowledge: declarative knowledge and procedural knowledge. Declarative knowledge is the factual information stored in memory. Procedural knowledge is the stored information about how to perform tasks.

Hurtienne, Horn, and Langdon (2010) identified three different components of prior experience: (a) exposure, (b) competence, and (c) subjective feeling. Exposure to technology describes the duration, intensity, and diversity of use. Competence with technology describes the level of skills and knowledge required for interaction with a product. Subjective feeling relates to the actual user experience when using the product. Hurtienne et al. (2010) identified three levels of prior experience associated with product interaction: (a) prior experience with the same product, (b) prior experience with other products of the same type, and (c) prior experience with a broad range of products of different types.

Lawry, Popovic, and Blackler (2009) pointed out that prior knowledge and experiences are closely related to familiarity (or similarity). Gefen (2000) described familiarity as "an understanding, often based on previous interactions, experiences and learning of what, why, where and when others do what they do" (p. 727). O'Brien (2010) stated that technology devices may be similar to a target technology device either because of overall functionality and goals (top-down) or because of a specific feature and interaction style (bottom-up). Dixon and O' Reilly (2002) stated that similarity can occur at any of the three levels associated with product interaction. The top level consists of a sequence of sub-goals. The next level consists of a series of steps to carry out a sub-goal. The bottom level consists of a motor-control schema (physical actions) to accomplish a particular step. They used the term “functional similarity” for tasks in which the same sequence of sub-goals was involved, “procedural similarity” for those in which the same steps were used to achieve a given sub-goal, and “interface similarity” for those in which the same motor-control schema was used to carry out a given step.

Prior knowledge and experiences—long-term memory. Memories relating to the experience of product interactions are stored in the long-term memory. “It is the repository of the collective experience and learning of a person. It contains both factual knowledge as well as knowledge of how to perform procedures.” (Pirolli, 1999, p. 449)

Based on the Model Human Processor (Pirolli, 1999), the cognitive process of people using prior knowledge and experiences to guide their interactions with new technologies can be described as follows: (a) information of a new technology is at first input from the world through the user’s perceptual processors (visual processor and auditory processor) into the visual and auditory stores, (b) some of the information enters into the user’s working memory, (c) the cognitive processor then uses the associations between information in the working memory (information about the new technology) and information in the long-term memory (knowledge and experience gained relevant to using this technology) to make decisions and formulate actions, and (d) the motor processor is triggered by working memory to perform the actions. Lewis, Langdon, and Clarkson (2006) suggested that the ability to retrieve that memory depends on the cues provided (associations between the perceived information and the long-term memory) and the amount of previous experience, which entails how well the information was encoded in the long-term memory.

Benefits of leveraging prior knowledge and experiences in designing for older adults. Prior knowledge and experiences are stored in the long-term memory, which typically shows minimal decline with normal aging, such as the semantic memory and the procedural memory, which are two types of long-term memory. Semantic memory is a store of factual information acquired through a lifetime of learning. Semantic memory generally remains with aging. Procedural memory is the knowledge about how to perform activities. Although older adults have difficulties developing new automatic processes, the old procedures learned before the aging process remain (Fisk et al., 2009).

Designing by leveraging older adults' prior knowledge and experiences would utilize their crystallized intelligence rather than their fluid intelligence. It has been found that the crystallized intelligence remains throughout the lifespan, but the fluid intelligence declines with age. Crystallized intelligence is the ability related to retaining and applying previous knowledge gained through past experiences. Fluid intelligence is the ability related to novel problem solving (Ackerman, 1996).

In addition, designing by leveraging older adults' prior knowledge and experiences would minimize the learning needed to use the technologies. Older adults usually have more problems learning to use new technologies because they have to learn new skills (Reddy, Blackler, Popovic, & Mahar, 2009). Studies have shown that learning ability tends to decline with age. The level of skill acquisition of older adults is lower than that of younger adults (Baltes, 1997; Fisk, Rogers, & Giambra, 1990; KIiegl, Smith, & Baltes, 1989; Rogers & Fisk, 1991; Rogers, Fisk, & Hertzog, 1994).

Risks of leveraging prior knowledge and experiences in designing for older adults. Blackler, Popovic, and Mahar (2005) suggested that designers need to identify the target market for each product and get information about what users are familiar with (what they know). However, Hurtienne, and Langdon (2009) pointed out that data about prior knowledge and experiences on tool usage (e.g., the familiar appearance and location of a feature) quickly become outdated as technology develops, so it is not cost-effective to access the very specific product feature that are familiar to the users.

More importantly, simply repeating the existing features is not friendly to design innovation (Hurtienne, 2004; Raskin, 1994). Hence, one of the risks of leveraging prior knowledge and experiences in designing for older adults is that it may reduce design innovation if the prior knowledge, experience, and memory are overemphasized.

Role of Prior Knowledge and Experience on Usability

Usability refers to "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use" (ISO 9241-11:1998 (E), p. 2). Usability is usually measured by effectiveness (e.g., accuracy and completeness of a goal), efficiency (e.g., time and mental or physical effort), and satisfaction of users working with a product.

Studies have found that prior knowledge and experiences have an impact on users' performances. Products that better match users' prior knowledge and experiences can improve users' performance.

Background knowledge. Kang and Yoon (2008) discovered that background knowledge is an important factor for workload and interaction strategy. They found that older adults' lack of background knowledge about PCs resulted in higher ratings of effort and their lack of background knowledge about PCs and the Internet resulted in higher ratings of frustration when using a portable multimedia player (PMP). They also found that older adults' lack of background knowledge about cellular phones resulted in higher ratings of frustration when using an MP3 player. In addition, they found that older adults did not have the background knowledge of various electronic devices which could help facilitate their operation of new devices and this lack of background knowledge resulted in a trial-and-error interaction strategy. The trial-and-error strategy was typically not a characteristic of older adults, but it was a characteristic of novice users. Ziefle (2002) also found that general background knowledge about mobile phones was proven to play an important role for the usability of mobile phones used in the experiments. Users with higher general background knowledge about mobile phones solved the tasks more efficiently and effectively.

Mental model knowledge. Freudenthal (2001) found that users' prior knowledge about the mental model of a simulated medical laser facilitated their performances. The presence of the mental model of the device reduced the number of actions needed to complete the tasks and increased the efficiency of interactions (avoided controls irrelevant to the task). Kiereas and Bovair (1984) also found that users' prior knowledge about the mental model of a device has an effect on their performances. Participants' knowledge about the working of the device helped them with operating procedures.

Sensorimotor knowledge. Hurtienne, Weber, and Blessing (2008) found that user interface designs that tapped users' sensorimotor knowledge regarding the "up-down" image schema and its metaphorical extensions led to more efficient interaction. For example, users responded faster when the labeling of a vertical button layout was compatible with the metaphors “good is up”, “bad is down”, or “virtue is up”, and “depravity is down” than when labeling was not compatible. Image schema is a form of sensorimotor knowledge gained by repeated interactions with the physical world (Hurtienne, Weber, & Blessing, 2008). Hurtienne and Israel (2007) also suggested other groups of image schemas that designers could utilize when developing intuitive user interfaces, including space (e.g., left-right, near-far, and front-back), containment (e.g., in-out and full-empty), multiplicity (e.g., part-whole and count-mass), attribute (e.g., heavy-light, dark-bright, and warm-cold), indentify (e.g., face and matching), process (e.g., iteration and cycle), and force (e.g., diversion and counterforce).

Prior experience with product features. Blackler (2006) found that prior exposure to digital cameras that employed similar features to the digital camera encountered during the experiment helped participants complete the tasks more quickly and intuitively and with fewer errors. She also found that users’ familiarity with the appearance of a feature plays a bigger role in their performances than their familiarity with the location of a feature. Similarly, Langdon et al. (2007) found that prior experience with similar products and product features was a strong predictor of the usability of products (e.g., a digital camera or a motor car). Blackler et al. (2009) found that participants’ prior experiences with relevant products that had similar features to the microwave prototype they used during the experiment was an important factor in fast, accurate, and intuitive use of an interface. Reddy et al. (2009) found that there was a strong correlation between task completion time and users’ prior experiences with relevant products that had similar features to the body fat analyzer to be tested in the experiment. Langdon et al. (2007) found that prior experience with similar products and product features was a strong predictor of the usability of a digital radio. Langdon et al. (2007) also found that users’ prior experiences with the sequence of interaction of using controls had a greater impact on usability than did their prior experiences with the layout and appearance of the controls. O’Brien (2010) found that prior knowledge with features of a control (control appearance, location, and operation) was an important factor in successful interaction with a technology. O’Brien (2010) also found that prior knowledge about the technology feedback of a control (expectations on what is likely to happen when a control is activated) was also an important factor. Wilkinson et al. (2011) discovered that users' knowledge about product features and warning icons contributed to better interactions with a laser level.

Prior experience with interaction style. Lewis, Langdon, and Clarkson (2008) found that older adults performed tasks more quickly and accurately with a microwave that employed an interaction style that they were very familiar with (a dial model) than they did with a microwave employing an interaction style they were less familiar with (a button-display model). Wilkinson, Langdon, and Clarkson (2010) suggested that a well-rehearsed or well-learned interaction style could aid successful initial and subsequent interactions by users. Okoye (1998) pointed out that familiarity of the interaction style appeared to be a key feature for successful and intuitive interaction. O'Brien (2010) also mentioned that reuse of the interaction style within the technology generation of today's older adults may be particularly helpful due to their great familiarity with the specific interaction style.

Role of Prior Knowledge and Experience on Acceptance

Technology acceptance can be described as the "approval, favorable reception and ongoing use of newly introduced devices and systems" (Arning & Ziefle, 2007, p. 2905). A distinction between technology acceptance and technology adoption was pointed out by Renaud and Bijon (2008). Technology acceptance is an attitude toward a technology, while technology adoption is a process that starts with the user becoming aware of the technology and ends with the user embracing the technology and making full use of it.

Over the past decades, various models have been proposed to explain and predict user acceptance technology. Among the different models, the Technology Acceptance Model (Davis, 1989) which was adapted from the theory of reasoned action (Ajzen & Fishbein, 1980) has been widely recognized as the most influential and has been validated as a powerful and parsimonious model to study user technology acceptance (Arning & Ziefle, 2007; Hasan & Ahmed, 2007; Hong, Thong, Wong, & Tam, 2002; Huang & Liaw, 2005; Legris, Ingham, & Collerette, 2003; Venaktesh & Davis, 2000).

According to the Technology Acceptance Model (Davis, 1989), technology usage is determined by users' behavioral intention (BI) to use the technology, and the BI is determined by users' attitude toward using the technology (ATU), which, in turn, is determined by users' perceived usefulness (PU) and perceived ease of use (PEOU) of the technology. The model also suggests that PEOU and PU are directly determined by external variables (Figure 2.3).

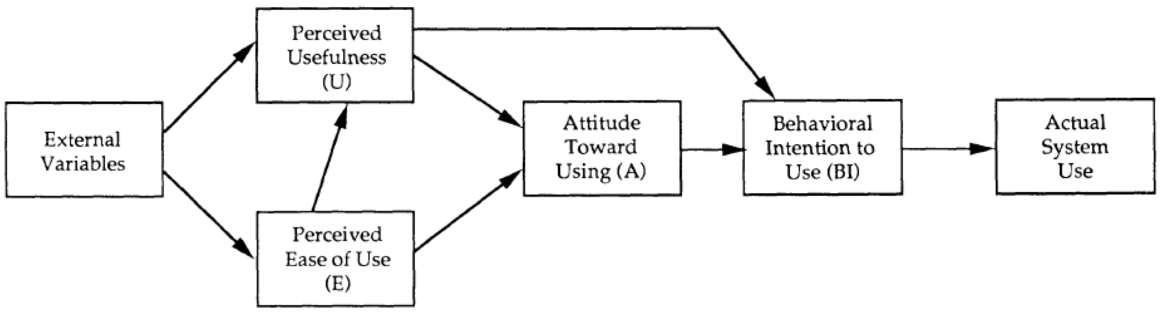

Figure 2.3. Technology Acceptance Model (Davis, 1989).

There are also other models which have been proposed to explain and predict user acceptance technology (e.g., Goodhue & Thompson, 1995; Kwon & Chidambaram, 2000; Melenhorst et al., 2001; Mollenkoph et al., 2003; Venkatesh & Davis, 2000; Venkatesh et al., 2003).

Many studies have found that prior knowledge and experiences are important factors for technology acceptance. Studies have shown that experience affects the two factors of technology acceptance, the perceived ease of use (Ziefle, 2002) and the perceived usefulness (Taylor & Tedd, 1995). People with more exposure to and more knowledge of and expertise in the relevant technologies are more likely to accept new technology, such as software (Holzinger, Searle, & Wernbacher, 2011), mobile phone (Ziefle, 2002), microcomputer (Igbaria, 1993). Past relevant experiences were found to influence users' skills, anxiety, and confidence, which all have an impact on perceived ease of use (Bandura, 1986; Hackbarth et al., 2003; Kanfer & Ackerman, 1989). In addition, past histories of usage were found to color the expectations toward the technology, which had an impact on perceived ease of use, as well as perceived usefulness (Widenbeck & Davis, 1997).

Skills. As the theory of resource allocation suggested, as skills are acquired and improved and the tasks become automated, the demands on cognitive effort are greatly reduced, which leads to perception of the tasks (using the technology) as easier to do (Kanfer, Ackerman, Murtha, Dugdale, & Nelson, 1994).

Anxiety. Studies have found that experience is negatively associated with anxiety. Igbaria and Chakrabarti (1990) reported that computer experience is negatively associated with computer anxiety, in that higher computer experience is related to lower computer anxiety. Similarly, Necessary and Parish (1996) reported that computer anxiety was higher for the users with little or no computer experience than it was for users with previous experience. Anxiety was found to be negatively associated with perceived ease of use, in that lower anxiety was related to higher perceived ease of use (e.g., Hackbarth et al., 2003).

Efficacy. Studies have found that experience is positively associated with self-efficacy. Self-efficacy describes the confidence in one's personal abilities to use the targeted or related technologies (Kinzie, Delcourt, & Powers, 1994). Potosky (2002) reported that increased exposure and knowledge (computer training) was positively associated with computer self-efficacy. Similarly, Igbaria and Iivari (1995) found a positive relationship between computer experience and computer self-efficacy. Besides, self-efficacy was found to be positively associated with perceived ease of use, in that higher self-efficacy was related to higher perceived ease of use (e.g., Chung et al., 2010; Hong et al., 2002).

Expectations. Widenbeck and Davis (1997) found that users' past histories of usage had an effect on perceived ease of use and perceived usefulness. In the experiment, they divided participants into two groups. One group used the application with a direct-manipulation interface in the first session of training and then used a menu-based or command-based interface in the second session of training. The direct-manipulation interface was more direct and simple than the menu-based interface and the command-based interface. The other group had the opposite sequence of usage, which was use of a menu-based or command-based interface in the first session of training and then use of a direct-manipulation interface in the second session of training. The authors found that the group that used the direct-manipulation interface prior to using a menu-based or command-based interface had a significantly negative perception toward the menu-based or the command-based interface (lower perceived ease of use and lower perceived usefulness) than did the group that used a menu-based or command-based interface at the initial training session. The results indicated users' histories of past usage and their prior experiences colored their expectations toward the technologies, which had an effect on perceived ease of use and perceived usefulness of the technologies.

Technology Generation and Interaction Style

Early experience. Early experience refers to the experience acquired during one's formative period (adolescence and young adulthood; about 10–25 years old). It is argued that one's most established knowledge is the knowledge that was acquired during this period of time in life. Studies have shown that people could answer general-knowledge and semantic-memory questions about information learned during adolescence and young adulthood more accurately than they could answer questions about information learned after these years (Rubin, Rahhal, & Poon, 1998). This effect of early experience could be explained by findings from developmental studies and sociological studies.

Developmental studies on intellectual development showed that the formative period is a critical period for learning. As shown in Figure 2.4, both main categories of intellectual functioning, the pragmatics abilities (crystallized intelligence) and the mechanics abilities (fluid intelligence) increase during one's formative period and reach their peaks around 25 years of age. After this period of life, the pragmatics abilities that critically influence one's learning ability (e.g., reasoning, perceptual speed) show roughly linear decline, while the mechanics abilities (e.g., semantic memory) generally remain (Baltes, Staudinger, & Lindenberger, 1999).

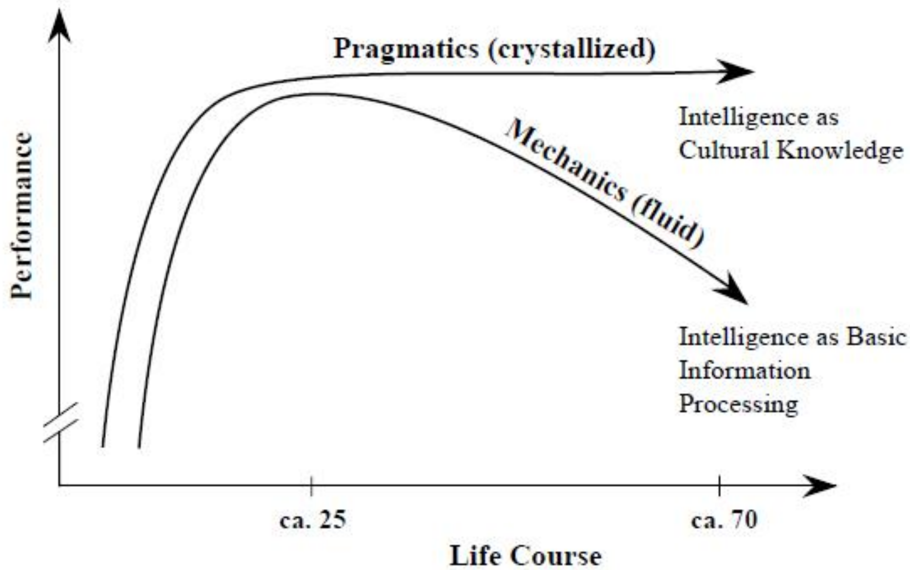

Figure 2.4. Lifespan Research on Two Components of Cognition, the Fluid Mechanics and the Crystallized Pragmatics (Baltes, et al., 1999).

Sociological studies have found that experience gained from frequent and close exposure during a critical period early in one's life has an imprinting-like effect on one's lifetime values and preferences (Holbrook & Schindler, 1989). Schindler and Holbrook (2003) found that early experience played a strong positive role in shaping the development of preferences in that users' preferences peaked for products that were popular when they were young.

Technology generation. Docampo Rama (2001) developed the concept of technology generation and distinguished three technology generations based on the predominant interface type (interaction style) of electrical consumer products (e.g., television, telephone, and video recorder) to which people were exposed during their formative periods (early experience).

The three technology generations identified were: the electro-mechanical generation (people born 1930–1960), the display generation (people born 1960–1970), and the menu generation (people born after 1970). During the formative years, the electro-mechanical generation were exposed to the electro-mechanical style interfaces, the display generation were exposed to the display style, and the menu generation to the menu style.

According to the technology generation boundaries, today's older adults (65 years and older) typically belong to the electro-mechanical generation, and today's younger adults belong to the menu generation.

Components of interaction style. As shown in Figure 2.5, an interaction style can be decomposed into conceptual operation, interaction technique, and interaction structure (De Vet & De Ruyter, 1996).

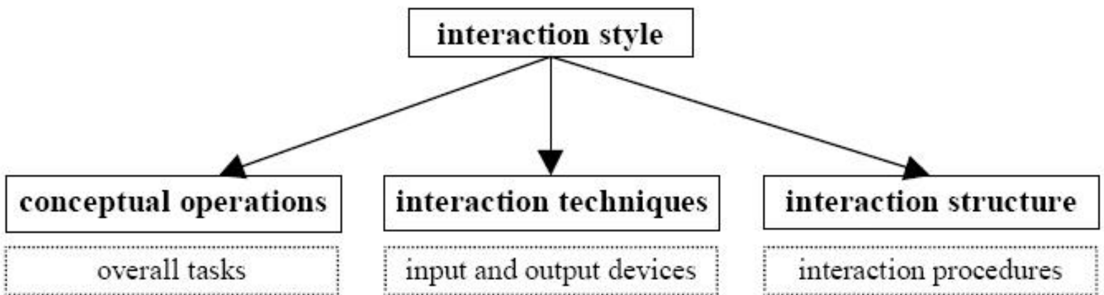

Figure 2.5. Components of Interaction Style (De Vet & De Ruyter, 1996).

According to De Vet and De Ruyter (1996), conceptual operation refers to functionality or overall tasks. Interaction technique refers to input and output devices. Interaction structure refers to interaction procedures. Interaction structure (operational procedure) is characterized by both the mapping between control and function (one control with one function or one control with multiple functions) and the number of layers (single-layered operation or multi-layered operation).

Historical development of interaction style. Docampo Rama (2001) overviewed and analyzed the historical development between 1930 and 2000 of the interaction style of the information, communication, and entertainment appliances (including television, telephone, and video recorder). The historical overview and analysis covered all three main components of an interaction style, including the conceptual operation, the interaction technique, and the interaction structure of these devices.

Based on the period during which all interaction style components of one device have changed, Docampo Rama (2001) distinguished three interaction styles between 1930 and 2000, including the electro-mechanical style (1930–1980), the display style (1980–1990), and the menu style (1990–2000). Based on the findings of Docampo Rama (2001), the features of the three interaction styles are summarized in Table 2.1.

Table 2.1.
Features of the Electro-Mechanical Style, the Display Style, and the Menu Style

Components of Interaction Style	**Electro-Mechanical Style** (1930-1980)	**Display Style** (1980-1990)	**Menu Style** (1990-2000)
Conceptual Operations (Functions or Overall Tasks)	Basic functions	More functions	A large amount of functions
Interaction Techniques (Input and Output Devices)	Hardware-based input and output devices	Software-based input and output devices	Visualized software-based input and output devices
Interaction Structures (Operational Procedures)	One input device (control) has one function & One-layered operations	One input device (control) has multiple functions	Multi-layered operations

Note: This table is a summary of the findings of Docampo Rama (2001).

Since the beginning of the twenty-first century, with the development of new technologies, other newer interaction styles have emerged and are becoming increasingly popular, such as touch-based interfaces (Häikiö et al., 2007), speech-based interfaces (Ibrahim & Hadidi, 2006), gestures-based interfaces (Waldherr, Romero, & Thrun, 2000), multimodal interfaces (Naumann, Wechsung, & Hurtienne, 2009), and embodied interfaces (Vines & Thompson, 2007).

The electro-mechanical style is the interaction style that today's older adults grew up with. Based on the findings by Docampo Rama (2001), characteristics of the electro-mechanical style are summarized as follows:

- Conceptual operation: very basic functions.
- Interaction technique: hardware-based input and output devices, such as dials and switches. The hardware-based input devices (controls) provided a tangible, concrete, and direct physical manipulation and a direct physical feedback.
- Interaction structure: (a) one control has one function. The 1:1 mapping between control and function offers a straightforward operation. In contrast, the display style (1980–1990) features one control with multiple functions depending on the mode of the product which is less straightforward; and (b) single-layered operation. Placing all

functions and their controls on the surface of the product (single-layered operation) provides a high level of directness and visibility (Norman, 1993) and opacity (Fischer, 1991), which allows the users to see all the functions and available options at once. In contrast, the menu style (1990–2000) features a multi-layered operation in which most of the functions are hidden behind the layers (less direct for operation).

Input devices can be categorized as direct and indirect input devices. Studies have found that older adults preferred direct input devices to indirect input devices (Charness, Holley, Feddon, & Jastrzembski, 2004; Chou & Hsiao, 2007). According to Rogers, Fisk, McLaughlin, and Park (2005), a direct input device is "one for which no translation is required between the activity performed by the person and the action of the device" (p. 271). Examples include touch screen, light pen, and voice recognition. However, an indirect input device "requires a translation between the activity of the person and action of the device" (p 271.). Examples include rotary encoder, mouse, joystick, and trackball. In addition, Rogers et al. (2005) asserted that the preference for input devices was task-dependent.

The structure of the interface regarding the number of layers is a tradeoff between depth and breadth (Fisk et al., 2009). Studies have found that older adults have more difficulties with a multi-layered interface (a deep structure with many levels). Docampo Rama (2001) found that older adults performed tasks more slowly and less accurately with the multi-layered interface than they did with the single-layered interface.

Lewis and Clarkson (2005) reported that older adults mentioned in the interview that they had particular recurring difficulties when they had to use the same button for different functions that were dependent on the state of another variable. Similarly, Freudenthal (1999) observed that many older participants encountered serious problems when using the button on the remote control labeled "pause/stop" (one button with multiple functions). However, not one of the above studies provided empirical data on older adults' difficulties in interacting with the interface type of one control with multiple functions, nor did they compare it to the multi-layered interface type.

Cognitive Abilities vs. Prior Experiences and Knowledge

There are mixed findings on how older adults' cognitive abilities and prior experiences and knowledge come into play in their performance with new technologies. For example, Langdon et al. (2007) found that prior experiences were the best predictors of performance than were cognitive abilities. Lewis et al. (2007) reported that prior experiences were not important predictors of performance. Blackler et al. (2009) suggested that a complex mix of cognitive abilities and prior experiences (with relevant products that use similar features) was the most important factor affecting how older people use new interfaces.

The mixed results on the relative weights of the aging factor and the prior experience factor on older adults' interactions with new technologies may be caused by different products tested, different natures of the tasks, and different methods of scoring prior knowledge and experiences.

Summary of Literature Review

The literature review showed that prior knowledge and experiences were important aspects of user characteristics and should be taken into account when designing products and interfaces for the target users. Design by leveraging users' prior knowledge and experiences would be particularly beneficial for the older adult users because it utilizes the crystallized intelligence which remains during the process of normal aging and reduces the requirements of learning abilities that show declines with aging.

There are only a few design recommendations for utilizing users' prior experiences and knowledge. Most of the existing recommendations suggested repetition and reuse of an existing feature or interaction style that users are familiar with, but they did not provide guidance on how to reshape or redesign an existing feature or style, or how to design a new feature or style while highlighting users' prior knowledge and experiences.

The review also showed many studies have found that prior knowledge and experiences have had an impact on users' performance and acceptance. Technologies that better match users' prior knowledge and experiences increased the effectiveness and efficiency of interaction. More knowledge and experiences relevant to the target technology led to improving skills, reducing anxiety, and increasing self-efficacy, which all had positive effects on users' acceptance of new technologies. The review also noted that past histories of usage colored users' expectations, which also influenced users' attitudes toward accepting the technologies.

A previous study identified that today's older adults typically belong to the electro-mechanical generation (born 1930–1960), and the interaction style available to them during their formative years (10–25 years old) was the electro-mechanical style.

It was found that older adults performed better with a product employing the interaction style within their technology generation (the electro-mechanical style) than they did with a newer interaction style beyond their generation. However, since an interaction style consists of three main components, it was unclear which component provided the usability benefits of the electro-mechanical style. It was unknown how older adults' early experiences with the electro-mechanical style influenced their technology acceptance—whether new technologies employing the interaction style within the technology generation of today's older adults (the electro-mechanical style) would more likely be accepted by older adults than those employing a newer interaction style beyond their technology generation. In addition, there are mixed findings on how cognitive abilities and prior experiences come into play in older adults' performances with technologies.

CHAPTER 3

DEVELOPING A FRAMEWORK OF GUIDING INTERFACE DESIGN FOR OLDER ADULTS

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Title: Developing a Framework of Guiding Interface Design for Older Adults

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Abstract: Many design recommendations have been provided for designing user interfaces for older adults. Existing design recommendations over the last twenty years were reviewed. Most of the design recommendations focused on older adults' age-related changes in physical, sensory, and cognitive abilities, from an aging perspective or aging-oriented approach. Few design recommendations have been generated focusing on older adults' prior knowledge and experience from a generation perspective or generation-oriented approach. The comparison of the two approaches is provided and the significance of taking into account both approaches during the design process is discussed. A framework guiding interface design for older adults systematically combining both the aging-oriented approach and the generation-oriented approach is proposed. This paper describes the framework which aims to assist developing user interfaces for maximum usability and accessibility for older adults.

Introduction

As the aging population grows and technologies continue to develop, the issue of how to design user interfaces of modern technologies for older adults supporting their independent living has become a central question for designers and researchers.

Like many industrialized countries, the United States is projected to experience rapid growth in its older population over the next four decades. Based on the data of 2008 for estimating U.S. national population growth, the number of Americans aged 65 and older was projected to be 40.2 million in 2010 and more than double to 88.5 million by 2050 (U.S. Census Bureau, 2010). At the same time, modern technologies are becoming increasingly ubiquitous in people's life. An inability to use current technologies puts older adults at a disadvantage to successfully perform everyday tasks, to remain active and to live independently. This in turn may increase burdens on society and also impair market shares for industry (Czaja, Fisk, Hertzog, Rogers, Charness, Nair, & Sharit, 2006a).

Many design recommendations have been provided for designing user interfaces for older adults. However, there are still daily living products and systems that are challenging for older adults; there are still complaints from older adults that today's products are not designed for them (Docampo Rama, 2001). Hence, a critical review of the existing design recommendations is needed with a particular emphasis placed on examining whether the user characteristics of this target population have been fully considered and reflected in design recommendations.

Reviewing existing design recommendations on user interface design for older adults over the past twenty years showed that existing design recommendations focused on older adults' age-related changes (declines) in physical, sensory, and cognitive abilities, and accordingly provided design recommendations to accommodate these aging characteristics of older adults (e.g., Hawthorn, 2000; Pattison & Stedmon, 2006; Morris, 1994; Zajicek, 2001a). These design recommendations were generated from an aging perspective which we termed it the 'aging-oriented approach'.

Few design recommendations focused on older adults' prior knowledge and experience gained in which the experience is coupled with societal and technological context providing a perspective to an entire generation of individuals. In this paper, we termed this the ‘generation-oriented approach’. Unfortunately, older adults’ prior knowledge and experience, especially the knowledge and experience gained collectively at a generation level has been underexplored. Studies have shown that prior knowledge and experience affected user’s performance of interacting with products. Products that better match prior knowledge and experience of their users increased the speed and effectiveness of interaction (e.g., Blackler, 2006; Langdon, Lewis, & Clarkson, 2007; Lewis, Langdon, & Clarkson, 2008; O’Brien, 2010).

According to the ISO 20281-1:2006 (E), entitled “Ease of operation of everyday products” (International Standards Organization, 2006), the three main groupings of user characteristics were defined as demographics, physical and sensory characteristics, and psychological and social characteristics (including cognitive abilities, prior knowledge and experience, etc.). The aging-oriented approach and the generation-oriented approach addressed different aspects of older adults’ user characteristics. The aging-oriented approach addressed physical and sensory abilities, and cognitive abilities; the generation-oriented approach addressed prior knowledge and experience.

In this paper, a framework which would systematically combine both the aging-oriented approach and the generation-oriented approach is proposed. The main user characteristics central to this paper are: physical and sensory abilities, cognitive abilities, and prior knowledge and experience. This framework would provide a holistic view of older adults as a cohort and provide guidance during the interface design process when seeking an ultimate design solution. The framework will support usability specialists, product designers, interaction designers, product manufacturers and others involved in the design and development of user interfaces of modern technologies for older adults.

Review

Literature addressing design recommendations for user interface design specific to older adults published in the last twenty years, 1992-2012, from a necessarily wide range of disciplines (including human factors, gerontology, human computer interaction, inclusive design, product design, and interaction design) was reviewed. Using keywords of ‘user interface', 'interface design', 'older adults', and 'elderly' to search databases (Ergonomics Abstracts, Compendex, and Web of Science), 303 articles were identified for abstract review. Studies were excluded from further review when abstracts indicated that the work only applied previously developed design recommendations rather than generating new recommendations or centered on products that did not have an interactive interface. Based on the exclusion criteria, the set of literature was refined to 201 for review using a phased approach. First, articles documenting existing design recommendations focused on older adults' age-related ability changes (sensory, physical, and cognitive abilities) were reviewed. Second, existing design recommendations focused on older adults' prior knowledge and experience were reviewed. Finally, the two approaches (focusing on the age-related ability changes vs. focusing on the generation-specific knowledge and experience) were compared.

The purpose of this literature review was to identify user characteristics addressed by the existing design recommendations, and by which perspective. It also provides the rational and evidence supporting the proposed framework.

Design recommendations focused on older adults' age-related ability changes. The majority of the literature reviewed focused on older adults' age-related ability changes, including sensory, physical, and cognitive abilities.

Comprehensive, cogent reviews of the age-related ability changes are available (Fisk, Rogers, Charness, Czaja, & Sharit, 2009; Hawthorn, 2000; Morris, 1994; Pak & McLaughlin, 2011; Pattison & Stedmon, 2006; International Standards Organization, 2008). Simulation tools which are helpful for understanding the age-related physical and sensory ability changes have been developed (e.g., the simulation toolkit (e.g., Cardoso, Keats, & Clarkson, 2004), the simulation suit (e.g., Tremayne, Burdett, & Utecht, 2011)).

Design recommendations focused on age-related ability changes have been provided for developing user interfaces for a wide range of products and systems including: mobile phones (e.g., Batu, Kim, & Cheng, 2010), PDAs (e.g., Arning & Ziefle, 2007), ATMs (e.g., Mead, Batsakes, Fisk, & Mykityshyn, 1999), input devices (e.g., Smith, Sharit, & Czaja, 1999), online communities (e.g., Kim, Kim, & Han, 2011), health and medication management systems (e.g., Ansari, 2011), smart home systems (e.g., Zhang, Rau, & Salvendy, 2009), e-government systems (e.g., Lines, Ikechi, & Hone, 2007), etc.

Existing design recommendations are informed by age-related changes in:

- Sensory abilities: vision (e.g., Zajicek, 2001b), audition (e.g., Jacko, Scott, Sainfort, Moloney, Kongnakorn, Zorich, & Emery, 2003), haptics (e.g., Jones & Sarter, 2008), etc.
- Physical abilities: motor control (e.g., Smith et al., 1999), hand eye coordination (e.g., Rau & Hsu, 2002), strength (e.g., DiDomenico & Nussbam, 2003), dexterity (e.g., Jin, Plocher, & Kiff, 2007), etc.
- Cognitive abilities: working memory (e.g., Ogata, Kumada, Suto, Watanabe, & Ifukube, 2011), episodic memory (e.g., Mead et al., 1999), attention (e.g., Tsai & Lee, 2011), spatial ability (e.g., Rau & Hsu, 2002), etc.

The design recommendations were generated by various methods, including laboratory experiments (e.g., Rau & Hsu, 2002), questionnaires (e.g., Ansari, 2011), structured or semi-structured interviews (e.g., Lines et al., 2007), focus groups (e.g., Ansari, 2011), participatory approaches (e.g., Batu et al., 2010), etc.

Design recommendations focused on older adults' prior knowledge and experience. The lack of publications focusing on older adult's prior knowledge about user interfaces and their prior interaction experiences underscores the limited progress on developing cohesive design recommendations for older adults. In addition to a lack of design guidelines, currently there is no tool available for simulating older adults' prior knowledge and experience. "Simulation kits" can provide the designers an experience with a range of physical and sensory abilities; however, it would be extremely difficult to accurately simulate one's prior knowledge and experience (Cardoso et al., 2004).

Only a few studies have provided design recommendations focusing on older adults' prior knowledge and experience. Hurtienne, Horn & Langdon (2010) suggested that applying prior knowledge derived from basic sensorimotor experiences would improve user interface design for the aging population and highlighted its implications for inclusive design research. Hisham & Edwards (2007) pointed out that the culture of Malaysia is relevant and important for designing the user interface for Malaysian older adults as they hold the same pattern of thinking, acting, communication styles and behaviors because of the specific social and cultural environment. Vines & Thompson (2007) mentioned that designers can design a user interface which affords older adults unconscious retrieval of knowledge gained over a lifetime's experience in the world, especially that gained during the formative period (10-25 years old). Fisk et al. (2009) also recommended that designers should take advantage of older adults' well-developed knowledge base and develop products and systems that are consistent with their representations, expectations, and experiences.

Aging-oriented approach vs. generation-oriented approach. The aging-oriented approach and the generation-oriented approach differ in the following aspects.

Explanation of age-group differences. Older adults typically have more difficulties with today's user interface of modern technologies compared to the younger adults (Czaja et al., 2006a). The aging-oriented approach explained the differences by focusing on biological and genetic attributes and the decrements as a result of the process of aging. The generation-oriented approach focused on learned differences to explain the difficulties of older adults' with user-interfaces contrasting the generation-specific knowledge and experience to the requirements of the current user interface.

Period of lifespan. The aging-oriented approach focused on the later period of life of older adults when the age-related ability changes (declines) occur. On the other hand, the generation-oriented approach utilized knowledge and experience acquired over a lifetime, focusing on the formative period (10-25 years old).

Declining and maintaining. The aging-oriented approach focused on declines in abilities and provides design recommendations to accommodate the losses. The generation-oriented approach focused on what is remaining and provides design recommendation to leverage those abilities and knowledge.

Historical context. The aging-oriented approach typically lacks historical context and is isolated from societal and technological influencers. The generation-oriented approach is context-rich and regards history as an important component; each generation is unique given its historical context. Thus the generation-oriented approach is dynamic; the knowledge and understandings regarding the prior knowledge and experience of older adults need to be augmented and refined as new generations enter the older adult category.

In summary, the aging-oriented approach has been successful in facilitating user interface design for older adults but has limitations. The generation-oriented approach has the potential to complement the aging-oriented approach. Hence, a framework that systematically combines the two approaches is highly desirable for seeking the ultimate design solutions.

Guiding Interface Design for Older Adults

The lack of understanding of target user capabilities in interface design can lead to user frustration, human errors and accidents, and even user exclusion (Keates & Clarkson, 2003). As the capability-demand relationship suggested, design exclusion takes place when the demands of certain interface feature exceed the users' capabilities (Persad, Langdon, & Clarkson, 2006). Hence, it is crucial to take into account all main user capabilities and user characteristics of older adults in the design process in order to design an easy to use and accessible user interface for older adults.

Currently, there is a lack of complete and unified data to facilitate the design process and evaluate design concepts considering all main aspects of user characteristics of older adult. In order to address this gap in the literature, to emphasize the importance of a holistic view and complete understanding on what it means to be an older adult, and to guide interface design for older adults with more sensitivity, a framework blending the aging-oriented approach and the generation-oriented approach is proposed.

The overall framework. The proposed framework can serve as a conceptual tool which presents thought flow and design process (see Figure 3.1). As indicated at the top of the framework diagram, the first step in user interface design is to understand and describe the user characteristics of the target user group, the older adults. The designers then work through the diagram in two paths, the aging-oriented approach (left) and the generation-oriented approach (right). A holistic view and complete understanding of older adults' user characteristics can be achieved by working through the framework along both paths (applying both approaches). After this process, preliminary design solutions can be informed by each approach. It is important to note that at this stage, the preliminary design solutions generated from the two approaches are not necessarily the same. A dialogue is needed to compare the preliminary products generated from the two different approaches. A design solution informed by the comparison dialogue between the two preliminary design solutions would be generated at the end of the process.

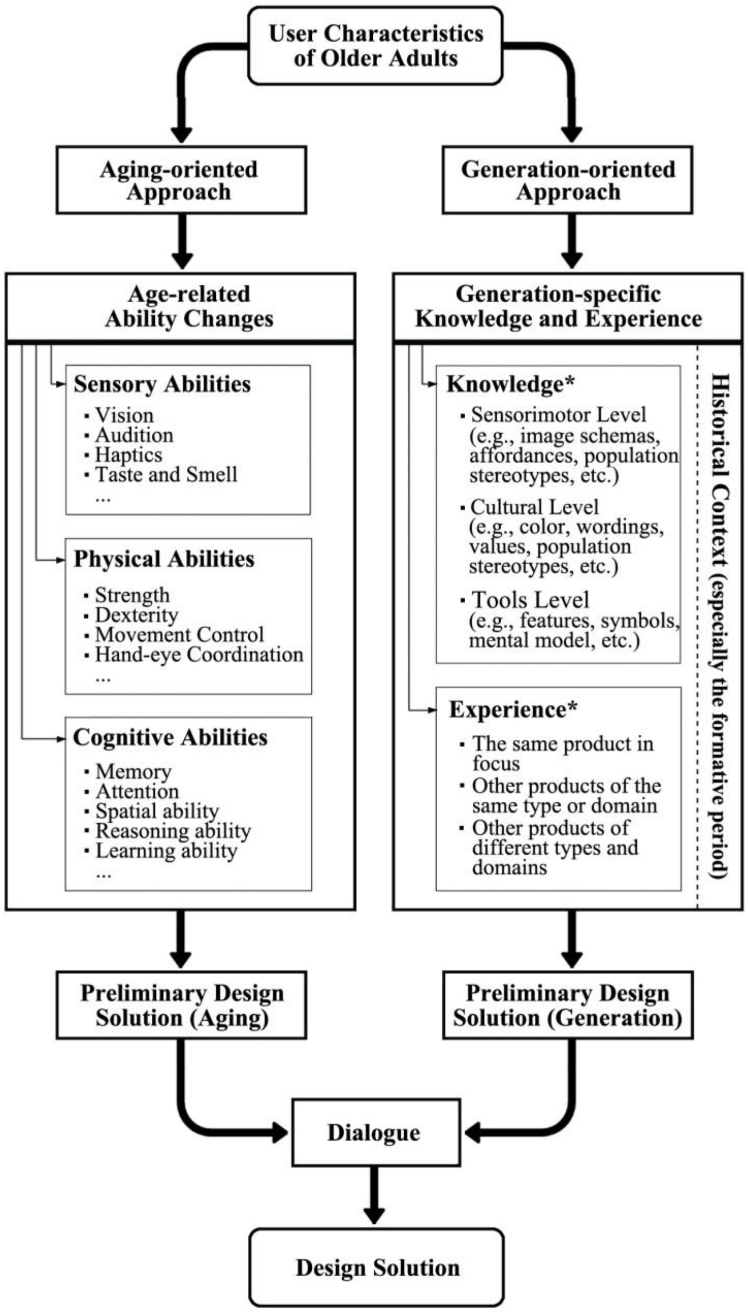

Figure 3.1. A Framework of Guiding Interface Design for Older Adults. Note: *More details regarding the Knowledge and Experience contents and guidelines are being addressed by current investigations.

Aging-oriented approach. The left-half of the diagram depicts the process of achieving design solutions by applying the aging-oriented approach. The aging-oriented approach establishes and understands the user characteristics of older adults by focusing on the age-related ability changes (declines and impairments) during the natural process of aging.

Three main categories of abilities change (decline) in the aging process: sensory, physical, and cognitive abilities. There are many aspects of these three abilities categories documented as declining in the aging process. However, only those aspects closely associated with user interface interaction and mostly addressed in usability literature were included in the framework within the three abilities categories.

In this frame work, aspects of sensory abilities included: vision, audition, haptics, taste and smell, etc. Aspects of physical abilities included: strength, dexterity, movement control, hand-eye coordination, etc. Aspects of cognitive abilities included: memory, attention, spatial ability, reasoning ability, learning ability, etc.

Age-related changes in sensory, physical, and cognitive abilities supporting this aspect of the framework are derived from the work of Fisk et al., 2009, Hawthorn, 2000, Morris, 1994, and Pak & McLaughlin, 2011.

Generation-oriented approach. The right-half of the diagram depicts the process of achieving design solutions by applying the generation-oriented approach. The generation-oriented approach establishes and understands the user characteristics of older adults by focusing on the generation-specific knowledge and experience.

As expressed in Hurtienne and Israel's (2007) table titled "continuum of knowledge", prior knowledge may stem from different sources and these sources can be classified along a continuum. The first and lowest level consists of innate knowledge, the next level is sensorimotor, the next is knowledge specific to the culture in which an individual lives, and the highest level is expertise. In addition, a level of tool knowledge was identified as spanning the sensorimotor, culture, and expertise levels of knowledge.

Knowledge. In the proposed framework, the sensorimotor level, cultural level, and tools levels were included within the category of knowledge. Notions such as image schemas, affordance, and population stereotypes reside at the sensorimotor level (Blackler & Hurtienne, 2007). Knowledge can vary considerably between cultures, for instance, color, wordings, values, and population stereotypes. At the tool level, there is knowledge about specific products features (appearance, location, and operation), symbols, and mental models (Blackler, 2006; O'Brien, 2010).

Innate and expertise knowledge described in the continuum of knowledge were not included in the proposed framework. Innate knowledge is not likely to differ among generations since it is acquired through the activation of genes but not by learned differences. Expertise knowledge can only be gained by a very small amount of users due to the nature of individual profession and specialization (Hurtinne & Isreal, 2007).

Experience. Prior experience can be differentiated into at least three groups: (1) with the product in focus, (2) with other products of the same type or domain, and (3) with a broad range of products of different types and domains (Hurtienne et al., 2010). All three groups of prior experience were included within the category of experience in the proposed framework.

Historical Context. A crucial component in the generation-oriented approach, historical context was included in the proposed framework because each generation grows up and lives in a specific historical context with unique societal, cultural, technological and environmental characteristics. Understanding the history of user interface development, the objects that older adults have encountered and their interaction experiences during the important developmental periods of their life is important. In particular, the formative period (10-25 years old) is a critical period in which people acquire norms, values, and skills which influence their future behaviors and preferences (Docampo Rama, 2001).

Dialogue and design solution. The preliminary design solutions informed by the aging-oriented approach and the generation-oriented approach are not necessarily the same. A dialogue comparing and contrasting the products produced using the two approaches is crucial to the success of the final product of this framework. By encouraging and conducting dialogue including careful analysis, evaluation, and discussion with respect to meeting the specific design goals and needs, and incorporating specific design challenges and situations, a final design solution can be reached using the framework.

Discussion

From the literature reviewed, a framework for guiding interface design for older adults was created which combines the aging-oriented approach and generation-oriented approach during design and development of user interfaces for older adults. The framework promotes consideration of both age-related ability changes and the generation-specific knowledge and experience when seeking user interface solutions designed for older adults.

The framework attempts to assist designers develop user interfaces for maximum usability and accessibility for older adults by considering all main user characteristics of this target population with more sensitivity and a wider perspective. It also attempts to raise awareness among designers for taking a holistic view and complete understandings regarding what it means to be an older adult. Thus designers must look beyond the decrements associated with the aging process in order to develop user interface solutions suitable for older adults.

Future work is needed for collecting data, designing methods, and creating tools that designers may utilize to efficiently access and synthesize older adults' prior knowledge and experiences. Future work is needed for identifying older adults' knowledge and experience gained after the formative period; periods in their lifetime when they encountered important design innovations and social changes that were influential for the target generation. Future work is also needed to provide more specific examples and detailed guidelines to expand and improve the proposed framework.

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References

Ansari, S. (2011). Designing interactive pill reminders for older adults: A formative study. In C. Stephanidis (Ed.), Universal Access in Human-Computer Interaction, pp.121-130. Berlin, Germany: Springer.

Arning, K., & Ziefle, M. (2007). Barriers of information access in small screen device applications: The relevance of user characteristics for a transgenerational design. In C. Stephanidis & M. Pieper (Ed.), User Interfaces for All: Universal Access in Ambient Intelligence Environments, pp. 117-136. Heidelberg, Germany: Springer.

Batu, Y., Kim, Y., & Cheng, H. (2010). Senior-friendly icon design for the mobile phone. In 6th International Conference on Digital Content, Multimedia Technology and its Applications (IDA), Seoul, Korea.

Blackler, A. (2006). Intuitive interaction with complex artefacts. Unpublished dissertation. Queensland University of Technology, Brisbane, Australia.

Blackler, A. & Hurtienne, J. (2007). Toward a unified view of intuitive interaction: definitions, models and tools across the world. MMI-Interaktiv, 13(8), 37–55.

Czaja, S. J., Fisk A. D., Hertzog, C., Rogers, W. A., Charness, N., Nair, S. N., & Sharit, J. (2006). Factors predicting the use of technology: findings from the center for research and education on aging and technology enhancement (CREATE). Psychology and aging, 21(2), 333-352.

Cardoso, C., Keates. S., & Clarkson, P. J. (2004). Comparing product assessment methods for inclusive design. In S. Keates, J. Clarkson, P., Langdon, & P. Robinson (Ed.), Designing a More Inclusive World, pp. 31-40. London, UK: Springer.

DiDomenico, A., & Nussbam, M. A. (2003). Measurement and prediction of single and multi-digit finger strength. Ergonomics, 46(15), 1531-1548.

Docampo Rama, M. (2001). Technology generations: handling complex user interfaces. Unpublished dissertation. Technical University of Eindhoven, Eindhoven, The Netherlands.

Fisk, A. D., Rogers, W. A., Charness, N., Czaja, S. J., & Sharit, J. (2009). Designing for Older Adults: Principles and Creative Human Factors Approaches. Boca Raton, FL: CRC Press.

Hawthorn, D. (2000). Possible implications of aging for interface designers. Interacting with Computers, 12, 507-528.

Hisham, S., & Edwards, A. (2007). Incorporating culture in user-interface: a case study of older adults in Malaysia, Papers presented at the Proceedings of the 18th Conference on Hypertext and Hypermedia, Manchester, UK.

Hurtienne, J., Horn, A., & Langdon, P. (2010). Facets of prior experience and their impact on product usability for older users. In P. M. Langdon, P. J. Clarkson, & P. Robinson (Eds.), Designing Inclusive Interaction, pp.123-132. London, UK: Springer.

Hurtienne, J., & Israel, J. H. (2007). Image schemas and their metaphorical extensions-intuitive patterns for tangible interaction. Papers presented at the Proceedings of the 1st International Conference on Tangible and Embedded Interaction, New York, US.

Hurtienne, J., Langdon, P., & Clarkson, P. J. (2009). Toward an account of sensorimotor knowledge in inclusive product design. Paper presented the Proceedings of the 5th International Conference on Universal Access in Human-Computer Interaction (Part I), San Diego, USA.

Jacko, J. A., Scott, I. U., Sainfort, F., Moloney, K. P., Kongnakorn, T., Zorich, B. S., & Emery, V. K. (2003). Effects of Multimodal Feedback on the Performance of Older Adults with Normal and Impaired Vision. In Carbonell, N., & Stephanidis, C. (Ed.), Universal Access Theoretical Perspectives, Practice, and Experience, pp. 3-22. Berlin, Germany: Springer.

Jin, Z., Plocher, T., & Kiff, L. (2007). Touch screen user interfaces for older adults: Button size and spacing. In C. Stephanidis (Ed.), Universal Access in Human Computer Interaction, pp. 933-941. Berlin, Germany: Springer.

Keates, S., & Clarkson, J. (2003). Countering Design Exclusion: An Introduction to Inclusive Design. London, UK: Springer.

Jones, L. A., & Sarter, N. B. (2008). Tactile Displays: Guidance for Their Design and Application. Human Factors, 50(1), 90-111.

Kim, J., Kim, H., & Han, K. (2011). Color image effect of online community on age: focusing on self-expression. In C. Stephanidis (Ed.), HCI International 2011 – Posters' Extended Abstracts, pp. 445-448. Berlin, Germany: Springer.

Langdon, P. M., Lewis, T., & Clarkson, P. J. (2007). The effects of prior experience on the use of consumer products. Universal Access in the Information Society, 6, 179–191.

Lewis, T., Langdon, P. M., & Clarkson, P. J. (2008). Prior experience of domestic microwave cooker interfaces: a user study. In P. M. Langdon, P. J. Clarkson, & P. Robinson (Ed.), Designing Inclusive Futures. pp. 95-106. London, UK: Springer.

Lines, L., Ikechi, O., & Hone, K. S. (2007). Accessing e-government services: design requirements for the older user. In C. Stephanidis (Ed.), Universal Access in Human-Computer Interaction, pp. 932-940. Berlin, Germany: Springer.

International Standards Organization. (2006). Ease of operation of everyday products – Part 1: Design requirements for context of use and user characteristics [ISO Standard 20282-1:2006(E)]. Geneva: International Standards Organization.

International Standards Organization. (2008). Ergonomics data and guidelines for the application of ISO/IEC Guide 71 to products and services to address the needs of older persons and persons with disabilities [ISO/TR 22411:2008]. Geneva: International Standards Organization.

Mead, S. E., Batsakes, P., Fisk, A. D., & Mykityshyn, A. (1999). Application of cognitive theory to training and design solutions for age-related computer use. International Journal of Behavioral Development, 23(3), 553–573.

Morris, J. M. (1994). User interface design for older adults. Interacting with Computers, 6(4), 373-393.

O'Brien, M. (2010). Understanding human-technology interaction: the role of prior experience and age. Unpublished dissertation. Georgia Institute of Technology, Georgia, US.

Ogata, K., Kumada, T., Suto, S., Watanabe, K., & Ifukube, T. (2011). Interface design of a central monitoring device taking cognitive aging into account. In 2011 IEEE International Conference on Systems, Man, and Cybernetics (SMS), Anchorage, Alaska, US.

Pak, R., & McLaughlin, A. (2011). Designing Displays for Older Adults. Boca Raton, FL: CRC Press.

Pattison, W., & Stedmon, A. (2006). Inclusive design and human factors: designing mobile phones for older users. Psychology Journal, 4(3), 267-284.

Persad, U., Langdon, P. M., & Clarkson, P. J. (2006). Inclusive design evaluation and the capability-demand. In P. J. Clarkson, P. M. Langdon, & P. Robinson (Ed.), Designing Accessible Technology, pp. 177-188. London, UK: Springer.

Rau, P., & Hsu, J. (2002). A Study of Interaction Devices and WWW User Interface Design for Older Adults. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 46(2), 219-223.

Smith, M.W., Sharit, J., & Czaja, S.J. (1999). Aging, motor control, and the performance of computer mouse tasks. Human Factors, 41(3), 389–396.

Tremayne, P., Burdett, J., & Utecht, C. (2011). Simulation suit aids tailored care. Nursing Older People, 23(7), 19-22.

Tsai, W., & Lee, C. (2011). A study on the icon feedback types of small touch screen for the elderly. In C. Stephanidis (Ed.), Universal Access in Human-Computer Interaction. pp. 422-431. Springer, Berlin, Germany: Springer.

U.S. Census Bureau. (2010). The next four decades: the older population In the United States, 2010 to 2050. <www.census.gov/prod/2010pubs/p25-1138.pdf>

Vines, J., & Thompson, S. (2007). Aging futures: toward an inclusive cognitive interaction design. Papers presented at the 4th International Conference for Inclusive Design, London, UK.

Zajicek, M. (2001a). Interface design for older adults. Papers presented at the Proceedings of the 2001 EC/NSF workshop on Universal accessibility of ubiquitous computing: providing for the elderly, Alcácer do Sal, Portugal.

Zajicek, M. (2001b). Making World Wide Web interfaces usable for elderly and/or visually impaired people. Papers presented at the 15th Annual Conference of the Human Computer Interaction Group of the British Computer Society IHMHCI, Toulouse, France.

Zhang, B, Rau, P. P., & Salvendy, G. (2009). Design and evaluation of smart home user interface: effects of age, tasks and intelligence level. Behaviour & Information Technology, 28(3), 239-249.

CHAPTER 4

OVERVIEW OF THE RESEARCH

Research Objective

This research investigated the effect of older adults' early experiences with interaction style on usability and acceptance of new technologies. Four main objectives of this research were: (a) to investigate how older adults' early experiences with the interaction technique and the interaction structure of the electro-mechanical style affected usability and acceptance of new technologies; (b) to investigate older adults' early experiences with the electro-mechanical style to determine which one of the two components (the interaction technique or the interaction structure) played a greater role; (c) to find out how aging-related abilities and generation-related knowledge and experiences come into play in older adults' performances with new technologies; and (d) to provide design recommendations that could inform designers about reshaping the electro-mechanical style and also designing new interaction styles that highlight older adults' early experiences with the electro-mechanical style.

Research Questions

The primary research questions of this research are as follows:

Research Question 1: Have older adults' early experiences with the electro-mechanical style had an effect on the usability of new technologies?

- Sub-Question 1-1: Have older adults' early experiences with the interaction technique of the electro-mechanical style had an effect on the usability of new technologies?
- Sub-Question 1-2: Have older adults' early experiences with the interaction structure of the electro-mechanical style had an effect on the usability of new technologies?

Research Question 2: Have older adults' early experiences with the electro-mechanical style had an effect on their acceptance of new technologies?

- Sub-Question 2-1: Have older adults' early experiences with the interaction technique of the electro-mechanical style had an effect on their acceptance of new technologies?

- Sub-Question 2-2: Have older adults' early experiences with the interaction structure of the electro-mechanical style had an effect on their acceptance of new technologies?

Research Question 3: How have the aging factor (age-related ability changes) and the generation factor (generation-specific knowledge and experience) come into play in older adults' performances with technologies employing new interaction styles (that beyond the technology generation of today's older adults)?

- Sub-Question 2-1: How aging factor and generation factor came into play in older adults' performance with technologies employing newer interaction techniques?
- Sub-Question 2-2: How aging factor and generation factor came into play in older adults' performance with technologies employing newer interaction structures?

Research Question 4: Overall, which one of the two main components of the electro-mechanical style (the interaction technique or the interaction structure) in older adults' early experiences had a greater impact on their future interaction with new technologies with respect to usability and acceptance?

Definitions of Key Terms

Early experience: the experience gained during one's formative period (adolescence and young adulthood, which is about 10–25 years of age).

Technology generation: a cohort of population having the same user interface experiences during their formative periods.

User interface: elements of a product used to control it and receive information about its status and the interaction that enables the user to use it for its intended purpose (ISO 20282-1: 2006).

Interaction style: user interfaces can be described in a structured and detailed way by specifying their interaction style. An interaction style consists of three main components: the conceptual operations, the interaction technique, and the interaction structure (De Vet & De Ruyter, 1996).

Interaction technique: input devices (controls) and output devices.

Interaction structure: interaction procedure for a structural level, which is characterized by both the mapping between control and function (one control with one function or one control with multiple functions) and the number of layers (single-layered operation or multi-layered operation).

Usability: the extent to which a product enables specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use (ISO 9241-11: 1998). Usability measures user performance, and satisfaction. User performance is usually assessed in terms of attainment (the number of problems completed in a fixed period of time) and also in terms of speed or reaction time (the time taken to complete one item) (Ackerma, 1988).

Technology acceptance: the approval, favorable reception and ongoing use of newly introduced devices and systems (Arning & Ziefle, 2007).

Aging-oriented approach: studies focused on older adults' age-related changes (declines) in physical, sensory, and cognitive abilities, and accordingly providing design recommendations to accommodate these aging characteristics of older adults.

Generation-oriented approach: studies focused on older adults' prior knowledge and experiences gained in which experiences coupled with a societal and technological context, providing a perspective about an entire generation of individuals, and accordingly providing design recommendations to highlight the generation-specific knowledge and experiences of older adults.

Research Design

The aims of this research were to investigate how older adults' early experiences with the electro-mechanical style of consumer products during their formative years (10–25 years) influenced usability and acceptance of new technologies, and to provide design recommendations for reshaping the electro-mechanical style and designing for older adults new interaction styles that highlight their early experiences.

This research was concerned with older adults' early experiences with the two main components of the electro-mechanical style (the interaction technique and the interaction structure) and the relative weights of the two components in influencing their performances with and acceptance of new technologies.

This study consisted of two experiments. Experiment 1 investigated the effects of older adults' early experiences with the interaction technique of the electro-mechanical style on usability and acceptance of new technologies. Experiment 2 investigated the effects of older adults' early experiences with the interaction structure of the electro-mechanical style on usability and acceptance of new technologies.

The goal was to experimentally separate the two components of interaction style (the interaction technique and the interaction structure) and to isolate the influences attributable to each. It is important to disentangle these effects because if the bulk of the benefits of early experiences with the electro-mechanical style are attributable to the interaction structure rather than the interaction technique, one would have less motivation to keep the specific feature of the interaction technique of the electro-mechanical style when redesigning the electro-mechanical style, and vice versa.

Older adults' early experiences with the two components of the electro-mechanical style potentially have different effects on usability and acceptance. However, these different effects can be difficult to discern in the real world because various features or components of the electro-mechanical style tend to go together in a consumer product. For example, a dial-based washer employs both the interaction technique and the interaction structure of the electro-mechanical style (featuring hardware dial, 1:1 mapping and single-layered operation). A touch-screen-based mobile phone employs both the interaction technique and the interaction structure of the menu style (featuring a visualized button and multi-layered operation). Hence, prototypes made for research purposes rather than commercial products on the market were used in this study to separate the effects of the two components of the interaction style.

In Experiment 1, four interface types with different interaction techniques across the historical changes were assessed, including the Physical Dial Interface (PDI), the Physical Button Interface (PBI), the Visualized Button Interface (VBI), and the Visualized Dial Interface (VDI). The Physical Dial Interface (PDI) represented the interaction technique of the electro-mechanical style that today's older adults grew up with. The other three interface types (PBI, VBI, and VDI) represented newer interaction techniques introduced after their formative years. The only difference among the four interface types was the interaction technique. The component of interaction structure was controlled in this experiment (all interface types used the 1:1 mapping between function and control and the single-layered operation).

In Experiment 2, three interface types with different interaction structures across the historical changes were assessed, including the One Control with Single Function and Single-Layered Interface (SFSLI), the One Control with Multi-Function Interface (MFI), and the Multi-Layered Interface (MLI). The SFSLI represented the interaction structure of the electro-mechanical style that today' older adults grew up with. The other two interface types (the MFI and the MLI) represented newer interaction structures introduced after their formative years. The only difference among the three interface types was the interaction structure. The component of interaction technique was controlled in this experiment (all interface types used visualized buttons on a touch-screen device).

Given the usability improvements that have occurred during the last century, interface types selected across the historical development and used in the two experiments were of different difficulties. It was important to disentangle the difficulty of the interface type from the users' early experiences with that interface type. Hence, participants from two age groups (technology generations) were recruited for each experiment of this study, a younger group (18–33 years of age) and an older group (65–80 years of age). The younger group served as a comparison (reference) group to establish performance benchmarks. Emphasis was placed on analyzing the age-group performance difference in each interface type and investigating whether the age-group performance difference was smaller for the particular interaction technique or the interaction structure that today's older adults grew up with.

The age-group performance differences could be influenced by the aging factor (age-related abilities) and the generation factor (generation-specific knowledge and experiences). It was important to separate the roles of the aging factor and the generation factor in older adults' interactions with technologies. Hence, a set of participants' abilities were assessed, including reaction time, processing speed, and working memory. These abilities were chosen because they were shown to decline with the natural process of aging and also were found to be closely associated with users' performances with interfaces as informed by the literature (Blackler et al. (2010), and Reddy et al. (2010)). If there were a significant portion of the age-group performance difference that could not be explained by the variance in these abilities, it would imply that the aging factor was not the only significant variable, and the generation factor might also have played a significant role. It was also important to investigate which one of the two factors played a greater role. Hence, older adult participants in this study were interviewed to collect subjective measurements of their perceived relative weights of the two factors (aging factor and generation factor) in their interactions with new technologies.

For both experiments, every participant performed tasks on all interface types assessed. The primary measurements were usability (task completion time, workload, and satisfaction) and acceptance (behavioral intention, perceived usefulness, and perceived ease of use). Also measured were preferences among the interface types, technology experience, reaction time, and cognitive abilities (processing speed and working memory) and older adults' perceived relative weights of the two factors attributable to their difficulties using new interfaces (aging factor vs. generation factor).

CHAPTER 5

EXPERIMENT 1 (INTERACTION TECHNIQUE)

Overview of Experiment

This experiment investigated the effects of older adults' early experiences with the component of interaction technique of the electro-mechanical style on usability and acceptance of new technologies.

As previously mentioned in the literature review, today's older adults (65 years and older) typically belong to the electro-mechanical generation, and the predominant interaction style they were exposed to during their formative years (10–25 years of age) was the electro-mechanical style. The interaction technique of this particular interaction style featured mechanical hardware-based input and output devices, which provided a concrete and direct physical manipulation of input devices with tangible feedback. Examples are dials, switches, and knobs.

In this experiment, four types of functionally equivalent interfaces were chosen to be examined: the Physical Button Interface (PBI), the Physical Dial Interface (PDI), the Visualized Button Interface (VBI), and the Visualized Dial Interface (VDI). The only difference among the interface types was the interaction technique.

Impacts of the feature of physical manipulation and tangible feedback would be informed by comparing PBI with VBI and comparing PDI with VDI.

The physical dial represented the type of interaction technique belonging to the electro-mechanical style with which older adults had early experiences. The physical button, the visualized button, and the visualized dial represented newer types of interaction techniques over the historical changes. Although mechanical physical buttons were also available during the formative years of older adults, they were much less prevalent than were physical dials.

Participants from two age groups were recruited in this experiment: 28 participants comprised a younger group (18–33 years old) and 28 participants comprised an older group (65–80 years old). The younger adults served as a comparison group. Each participant performed tasks twice with all four interface types. The order of presentations of the four interface types was counterbalanced among the 28 participants within each age group.

The independent variables were: interface type (PBI, PDI, VBI, and VDI), age group (younger group and older group), and trial (trial 1 and trial 2). Both interface type and trial were within-subject variables. Two primary groupings of dependent variables were usability (task completion time, workload, and satisfaction) and acceptance (behavioral intention, perceived usefulness, and perceived ease of use). Also measured were reaction time and cognitive abilities (processing speed and working memory), technology experience, preferences among the four interface types, and older adults' perceived relative weights of the two factors attributable to their difficulties using new interfaces (aging factor vs. generation factor).

Methods

Participants. A total of 56 participants, including 28 younger adults (18–31 years) and 28 older adults (65–77 years) participated in this study (see Table 5.1 and Table 5.2 for an overview of the participant characteristics). The mean age of the younger group was 22.43 years (SD = 3.53 years), and the mean age of the older group was 69.96 years (SD = 3.99). The younger group served as a comparison (reference) group to establish performance benchmarks.

Participants were recruited from North Carolina State University (NCSU) and the surrounding communities. A majority of the older adult participants were members of the Encore Program for Lifelong Enrichment of NCSU. Younger participants were undergraduate and graduate students and recent graduates of NCSU. Most of the participants received course credits or monetary compensation for participating in this study; the volunteer participants did not receive any compensation.

Participants with severe physical or cognitive impairments were excluded from participation. Participants were required to have at least a high school education, near and far vision of at least 20/40 (with or without correction) and normal hearing acuity (self-reported). Participants were also screened to ensure that they were able to follow the instructions and complete the tests in English. All 28 participants in the younger group and 27 participants in the older group were native English speakers. Only 1 participant in the older group was not a native English speaker, but the participant had lived in the United States for more than 7 years and spoke fluent English. Twenty-six participants in the younger group and 25 participants in the older group were righted-handed. Participants in both the younger and older groups represented a wide variety of occupations or majors. All participants had at least minimal usage experiences with touch-screen devices.

Table 5.1.
Participant Demographics (Exp 1)

		Mean (Std Dev)			
	N	Age (years)	Education Level	Health	Health (Compared to age)
Younger Group	28	22.43 (3.53)	6.29 (0.6)	4.21 (0.57)	4 (0.67)
Female	15	22.8 (3.36)	6.33 (0.62)	4.2 (0.56)	4 (0.65)
Male	13	22 (3.81)	6.23 (0.6)	4 (0.71)	4 (0.71)
Older Group	28	69.96(3.99)	6.64 (0.87)	3.93 (0.72)	4 (0.61)
Female	17	69.65 (4.17)	6.41 (0.71)	4.18 (0.64)	4.18 (0.53)
Male	11	70.45 (3.83)	7 (1)	3.55 (0.69)	3.73 (0.65)
All Participants	56	46.2 (24.27)	6.46 (0.76)	4.07 (0.66)	4 (0.63)

Note: (1) Explanation of Scoring for Education Level:
Score 5: Some college/Associate’s degree or currently working toward a college/Associate’s degree.
Score 6: Bachelor’s degree (BA, BS) or currently working toward a Bachelor’s degree.
Score 7: Master’s degree (or other post-graduate training) or currently working toward a Master’s degree.
Score 8: Doctoral degree (PhD, MD, EdD, DDS, JD, etc.) or currently working toward a Doctoral degree.
(2) Explanation of Scoring for both Health and Health Compared to Other People with Same Age):
Score 1: poor; Score 2: Fair; Score 3: Good; Score 4: Very good; Score 5: Excellent.

Table 5.2.
Ability Test and Technology Experience Test Sores (Exp 1)

		Mean (Std Dev)			
	N	Reaction Time (ms)	Processing Speed	Working Memory	Technology Experience
Younger Group	28	308.49 (31.57)	88.32 (11.44)	39.36 (12.54)	280.89 (20.85)
Female	15	316.6 (24.55)	91.27 (9.28)	43.73 (14.59)	285.27 (16.13)
Male	13	299.14 (36.91)	84.92 (13.07)	34.31 (7.32)	275.85 (24.97)
Older Group	28	367.14 (91.61)	69.39 (13.7)	27.29 (10.98)	287.21 (31.96)
Female	17	393.89 (103.5)	70.18 (14.12)	25.65 (10.49)	281.47 (30.96)
Male	11	325.79 (49.22)	68.18 (13.61)	29.82 (11.74)	296.09 (32.86)
All Participants	56	337.82 (74.06)	78.86 (15.73)	33.32 (13.17)	284.05 (26.92)

Note: This table showed the absolute score of the working memory.

As shown in the Table 5.3, a Wilconxon-Mann-Whitney test revealed marginally significant differences in education levels between the younger group and the older group ($p < 0.1$). But the Wilconxon-Mann-Whitney test did not identify significant differences in self-ratings of health conditions or health compared to other people of the same age between the two groups.

Table 5.3.
Wilconxon-Mann-Whitney Tests for Demographic Differences between Age Groups (Exp 1)

	Younger Adults vs. Older Adults	
	Z-score	P-value
Education Level	1.76	0.078*
Health Condition	-1.51	0.13
Health Compared to People with Same Age	0	1

Note: *p<0.1, **p<0.05, ***p<0.001.

The age-group difference in education levels was typical of those reported in previous research (Rogers, Hertzog, & Fisk, 2002; Sharit, Hernández, Czaja, & Pirolli, 2008) in that older adults had completed more years of education than younger adults (who were still pursuing their degrees). But the nonsignificant age-group difference in health conditions was not typical. Older adults often reported lower self-ratings of health than did younger adults (Rogers et al., 2002). So the older adults participating in this study might have been generally healthier than the average of the older adult population.

Participants each completed the following tests and questionnaire to assess reaction time, processing speed, working memory, and technology experience: (a) the Reaction Time Test (Human Benchmark, 2012), (b) the Digit Symbol Substitution (Wechsler, 1981), (c) the Alphabet Span (Craik, 1986), and (d) the Technology Experience Questionnaire (Czaja et al., 2006b).

As shown in Table 5.4, an independent sample *t*-test revealed significant differences in all three abilities tested (reaction time, processing speed, and working memory) between the younger group and the older group ($p < 0.05$). But the *t*-test did not identify a significant difference in technology experience between the two groups.

Table 5.4.
T-Tests for Three Abilities and Technology Experience between Age Groups (Exp 1)

	Younger Adults vs. Older Adults	
	t value	P-value
Reaction Time	3.20	0.0023**
Processing Speed	-5.61	<0.0001***
Working Memory	-3.83	0.0003***
Technology Experience	0.88	0.3845

Note: *p<0.1, **p<0.05, ***p<0.001.

The age-group differences in reaction time, processing speed, and working memory were consistent with those reported in previous research (e.g., Rogers et al., 2002) in that younger adults performed better on the reaction time tests, the digital-symbol substitution tasks, and the alphabet span tasks. But the nonsignificant age-group difference in technology experience was not typical. Older adults often reported lower technology experience than did younger adults (Czaja et al., 2006a). So the older adult participants in this study might have had higher technology experience than the average of the older adult population. It has previously been reported that the technology experience between younger adults and high technology older adults was not significantly different (O'Brien, 2010).

Setting. The experiment took place in the Research in Ergonomics and Design Laboratory (RED Lab) at North Carolina State University. The room was quiet and air-conditioned and contained adequate lighting.

The participant was seated in an adjustable chair in front of a conference table. A laptop that showed task instructions was placed on the table in front of the participant, and the prototype of the user interface was placed between the participant and the laptop. The researcher was seated on the non-dominant side of the participant to monitor his or her interactions and record the task completion time.

Materials. Materials in this study included prototypes, recording and computing devices, experiment instruction and task instructions, abilities tests, technology experience questionnaire, demographic information questionnaire, workload questionnaire, satisfaction questionnaire, technology acceptance questionnaire, preference questionnaire, and structured interview script.

Prototypes. Four types of user interface prototypes were made by the researcher for this experiment, including the Physical Button Interface (PBI), the Physical Dial Interface (PDI), the Visualized Button Interface (VBI), and the Visualized Dial Interface (VDI). Characteristics of the four interface types are shown in Table 5.5.

Table 5.5.
Characteristics of the Four Interface Types (Exp 1)

Interface Type	**Physical Manipulation and Tactile Feedback**	**Appearance**	**Operation**
Physical Buttons Interface (PBI)	Yes	Button	Press the Button
Physical Dials Interface (PDI)	Yes	Dial	Rotate the Dial
Visualized Buttons Interface (VBI)	None	Button	Press the Button
Visualized Dials Interface (VDI)	None	Dial	Rotate the Dial

The two hardware-based interfaces (PBI and PDI) provided physical manipulation capability and tactile feedback while participants were interacting with the real buttons or the real dials. In contrast, the two software-based interfaces (VBI and VDI) did not provide any physical manipulation capability or tactile feedback while participants were interacting with the visualized buttons or visualized dials on a touch-screen device.

The two button-based interfaces (PBI and VBI) shared the same appearance and layout, and the two dial-based interfaces (PDI and VDI) shared the same appearance and layout. The layouts of the four interface types are shown in Figure 5.1.

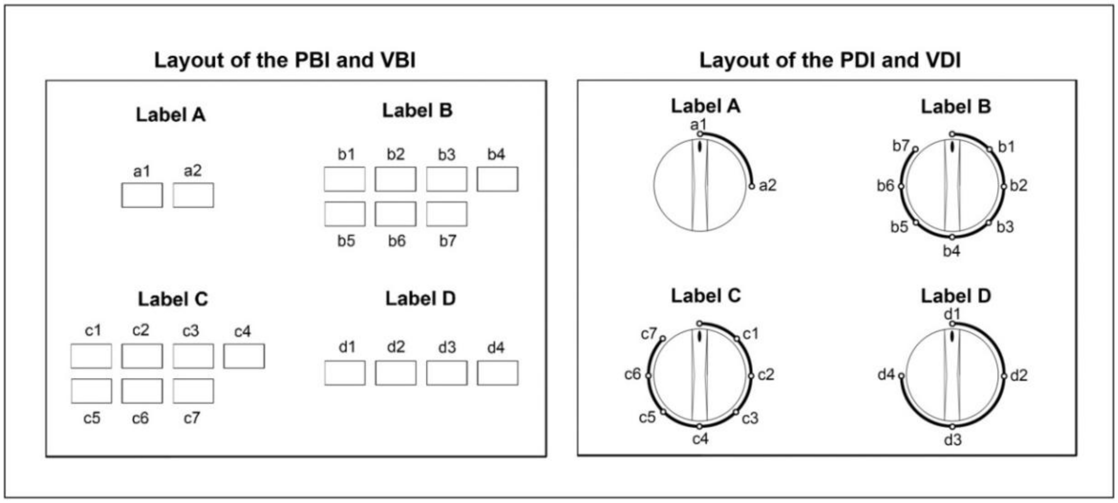

Figure 5.1. Layout of the Four Interface Types. Note: (1) Left: PBI and VBI; Right: PDI and VDI. (2) This picture only showed the locations of the labels and the settings, but not the contents of the labels or the settings. (For example, "Label A" showed "Power On/Off", "a1" showed "On", and "a2" showed "Off" on the interface prototypes.)

The two button-based interfaces (PBI and VBI) also shared the same method of operation which was to press the button. The two dial-based interfaces (PDI and VDI) also shared the same method of operation, which was to rotate the dial. The visualized dial was rotated by placing a finger near the pointing indicator of the dial and sliding the finger to the target setting in a circular motion (clockwise) on a touch screen device. This was similar to a touch-and-drag motion completed in a circular path.

Prototypes of PBI, PDI, VBI, and VDI varied only in the interaction technique. Prototypes of all four interface types were exactly the same in terms of interaction structure; size; background color; button and dial color; text color, font and size; and number of functions and settings.

The interaction structure of all prototypes was 1:1 mapping between control and function and single-layered operation. The size of the prototype screen was the same as a first-generation iPad (Apple Inc., 7.76 in x 5.82 in). The color of the background was blue, the color of the buttons and dials was white, and the color of the text was white. There were 4 main functions and 20 total settings. As shown in Figure 5.1, all prototypes had 4 main functions (Label A, Label B, Label C, and Label D). There were 2 settings for Function A (a1, a2), 7 settings for Function B (b1, b2, …, b7), 7 settings for Function C (c1, c2, …, c7), and 4 settings for Function D (d1, d2, …, d4).

Prototypes of the PBI and the PDI were composed of three-dimensional physical dials or physical buttons securely located (soldered) on the top of printed circuit boards (with text labels). Transparent plastic boards were securely located under the printed circuit boards to provide smooth and sturdy bottom surfaces for participants.

Prototypes of the VBI and the VDI were composed of two-dimensional visualized buttons or dials on a first-generation iPad and were programmed with Xcode in iPad developer software as software applications.

Because every participant was exposed to all four interface types, participants likely performed better with the interface types encountered later in the experiment, because they may have remembered the text labels and locations from prior exposures. To avoid the ordering effect and to provide an insight into the effects of interaction styles on technology acceptance, four different prototypes were made for each interface type to represent four new technologies. The only difference among the four prototypes of the same interface type was the text labels (functions and settings modified in the context of the particular new technology).

Four new technologies were selected based on the following criteria:

- Both younger and older adults would be motivated to participate and use them.
- The technologies were relatively new and had not been widely used as yet.
- The technologies did not have many functions.
- The technologies had interactive user interfaces.
- The technologies were normally used in a home context, not for professional use at work.
- The technologies were intended to be used with little or no instruction or assistance.
- The technologies selected were comparable in terms of functionality, complexity, and product category.

Hawthorn (2007) suggested that a test product should be perceived as relevant to motivate the participants to engage in the experiment. The four new technologies selected for this experiment all belonged to the product category of health and personal care. The four technologies included a sound conditioner, a personal biofeedback device, an herbal vaporizer, and an air humidifier and freshener.

For all new technologies, only the user interfaces (elements of a product used to control it and receive information) were prototyped; the functions were not prototyped. Hence, there were no actual stimuli produced as a result of interactions with the user interface prototypes in this experiment.

In total, 16 prototypes (4 interface types x 4 new technologies = 16 prototypes) were made for this experiment. Pictures of the sixteen prototypes are shown in Figure 5.2, Figure 5.3, Figure 5.4, and Figure 5.5.

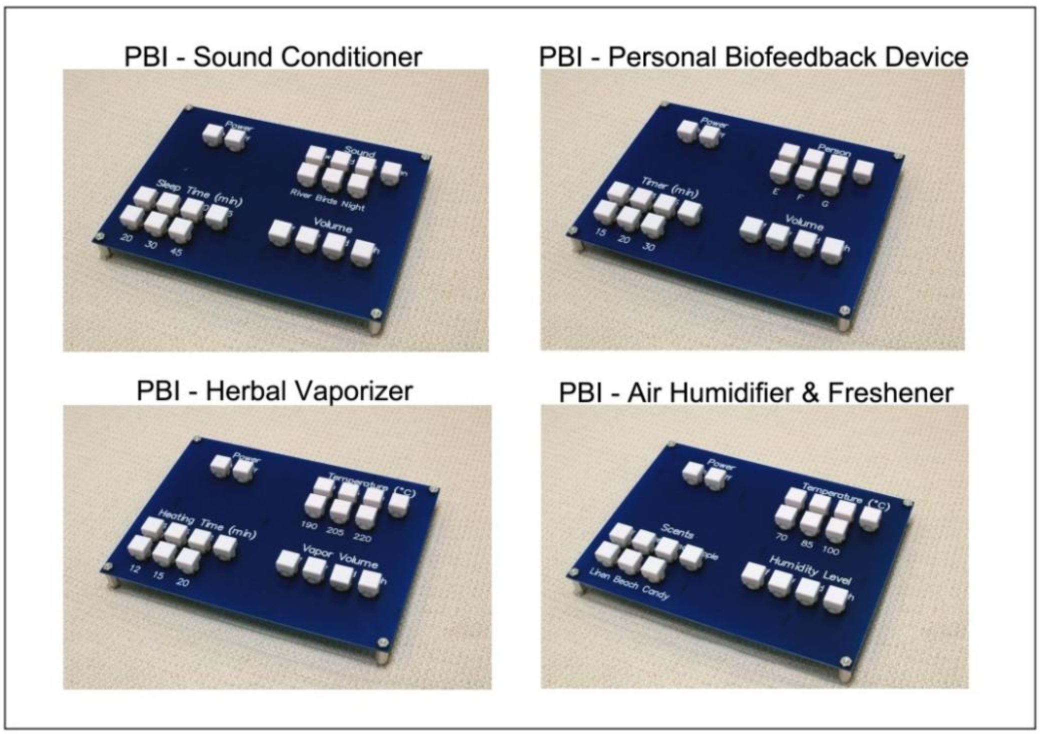

Figure 5.2. Four Prototypes of the Physical Button Interface (PBI).

Figure 5.3. Four Prototypes of the Physical Dial Interface (PDI).

Figure 5.4. Four Prototypes of the Visualized Button Interface (VBI).

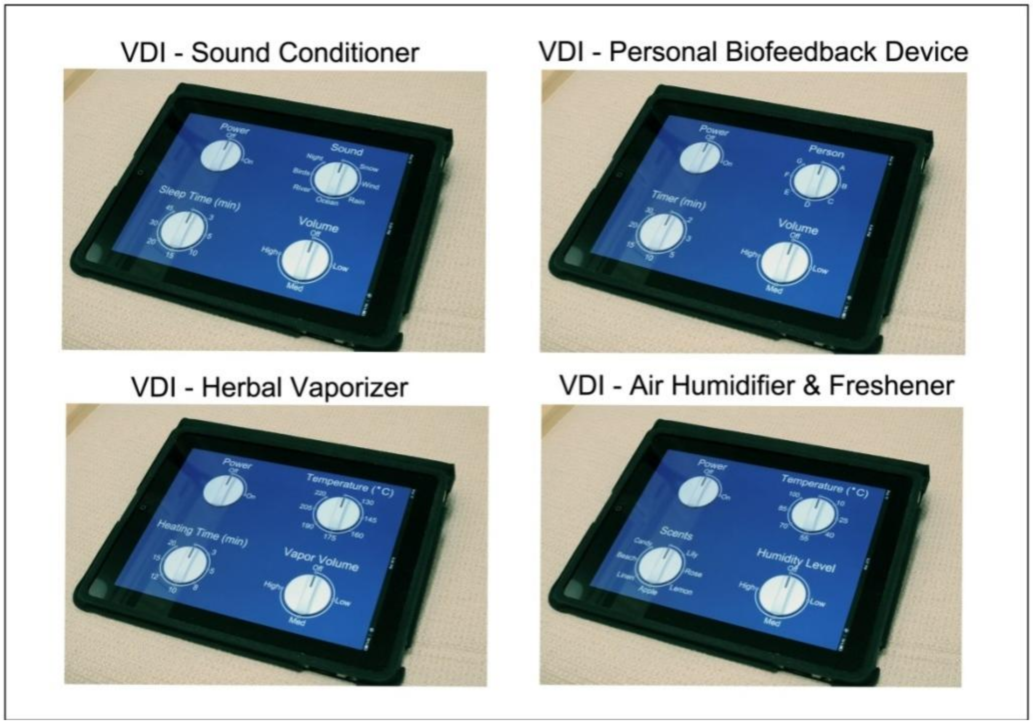

Figure 5.5. Four Prototypes of the Visualized Dial Interface (VDI).

Recording and computing devices. Task completion time was recorded by a stop watch (1/100 second precision). The reaction time test was performed on a 13-in Apple MacBook Pro laptop with a mouse. The laptop accessed the Internet through the North Carolina State University high-speed broad band connection. The system was configured with Firefox 10.0.1. The pre-recorded audio of the word lists for the alphabet span test as well as the presentation slides of the experiment introduction and the task instructions were also played on the laptop. The word lists were played by Windows Media Player and the presentation slides were played by PowerPoint 2010.

Experiment introduction and task instructions. The researcher introduced the experiment to the participant using a written script coupled with a presentation slide. The written script and the presentation slides were used to ensure that the experiment introductions were consistent among participants.

Task instructions were shown as presentation slides. The task instructions were shown in black text (54 point, Arial) on a white background. The researcher controlled the playing of the slides by using a mouse.

For each task, there were five subtasks representing a series of typical interactions with the new technologies, including turning on the device, selecting several settings, and turning off the device. Each subtask was shown as an individual slide. This separation of subtasks allowed the researcher to control the start of each subtask. Asking participants to perform subtasks individually rather than performing five subtasks in a row reduced participants' memory loads, especially for the older group.

Ability tests. Three ability tests were administered to each participant (see Table 5.6). The tests were chosen to indentify reaction time, processing speed, and working memory. The Reaction Time Test was used to measure reaction time (Human Benchmark, 2012), the Digit Symbol Substitution (Wechsler, 1981) was used to measure processing speed, and the Alphabet Span (Craik, 1986) was used to measure working memory. These measurements have been widely used in the literature and have demonstrated reliability and validity. An ability score was computed for each participant by taking into account his or her performance (test scores) on all three ability tests.

Table 5.6.
Description of Ability Tests (Exp 1)

Test	**Ability**	**Description**
Reaction Time (Human Benchmark, 2012)	Reaction Time	Computer-based test. The participant is required to click the mouse as quickly as s/he can when a stimulus appears in the center of the computer screen.
Digit Symbol Substitution (Weschsler, 1981)	Processing speed	Paper and pencil test. The participant is presented with a series of rows that pairs each digit (from 1 to 9) with a nonsense symbol, and is then required to fill in symbols below rows of digits.
Alphabet Span (Craik, 1986)	Working memory	Paper and pencil test. The participant listens to a series of words, and is then required to write down the words in alphabetical order.

Note: For administrating the test of alphabet span, the series of words was pre-recorded and played to the participant rather than read to. The audio recording could ensure consistency of speaking speed and clarity among participants.

Technology experience questionnaire. A reduced version of the Computer and Technology Experience Questionnaire developed by Czaja et al. (2006b) was used to assess participants' technology experience. The original questionnaire included questions regarding usage of technologies, computers, and the Internet. However, based on the focus and goal of this research, this experiment only used the questions regarding participants' technology familiarity and experiences, which covered usage of technology in a wide range of activities, including communication, shopping, financial transactions, healthcare-related activities, transportation, entertainment, education, home-based activities, and work. The technology experience questionnaire used this study is presented in Appendix A.

Demographic information questionnaire. A demographic questionnaire (modified from Czaja et al., 2006c) was used to get information about the participant's age, gender, hand dominance, education level, nationality, occupation, health condition, health condition compared to other people of the same age, and overall personal state (before and after the session). The demographic information questionnaire is presented in Appendix B.

Workload questionnaire. The NASA-RTLX inventory was used to measure the participant's workload of interacting with the interface types. Six aspects of workload were assessed on a 10-point scale, including mental workload, physical workload, temporal workload, effort, frustration, and success. An overall workload was computed by taking into account all six aspects of workload. The workload questionnaire is presented in Appendix C.

Satisfaction questionnaire. A satisfaction questionnaire (ISO 28202-1 (E), 2006) was used to measure the participant's satisfaction with his or her interaction with different interface types. Satisfaction was measured with a pictorial smiley scale (five faces). The satisfaction questionnaire is presented in Appendix D.

Technology acceptance questionnaire. A technology acceptance questionnaire (modified from Davis, 1989) was used to measure the participants' different attitudes toward the new technologies (different interface types). Behavioral Intention (BI), Perceived Usefulness (PU), and Perceived Ease of Use (PEOU) were assessed with a 7-point Likert scale. The technology acceptance questionnaire is presented in Appendix E.

Preference questionnaire. A preference questionnaire was used to measure participants' preferences among the four different interface types. Participants were first asked to rank personal preferences among the four interface types from the most preferred to the least preferred, and also to explain why a certain interface type was the most preferred or least preferred. Then participants were also asked to select the interface type that they believed their friends would like the most. The researcher specified that friends should be of similar ages and have average education levels, health condition levels, and technology experience levels. The reason for asking such a question was to shed light on the preferences of average younger adults and average older adults. The preference questionnaire is presented in Appendix F.

Structured interview script. A structured interview was conducted to ascertain the reasons for each participant's different ratings of perceived ease of use and satisfaction for the interface types. The structured interview also aimed to find out older adults' perceptions of the relative weights of the two factors attributable to their difficulties with using the new interfaces (aging factor vs. generation factor).

During the structured interview, participants in both the younger and older groups were asked to explain their ratings for perceived ease of use and satisfaction. They were asked why particular user interface types were perceived as easier to use than other types, and why they were more satisfied with a particular user interface type or types.

Participants in the older group were asked additional questions regarding their difficulties in using the interface types (interaction techniques) in the task. They were first asked to select the interface type they found most difficult to use. If they found the newer user interface type (VBI or VDI) difficult to use, they were then asked to provide their opinions on the relative weights of the two factors attributable to their difficulties, the aging factor vs. the generation factor (by assigning 100 points). The aging factor described the difficulties in using the VBI or the VDI that resulted from the aging-related declines in the abilities that were closely associated with interactions with the interfaces. The generation-related factor described the difficulties in using the VBI or the VDI that resulted from incompatibility with their early experiences (being different from the interface type that they grew up with).

Before assigning the relative weights of the two factors, older participants were asked some priming questions to prepare and guide them to have detailed thoughts on both factors before they made their decisions.

Older participants were asked to recall their early experiences with interaction techniques on consumer products, to compare the interaction techniques they grew up with to the newer interaction techniques they found difficult in the experiment, and to elaborate on how they believed the difference affected their interactions with the new interface types they found difficult in this experiment.

They were also asked to discuss the aging-related ability changes (declines) they had experienced that were closely associated with their interaction with the interfaces, and to elaborate on how they believed the ability changes affected their interactions with the new interface types they found difficult in this experiment.

Then they were asked to assign 100 points between the two factors (the aging factor and the generation factor), giving the factor they perceived as playing a greater role more points than they gave the other factor.

The structured interview was audio-recorded by permissions of the participants. Notes were taken on site by the researcher. The audio recording was used as backup to verify answers. The scripts of the structured interview are presented in Appendix G.

Tasks. Each participant was asked to perform four tasks, and each task was performed with a different new technology device. Task 1 was performed with the sound conditioner. Task 2 was performed with the personal biofeedback device. Task 3 was performed with the herbal vaporizer. Task 4 was performed with the air humidifier and freshener. There were five sub tasks within each task. For each task, there were two trials. When a task was applied for the second time, a slightly modified version was used (e.g., if the participant had to set the sound to “wind” in the first trial, it had to set the sound to “bird” in the second trial). The tasks involved searching the label or setting and then activating the control. The task instructions are shown in Table 5.7.

Table 5.7.
Task Instructions (Exp 1)

Task	Technology	Trial 1 (Subtask)	Trial 2 (Subtask)
1	Sound Conditioner	1. Turn On the Device. 2. Set the Sound to Wind. 3. Set the Sleep Time to 20 Minutes. 4. Set the Sound Volume to Low. 5. Turn Off the Device.	1. Turn On the Device. 2. Set the Sound to Bird. 3. Set the Sleep Time to 5 Minutes. 4. Set the Sound Volume to High. 5. Turn Off the Device.
2	Personal Biofeedback Device	1. Turn On the Device. 2. Set the Person to E. 3. Set the Timer to 5 Minutes. 4. Set the Sound Volume to Medium. 5. Turn Off the Device.	1. Turn On the Device. 2. Set the Person to B. 3. Set the Timer to 10 Minutes. 4. Set the Sound Volume to Medium. 5. Turn Off the Device.
3	Herbal Vaporizer	1. Turn On the Device. 2. Set the Temperature to 160^{o}. 3. Set the Heating Time to 15 Minutes. 4. Set the Vapor Volume to High. 5. Turn Off the Device.	1. Turn On the Device. 2. Set the Temperature to 175^{o}. 3. Set the Heating Time to 3 Minutes. 4. Set the Vapor Volume to Low. 5. Turn Off the Device.
4	Air Humidifier and Freshener	1. Turn On the Device. 2. Set the Temperature to 85^{o}. 3. Set the Scent to Apple. 4. Set the Humidity Level to Medium. 5. Turn Off the Device.	1. Turn On the Device. 2. Set the Temperature to 10^{o}. 3. Set the Scent to Lemon. 4. Set the Humidity Level to Medium. 5. Turn Off the Device.

The emphasis of the task was on accuracy. Participants were told that the goal was to perform the tasks correctly. They were told they should try to perform the tasks as accurately as they could (as opposed to as fast as they could), and the time taken to complete the tasks successfully would be measured. The reason for instructing participants to emphasize accuracy was to ensure a same interaction strategy for the two age groups to avoid a situation in which some participants employed an interaction strategy emphasizing accuracy while other participants emphasized speed.

Procedure. The research took place in the Research in Ergonomics and Design Lab (RED Lab) at North Carolina State University (NCSU). The whole experiment was scripted to ensure consistency among participants.

The participants were first welcomed to the lab and were provided with a brief overview of the study and reminded of the exclusion criteria (participants with severe physical or cognitive impairments were excluded from participation). These exclusion criteria were based on casual general discussions with the participants. Participants then were given a copy of the consent form to read and the researcher answered any questions. Participants were told before the session that they could ask the researcher to rest any time during the study as needed. They were also informed that they could stop the experiment at any time and request all the audio recordings of the interview be deleted without any penalty.

After signing the consent form, participants were asked to complete a demographic information questionnaire. Then participants each completed three ability tests (reaction time, processing speed, and working memory). Before the tests, participants were told that the tests were designed to be difficult, so that no one could achieve 100%, and they should just give their best efforts and not feel bad if they could not achieve 100%. They were told their efforts to continue trying were highly appreciated. Participants were told that the result of their ability assessments would not be analyzed or compared individually, but the result would instead be looked at as groups. Participants were allowed to rest for at least 3 minutes after taking the three ability tests.

After the rest period, participants performed tasks on prototypes of the four interface types. Each participant performed four tasks. For each task, there were five subtasks and two trials.

Each task was performed on a new technology. Task 1 was performed on the sound conditioner. Task 2 was performed on the personal biofeedback. Task 3 was performed on the herbal vaporizer. Task 4 was performed on the air humidifier and freshener. In addition, participants were presented with a different interface type for each new technology. The order of presentations of the interface types was counterbalanced among the 28 participants within each age group. All prototypes were reset and wiped clean before being presented to the next participant.

Participants were allowed to practice with the interaction techniques (practice versions), until they felt comfortable using them. Participants were told that the goal of the task was to perform the task correctly. The time taken to successfully perform the task was recorded by the researcher. For the two dial-based interfaces (PDI and VDI), because there was not a “notch,” a pointer location of $\pm 10°$ of the target setting was considered as correct (Figure 5.6).

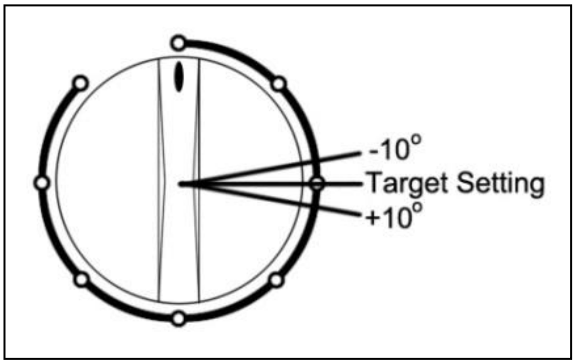

Figure 5.6. Range of Correct Setting of the Two Dial-based Interfaces (PDI and VDI). Note: Plus or minus 10 degree of the target setting was acceptable.

After the two trials of each task were completed, each participant was asked to fill out a workload questionnaire (Appendix C), a satisfaction questionnaire (Appendix D), and a technology acceptance questionnaire (Appendix E). After all four tasks were completed, each participant was asked to fill out a preference questionnaire (Appendix F). Participants were allowed to rest for at least 2 minutes after each task and filling out the questionnaires regarding the task.

After the rest period, the researcher then conducted a structured interview to allow participants to elaborate on their ratings for perceived ease of use and satisfaction with the interface types, and also to find out how older adults perceived the relative weights of the two factors attributable to their difficulties with using the new interfaces. The interview was audio-recorded with permission of the participants. Notes were also taken on site by the researcher. Each participant was allowed to rest for at least 3 minutes after the structured interview.

After the rest period, each participant was asked to fill out a technology experience questionnaire (Appendix A).

The whole experiment took approximately 1.5 hours for younger adults and approximately 2 hours for older adults.

Measurements. Primary measurements of the two experiments were usability and acceptance. Also measured were demographic information, abilities, technology experiences, preferences, and older adults' perceived relative weights of the two factors attributable to their interaction difficulties (aging factor vs. generation factor). The measurements of this experiment are shown in Table 5.8.

Table 5.8.
Measurements and Tools (Exp 1)

Measurements	Tools
Demographic Information	Demographic Questionnaire (modified from Czaja et al., 2006c)
Ability	
Reaction Time	Simple Reaction Time Test (Human Benchmark, 2012)
Processing Speed	Digit Symbol Substitution (Weschsler, 1981)
Working Memory	Alphabet Span (Craik, 1986)
Technology Experience	Technology Experience Questionnaire (Czaja et al., 2006b)
Usability	
Task Completion Time	Stop watch
Workload	Workload Questionnaire (NASA-RTLX)
Satisfaction	Satisfaction Questionnaire (ISO 28202-1 (E), 2006)
Technology Acceptance	
Behavioral Intention	Technology Acceptance Questionnaire (modified from Davis, 1989)
Perceived Usefulness	Technology Acceptance Questionnaire (modified from Davis, 1989)
Perceived Ease of Use	Technology Acceptance Questionnaire (modified from Davis, 1989)
Preference	
Personal Preference	Preference Questionnaire
Friend's Preference	Preference Questionnaire
Aging Factor vs. Generation Factor	Structured Interview

Usability was measured according to ISO 9241-11 (ISO, 1998). However, only the efficiency (task completion time and workload) and the satisfaction were measured. Effectiveness was not measured because the time taken to complete the tasks successfully was measured. The reason for controlling the accuracy was to ensure that all participants from the two groups used the same interaction strategy. Older adults have often been reported to exploit a slow but error-free style, while younger adults were reported to exploit a fast style with more errors (trial-and-error) (Docampo Rama, 2001; Wilkinson et al., 2010). Hence, this experiment required all participants to use the same interaction strategy.

Results

Usability. Usability was measured by task completion time (efficiency), workload (efficiency), and satisfaction.

Task completion time. A 4 (interface type) x 2 (age group) x 2 (trial) ANOVA mixed repeated measures test was carried out with the log-transformed task completion time as the dependent variable.

There were five sub tasks within each task and the time to complete each subtask was recorded separately. Task completion time was the sum of completion time of all five subtasks. The original task completion time data was then log-transformed to meet the assumptions of ANOVA.

As shown in Table 5.9, trial was the main effect on task completion time ($F(1, 54) = 78.93$, $p < 0.0001$). There was also a significant interaction between age group and interface type ($F(3, 162) = 5.82$, $p = 0.0008$).

Table 5.9.
Mixed ANOVA (Task Completion Time-Exp 1)

Effect	Num DF	Den DF	F Value	P Value
Age Group	1	54	46.96	<0.0001***
Interface Type	3	162	232.2	<0.0001***
Trial	1	54	78.93	<0.0001***
Age Group x Interface Type	3	162	5.82	0.0008***
Age Group x Trial	1	54	0.09	0.7642
Interface Type x Trial	3	162	0.69	0.5591
Age Group x Interface Type x Trial	3	162	0.68	-0.5661

Note: *p<0.1, **p<0.05, ***p<0.001.

Main effect of trial. As shown in Figure 5.7, tasks in all interface types were performed significantly faster during the second time (trial 2) than during the first time (trial 1).

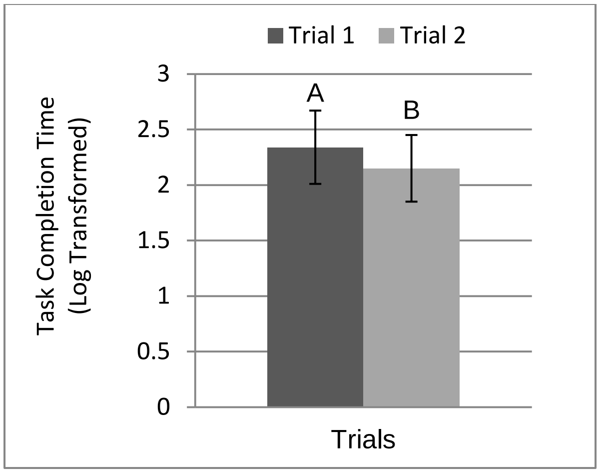

Figure 5.7. Task Completion Time (Log-Transformed) for Two Trials. Note: Means with same letter were not significantly different. Bars represent standard deviation.

Interaction between age group and interface type. The interaction between age group and interface type is shown in Figure 5.8.

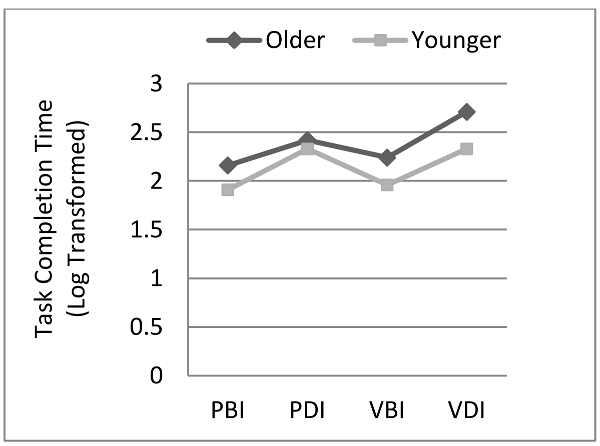

Figure 5.8. Interaction of Age Group and Interface Type.

A test of simple main effects was conducted looking at age-group differences in task completion time at each level of interface type. With a Bonferroni correction, the results showed that there was a significant age group difference for each interface type. As shown in Figure 5.8 and Figure 5.9, the age-group difference in task completion time was the least pronounced in the Physical Dial Interface (PDI) and the most pronounced in the Visualized Dial Interface (VDI).

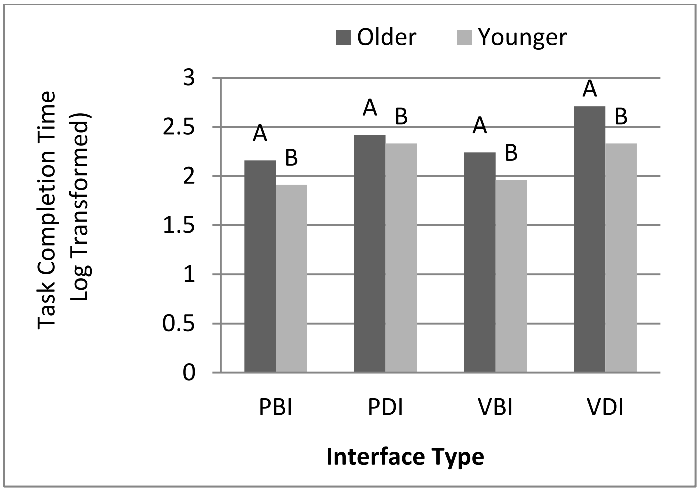

Figure 5.9. Simple Main Effect of Age Group at Each Level of Interface Type. Note: Means with same letter were not significantly different.

Another test of simple main effects was conducted looking at interface differences in task completion time at each level of age group. With a Bonferroni correction, the results showed that task completion time was significantly different among the four interface types for the older group and the younger group. Tukey's HSD test was carried out to determine which conditions were significantly different for each age group. Results of the Tukey's HSD test ($p < 0.05$) showed the same pattern for the two age groups. Task completion time of the VDI was significantly longer than that of the others. Task completion time of the PBI and the VBI was significantly shorter than that of the others. Task completion time of the PBI and the VBI was not significantly different from one another (Figure 5.10).

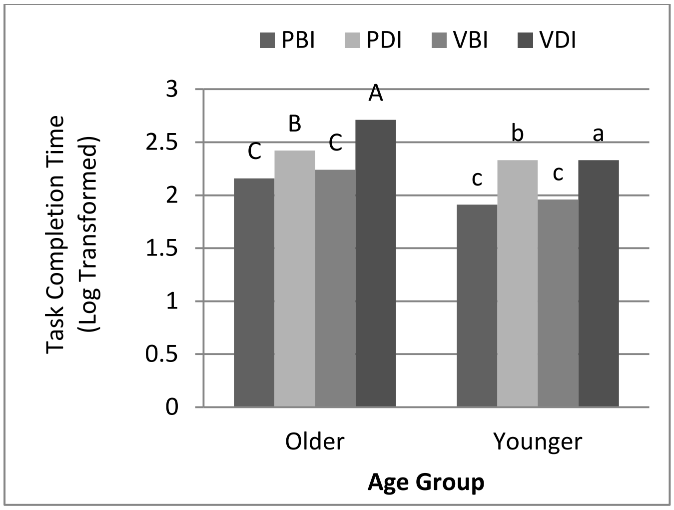

Figure 5.10. Simple Main Effect of Interface Type at Each Level of Age Group. Note: Means with same letter were not significantly different.

Workload. Table 5.10 shows older adults' self-reported workload of their interactions with the four interface types, and Table 5.11 shows younger adults' self-reported workload. Six aspects were assessed in the workload questionnaire, including mental workload, physical workload, temporal workload, effort, frustration, and success. An overall workload was calculated, taking into account all six aspects.

Table 5.10.
Self-Reported Workload of the Four Interface Types (Older Adults)

	Older Adults (n=28) Mean (Std Dev)			
	PBI	PDI	VBI	VDI
Overall Workload	1.95 (0.86)	2.08 (0.94)	1.8 (0.82)	2.23 (1.29)
Mental Workload	2.57 (1.48)	2.64 (1.52)	2.57 (1.55)	3.29 (2.05)
Physical Workload	2.25 (1.24)	2.82 (1.39)	1.93 (1.16)	2.64 (2.09)
Temporal Workload	2.68 (1.77)	2.54 (1.77)	2.32 (1.63)	2.57 (1.87)
Effort	2.11 (0.99)	2.11 (1.03)	1.89 (1.17)	2.46 ((1.57)
Frustration	1.61 (1.26)	1.64 (1.03)	1.61 (1.4)	1.71 (1.01)
Success	9.54 (0.79)	9.29 (1.15)	9.5 (0.64)	9.32 (1.02)

Table 5.11.
Self-Reported Workload of the Four Interface Types (Younger Adults)

	Younger Adults (n=28) Mean (Std Dev)			
	PBI	PDI	VBI	VDI
Overall Workload	2.44 (1.11)	2.72 (1.26)	1.92 (0.95)	2.53 (1.11)
Mental Workload	3.75 (2.17)	3.75 (2.12)	3.11 (1.85)	3.75 (1.88)
Physical Workload	2.5 (1.56)	3.14 (1.65)	1.5 (0.92)	2.36 (1.22)
Temporal Workload	3.29 (2.32)	3.68 (2.42)	2.79 (2.18)	3.39 (2.2)
Effort	2.46 (1.45)	2.89 (1.87)	1.96 (1.17)	2.57 (1.6)
Frustration	1.93 (1.68)	1.79 (1.2)	1.54 (0.74)	2.07 (1.61)
Success	9.29 (0.98)	8.93 (1.18)	9.36 (1.22)	8.96 (1.26)

Overall workload. A Friedman's test was carried out to assess whether the overall workload was significantly different among the four interface types for each age group. Results showed that overall workload was significantly different among the four interface types for the older group ($\chi^2(3) = 9.62$, $p = 0.022$) and for the younger group ($\chi^2(3) = 23.94$, $p < 0.0001$).

Pairwise comparisons with Bonferroni correction were performed to determine which conditions were significantly different (with a critical alpha level at 0.05/6 = 0.0083). Results showed different patterns for the two age groups. For the older group, overall workload was significantly different between the VBI and the VDI ($p = 0.0078$). For the younger group, overall workload was significantly different between the VBI and the PBI ($p = 0.0008$), the VBI and the PDI ($p = 0.0003$), and the VBI and the VDI ($p = 0.0045$). Figure 5.11 shows the results of overall workload for both groups.

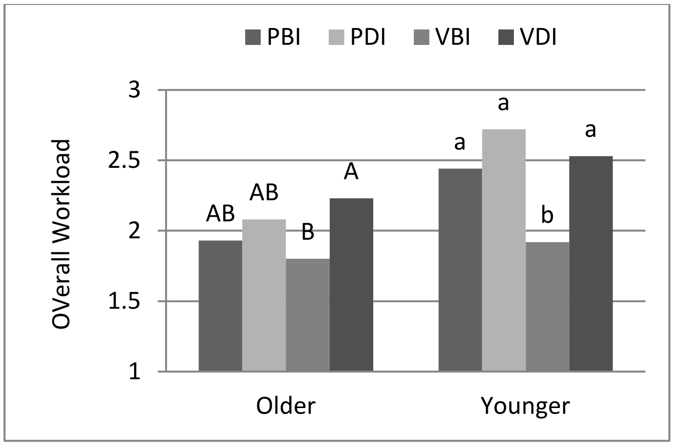

Figure 5.11. Overall Workload for the Four Interface Types. Note: Means with same letter were not significantly different.

Friedman's tests were carried out to assess whether the mental workload, physical workload, temporal workload, effort, frustration, and success were significantly different among the four interface types for each age group. Pairwise comparisons with Bonferroni correction were then performed to determine which conditions were significantly different (with a critical alpha level at 0.05/6 = 0.0083).

Mental workload. Results of the Friedman's tests showed that mental workload was significantly different among the four interface types for the older group (χ^2 (3) = 10.98, p = 0.012) and for the younger group (χ^2 (3) = 10.44, p = 0.016). However, results of the pairwise comparisons showed different patterns for the two age groups. For the older group, mental workload was significantly different between the VBI and the VDI (p = 0.006). For the younger group, mental workload was significantly different between the PBI and the VBI (p = 0.013). Figure 5.12 shows the results of mental workload for both groups.

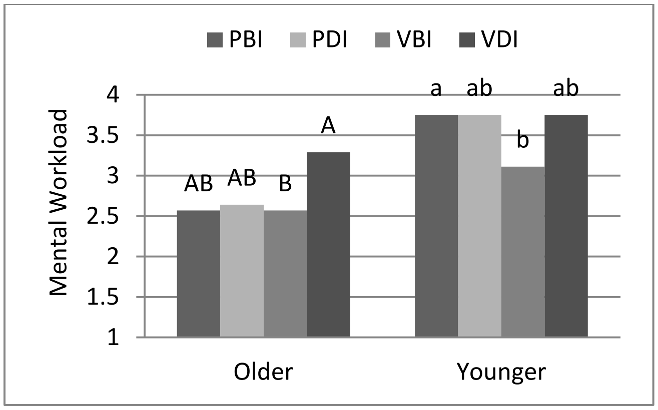

Figure 5.12. Mental Workload for the Four Interface Types. Note: Means with same letter were not significantly different.

Physical workload. Results of the Friedman's tests showed that physical workload was significantly different among the four interface types for the older group (χ^2 (3) = 14.93, p = 0.002) and for the younger group (χ^2 (3) = 34.55, p < 0.0001). However, results of the pairwise comparisons showed different patterns for the two age groups. For the older group, physical workload was significantly different between the PDI and the VBI (p = 0.001), and between the VBI and the VDI (p = 0.0068). For the younger group, physical workload was significantly different between the PBI and the PDI (p = 0.0058), the PBI and the VBI (p < 0.0001), the PDI and the VBI (p < 0.0001), the PDI and the VDI (p = 0.0019), and the VBI and the VDI (p = 0.0005). Figure 5.13 shows the results of physical workload for both groups.

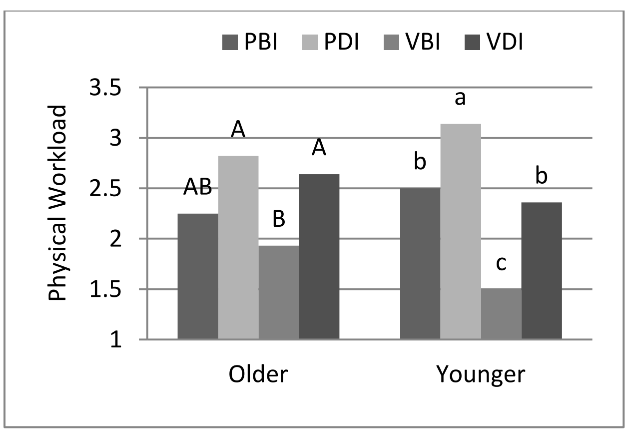

Figure 5.13. Physical Workload for the Four Interface Types. Note: Means with same letter were not significantly different.

Temporal workload. Results of the Friedman's tests showed that temporal workload was significantly different among the four interface types for the younger group (χ^2 (3) = 14.4, p = 0.0002), but no significant difference was found for the older group. For the younger group, results of the pairwise comparisons showed that temporal workload was significantly different between the PDI and the VBI (p = 0.0015). Figure 5.14 shows the results of temporal workload for the younger group.

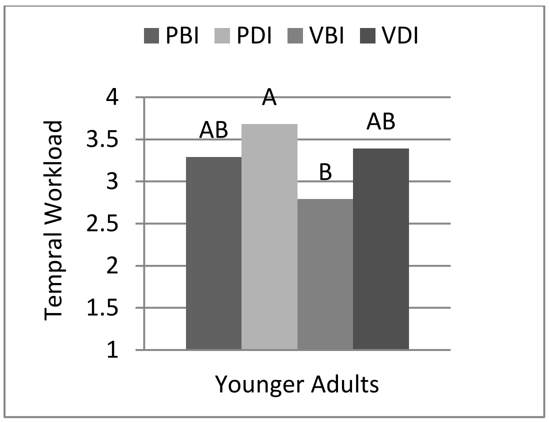

Figure 5.14. Temporal Workload for the Four Interface Types. Note: Means with same letter were not significantly different.

Effort. Results of the Friedman's tests showed effort was significantly different among the four interface types for the older group (χ^2 (3) = 7.43, p = 0.05) and the younger group (χ^2 (3) = 14.31, p = 0.003). However, results of the pairwise comparisons showed different patterns for the two age groups. For the older group, effort was significantly different between the VBI and the VDI (p = 0.0056). For the younger group, effort was significantly different between the PDI and the VBI (p = 0.0021). Figure 5.15 shows the results of effort for both groups.

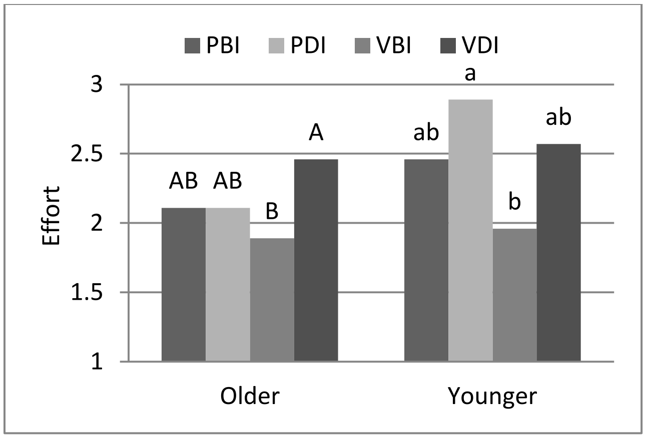

Figure 5.15. Effort for the Four Interface Types. Note: Means with same letter were not significantly different.

Frustration. Results of the Friedman's tests showed frustration was not significantly different among the four interface types for either group.

Success. Results of the Friedman's test showed success was significantly different among the four interface types for the younger group (χ^2 (3) = 13.07, p = 0.005), but no significant difference was found for the older group. For the younger group, results of the pairwise comparison showed that success was significantly different between the PBI and the PDI (p = 0.0039). Figure 5.16 shows the results of success for the younger group.

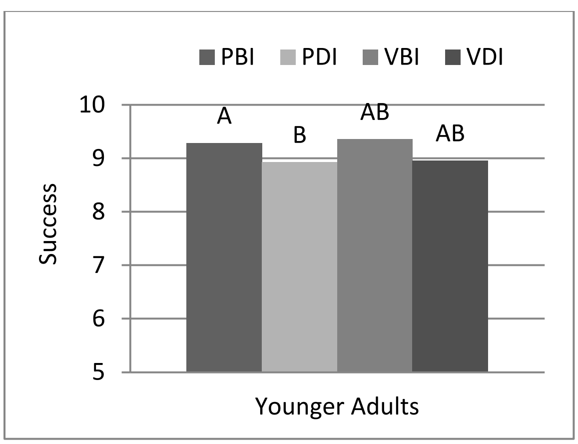

Figure 5.16. Success for the Four Interface Types. Note: Means with same letter were not significantly different.

Satisfaction. Table 5.12 shows participants' self-reported satisfaction with their interaction with the four interface types for both age groups.

Table 5.12.
Satisfaction of the Four Interface Types

	Mean (Std Dev)			
	PBI	PDI	VBI	VDI
Older Adults (n=28)	1.18 (0.77)	1 (0.72)	1.68 (0.61)	1.14 (0.85)
Younger Adults (n=28)	1.31 (0.83)	1 (0.82)	1.18 (1.06)	1 (0.82)

A Friedman's test was carried out to assess whether the satisfaction was significant different among the four interface types for each age group. Results showed that satisfaction was significantly different among the four interface types for the older group ($\chi^2(3) = 14.84$, $p = 0.002$), but no significant difference was found for the younger group.

Pairwise comparisons with Bonferroni correction were performed to determine which conditions were significantly different (with a critical alpha level at 0.05/6 = 0.0083). For the older group, pairwise comparison showed that satisfaction was significantly different between the PBI and the VBI ($p = 0.0092$), the PDI and the VBI ($p = 0.0004$), and the VBI and the VDI ($p = 0.0015$). Figure 5.17 shows results of satisfaction for the older group.

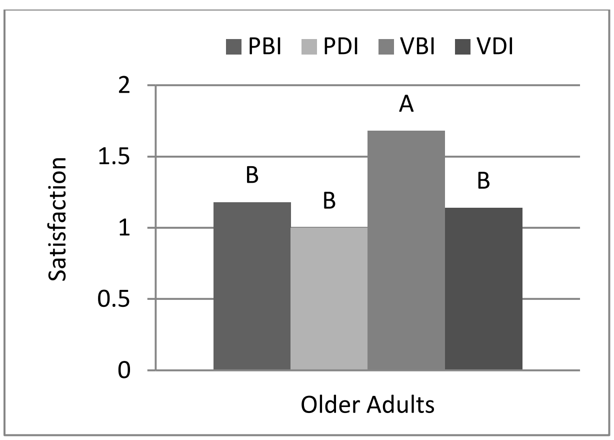

Figure 5.17. Satisfaction for the Four Interface Types. Note: Means with same letter were not significantly different.

Technology acceptance. As the Technology Acceptance Model suggested, technology acceptance is determined by users' behavioral intention (BI) to use the technology and the BI is influenced by users' perceived usefulness (PU) and perceived ease of use (PEOU) of the technology. In this study, BI, PU, and PEOU were measured. Cronbach's alpha was computed for each scale to ascertain internal consistency among the items. The results of the Cronbach's alpha are shown in Table 5.13.

Table 5.13.
Scale Reliability (Cronbach's Alpha)-Exp 1

Scale	Number of Items	Reliability
Behavioral Intention (BI)	2	0.91
Perceived Usefulness (PU)	4	0.97
Perceived Ease of Use (PEOU)	5	0.94

Behavioral intention. Table 5.14 showed participants' self-reported behavioral intention (BI) toward the four interface types for both age groups.

Table 5.14.
Behavior Intention toward the Four Interface Types

	Mean (Std Dev)			
	PBI	PDI	VBI	VDI
Older Adults (n=28)	3.2 (1.86)	3.18 (1.79)	4.05 (2.11)	3.93 (2.2)
Younger Adults (n=28)	4.48 (1.79)	4.25 (1.55)	4.25 (1.73)	4.93 (1.66)

Note: Behavioral Intention (BI) was measured on 7-point Likert scales.

A Friedman's test was carried out to assess whether BI was significantly different among the four interface types for each age group. Results showed that there was marginally significant difference among the four interface types for the older group (χ^2 (3) = 6.78, p = 0.079), but no significant difference was found for the younger group.

Pairwise comparisons with Bonferroni correction were performed to determine which conditions were significantly different (with a critical alpha level at 0.05/6 = 0.0083). Results of the pairwise comparison showed that for the older group, there was marginally significant difference between the PBI and the VBI (p = 0.02), and between the PDI and the VBI (p = 0.02). Figure 5.18 shows the results of Behavioral Intention (BI) for the older group.

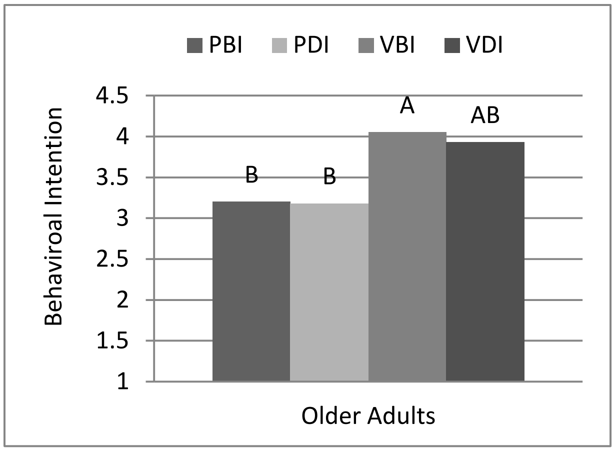

Figure 5.18. Behavioral Intention (BI) for the Four Interface Types. Note: Means with same letter were not significantly different. Score "4," Neutral Attitude; Less than "4" Negative Attitude.

One sample Wilcoxon Signed Rank test was also performed to assess whether the median of Behavioral Intention (BI) of each interface type differed significantly from 4 (a score of 4 meant a neutral attitude on the 7-point Likert scale) for the older group. Results showed that for the older group, BI was significantly different from 4 for the PBI ($S = -64.5$, $p = 0.0304$) and the PDI ($S = -66$, $p = 0.0165$). But there was not enough evidence to reject the null hypotheses for the VBI and the VDI. Hence, results revealed that older adults had significantly negative attitudes toward the PBI and the PDI (median of BI was significantly lower than 4), and they had neutral attitudes toward the VBI and the VDI (median of BI was not significantly different from 4).

Perceived usefulness. Table 5.15 shows participants' self-reported perceived usefulness (PU) of the four interface types for both age groups.

Table 5.15.
Perceived Usefulness of the Four Interface Types

	Mean (Std Dev)			
	PBI	PDI	VBI	VDI
Older Adults (n=28)	3.53 (1.73)	3.8 (1.58)	4.29 (1.94)	4 (2.03)
Younger Adults (n=28)	4.46 (1.24)	4.29 (1.35)	4.29 (1.18)	4.7 (1.12)

Note: Perceived Usefulness (PU) was measured on 7-point Likert scales.

A Friedman's test was carried out to assess whether PU was significantly different among the four interface types for each age group. Results of the Friedman's tests showed PU was not significantly different among the four interface types for either group.

Perceived ease of use. Table 5.16 shows participants' self-reported perceived ease of use (PEOU) of the four interface types for both age groups.

Table 5.16.
Perceived Ease of Use of the Four Interface Types

	Mean (Std Dev)			
	PBI	PDI	VBI	VDI
Older Adults (n=28)	6.57 (0.55)	6.52 (0.67)	6.74 (0.43)	6.52 (0.62)
Younger Adults (n=28)	6.39 (0.88)	6.45 (0.63)	6.29 (1.25)	6.48 (0.62)

Note: Perceived Ease of Use (PEOU) was measured on 7-point Likert scales.

A Friedman's test was carried out to assess whether PEOU was significantly different among the four interface types for each age group. Results of the Friedman's tests showed PEOU was not significantly different among the four interface types for either group.

Preference. Two types of preference were assessed for each age group. One type was derived by asking each participant to rank his or her own preference among the four interface types from the most preferred to the least preferred, and these choices were termed "personal preference" in this thesis. The other type was derived from asking each participant to select one interface type they believed that their friends (of with similar age and average education levels, health condition levels, and technology experience levels) would like the most, and these choices were termed "interpretation of friend's preference" in this thesis.

Personal preference. Table 5.17 shows participants' personal preferences among the four interface types for both age groups.

Table 5.17.
Preference of the Four Interface Types (Personal Preference)

	Mean (Std Dev)			
	PBI	PDI	VBI	VDI
Older Adults (n=28)	2.71 (0.96)	3.21 (0.84)	1.46 (0.92)	2.61 (0.99)
Younger Adults (n=28)	2.39 (1.03)	3 (0.98)	1.82 (1.06)	2.79 (1.1)

A Kruskal-Wallis test was conducted to assess whether the preference was significantly different among the four interface types for each age group. Results of the Kruskal-Wallis test showed that preference was significantly different among the four interface types both for the older group ($\chi 2$ (3) = 36.41, $p < 0.0001$) and for the younger group ($\chi 2$ (3) = 17.84, $p = 0.0005$).

Pairwise comparisons with Bonferroni correction were performed to determine which conditions were significantly different (with a critical alpha level at 0.05/6 = 0.0083). Results of the pairwise comparisons showed different patterns for the two age groups. For the older group, preference was significantly different between the PBI and the VBI ($p = 0.0002$), the PDI and the VBI ($p < 0.0001$), and the VBI and the VDI ($p = 0.0005$). For the younger group, preference was significantly different between the PDI and the VBI ($p = 0.0018$). Figure 5.19 shows the results of preference for both age groups.

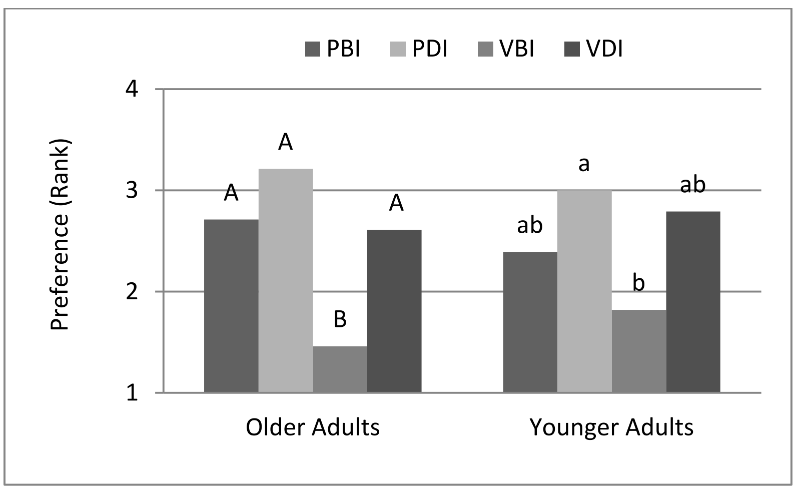

Figure 5.19. Preference for the Four Interface Types. Note: Means with same letter were not significantly different. Score "1," most preferred; "2," secondly preferred; "3," thirdly preferred; "4," least preferred.

Most preferred. Table 5.18 shows each interface type's number of times being selected as the "most preferred" for both age groups. For both age groups, the Visualized Button Interface (VBI) was selected most often as the "most preferred".

Table 5.18.
Counts of the "Most Preferred" among the Four Interface Types (Personal Preference)

	Counts			
	PBI	PDI	VBI	VDI
Older Adults (n=28)	2	1	21	4
Younger Adults (n=28)	7	1	15	5

A Pearson Chi-square test was conducted to assess whether there was a significant relationship between age group and the interface type that was the most preferred. Results showed that there was no significant relationship between age group and interface type that was the most preferred. In other words, there was no evidence that the two age groups favored (most preferred) the four interface types in significantly different portions.

Participants' comments on why they most preferred the VBI were analyzed to further understand the reasons for the preference and also to discover whether the most frequently mentioned reason was different for the two age groups. Table 5.19 shows the coding schema used to code the comments regarding why the VBI was most preferred.

Table 5.19.
Coding Schema Used to Code the Comments (Most Preferred)

Code	**Description**	**Sample participant quotes**
Less physical effort	Participant mentioned that the VBI was the most preferred because touching a visualized button on a touch-screen device required less physical effort.	"Not much pressure involved in hitting the touch-screen buttons." "It requires the least amount of effort and it is easy on my finger."
Quick	Participant mentioned that the VBI was the most preferred because touching a button took less time.	"It saves time." "I think it is the fastest."
Customized	Participant mentioned that the VBI was the most preferred because s/he was accustomed to using the visualized buttons on touch- screen devices nowadays.	"I am used to it." "I am more customized to it nowadays."
Easy to be precise	Participant mentioned that the VBI was the most preferred because it was easy to be precise and exact on a particular setting and did not have to be very careful or worry about overshooting.	"Do not have to worry about exactness of specific mark." "Each quantity has each button, it is nice and clean. I like to be very precise."
Modern	Participant mentioned that the VBI was the most preferred because it seemed modern and new.	"It seemed modern, newer technologies." "It looks modern, new."

The open-ended questions were designed to elicit why the VBI was the most preferred and data compiled from responses revealed a same pattern for the two age groups. As shown in Figure 5.20, the most frequently mentioned reason for both age groups was that the VBI required less physical effort (older group: 59.38%; younger group: 58.33%).

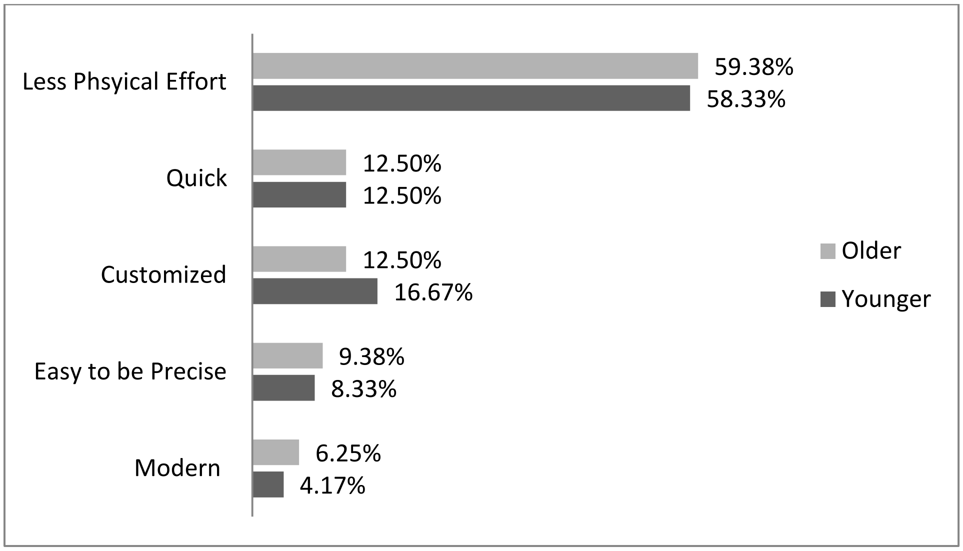

Figure 5.20. Reasons for Selecting the VBI as the "Most Preferred."

Least preferred. Table 5.20 shows each interface type's number of times being selected as the "least preferred" for both age groups. For both age groups, the Physical Dial Interface (PDI) was selected the most often as the "least preferred."

Table 5.20.
Counts of the "Least Preferred" among the Four Interface Types (Personal Preference)

	Counts			
	PBI	PDI	VBI	VDI
Older Adults (n=28)	8	12	2	6
Younger Adults (n=28)	4	12	3	9

A Pearson Chi-square test was conducted to assess whether there was a relationship between age group and the interface type that was the least preferred. Results showed that there was no significant relationship between age group and interface type that was the least preferred. In other words, there was no evidence that the two age groups disfavored (least preferred) the four interface types in significantly different portions.

Participants' comments on why they least preferred the PDI were analyzed to further understand the reasons for the PDI being disfavored and also to discover whether the most frequently mentioned reason was different for the two age groups. Table 5.21 shows the coding schema used to code the comments regarding why the PDI was the least preferred.

Table 5.21.
Coding Schema Used to Code the Comments (Least Preferred)

Code	**Description**	**Sample participant quotes**
More Physical Effort	Participant mentioned that the PDI was the least preferred because turning a physical dial required more physical effort.	"Required more work to get it, had to twist my wrist…Hard to finish in one motion." "Had to take two fingers to hold the dial, then bent the elbow, take much more motion."
Hard to be Precise	Participant mentioned that the PDI was the least preferred because it was hard to be precise or exact on a particular setting and had to be very careful.	"It is hard to be exact." "Have to make sure I am on the right number, not past or before the number… Have to be more careful."
Old-fashioned	Participant mentioned that the PDI was the least preferred because it looked old-fashioned.	"It looks dated." "It is old-fashioned."

The open-ended questions designed to elicit why the PDI was the least preferred, and data compiled from responses revealed different patterns for the two age groups (Figure 5.21). For the older group, the most frequently mentioned reason was that the PDI required more physical effort (60%). For the younger group, the most frequently mentioned reason was that it was hard to be precise with the PDI (57.14%). The next-frequently-mentioned reason for the older group was that the PDI seemed old-fashioned (26.67%). The next-frequently-mentioned reason for the younger group was that the PDI required more physical effort (35.71%).

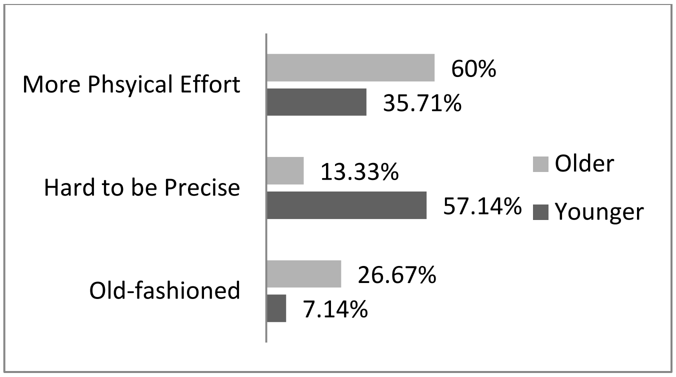

Figure 5.21. Reasons for Selecting the PDI as "the Least Preferred."

Interpretation of friend's preference. Table 5.22 shows the number of times each interface type was selected as the "most preferred" from a friend's perspective (similar age of the participant) for both age groups. The Visualized Button Interface (VBI) was selected the most often as the "most preferred" for both groups.

Table 5.22.
Counts of the "Most Preferred" among the Four Interface Types (Friend's Preference)

	Counts			
	PBI	PDI	VBI	VDI
Older Adults (n=28)	2	2	22	2
Younger Adults (n=28)	1	2	19	4

A Pearson Chi-square test was conducted to assess whether there was a significant relationship between age group and the interface type that participants perceived as being the most preferred by their friends. Results showed that there was no significant relationship between age group and the interface type that participants perceived as being the most preferred by their friends. In other words, there was no evidence that the two age groups favored (most preferred) the four interface types in significantly different portions.

Aging factor vs. generation factor. One objective measurement and one subjective measurement in this study helped to understand how the aging factor and the generation factor affected older adults' interactions with new technologies.

This study objectively assessed whether another significant age-group variable exsits other than the abilities score (reaction time, processing speed, and working memory which showed decline during the natural process of aging) to explain the age-group differences in task competion time. If there were another variable, it would imply that generation-related experiences and knowledge differneces between the two age groups also have played roles. This study also measured older adults' subjective perceptions on how the aging factor and the generation factor affected their interactions and also determine their perceptions on the relative weights of the two factors.

Explaining task completion time. Simple regression was conducted to assess whether ability score was a significant variable to explain the age-group differences in task completion time and also whether there were other significant age-group related variables other than the abilities.

Participants were assessed for reaction time, processing speed, and working memory. The ability score of each participant was calculated, taking into account all measurements of all three ability tests. For each participant, each one of the three test scores was converted to z-score (M = mean of the test score of the two age groups; SD = standard deviation of the test score of the two age groups), and the z-scores of the three ability tests were totaled to obtain a value for the participant's ability score.

Simple regression was conducted with ability score (numerical variable) and age group (categorical variable) as independent variables, and log-transformed task completion time as a dependent variable. The original task completion time was transformed to meet the assumptions of simple regression.

Results showed that the ability score variable was significant ($p = 0.0002$) and the age group variable was also significant ($p < 0.0001$), with R-square = 0.2. Results suggested that although a participant's ability was a significant variable, there was significant variance in task completion time that was not covered by this variable. Since the two age groups also belonged to two different technology generations (younger group: menu generation; older group: electro-mechanical generation), the age group differences in task completion time could also be caused by the differences in technology-generation-related experiences and knowledge.

Explaining older adults' difficulties with newer interface types (VBI and VDI). During the structured interview, older adults were asked to select the interface types they found difficult to use. If they found the newer user interface type (VBI or VDI) difficult, they were asked to assign 100 points between the two factors attributable to their difficulties (aging factor vs. generation factor).

Results showed that 10 older participants had difficulties with the Visualized Dial Interface (VDI) and assigned 100 points between the aging factor and the generation factor. Table 5.23 shows the points received by the two factors.

None of the older participants had difficulties with the Visualized Button Interface (VBI). However, 6 older participants found the Physical Dial Interface (PDI) was difficult, 2 two older participants found the Physical Button Interface (PBI) was difficult. The remaining 10 older participants did not find any interface type to be difficult to use.

Table 5.23.
Aging Factor and Generation Factor (Exp 1)

	Mean (Std Dev)	
	Aging Factor	Generation Factor
Older Adults (n=10)	56 (28.07)	44 (28.07)

One sample *t*-test was conducted to assess whether the mean of the generation factor was equal to 50 (null hypothesis: mean = 50) and to determine whether the two factors received equal points. Results showed that the null hypothesis that the mean of the generation factor was equal to 50 ($t\ (9) = -0.68$, $p = 0.516$) could not be rejected. So there was no significant difference between the aging factor and the generation factor. In other words, older adults perceived the aging factor (declines in abilities during the process of aging) and the generation factor (incompatibility with their early experiences) to play equally important roles in causing their difficulties in using the new interfaces (with new interaction techniques).

Discussion

Influences of early experiences with physical dials. Results showed that older adults' early experiences and their corresponding familiarity with the interaction technique of the electro-mechanical style had given them some advantages with respect to task completion time. There was a significant interaction between age group and interface type on task completion time; age-group difference in task completion time was the least pronounced for the Physical Dial Interface (PDI).

However, the Visualized Button Interface (VBI) outperformed the Physical Dial Interface (PDI) in all aspects of usability measurements, including task completion time, workload, and satisfaction. Older adults performed a task significantly faster with the VBI than they did with the PDI, they perceived the physical workload of using the VBI was significantly lower than that of using the PDI, and they were significantly more satisfied with their interactions with the VBI than the PDI.

Hence, older adults' early experiences with physical dials facilitated their interactions and offset the ability differences from the younger adults to some extent. However, the usability of a visualized button interface (VBI) was higher than that of the physical dial interface (PDI) despite older adults' greater familiarity with the PDI, which was mostly because the VBI required less physical effort and was quicker. This result was different from the findings by Lewis et al. (2007), as they found that older adults performed better with a dial model than a button-display model and recommended that older adults would benefit more from a dial model. The component of interaction structure was not controlled in their experiment since the dial model employed a much more straightforward and direct interaction structure than did the button-display model; therefore, the usability benefits of the dial model found in their experiment might be attributable to its interaction structure rather than the dial or button, per se. In contrast, this study controlled the component of interaction structure, and all interface types (PBI, PDI, VBI, and VDI) employed exactly the same interaction structure.

Results of behavioral intention (BI) showed that older adults were less likely to accept a new technology with the physical dial interface (PDI) than one with a visualized button interface (VBI). Older adults had significantly negative attitudes toward new technologies with the PDI and the PBI, and they had neutral attitudes toward new technologies with the VBI and the VDI. In addition, the results did not seem to be influenced by perceived usefulness (PU) or perceived ease of use (PEOU); there were no significant differences in PU or PEOU among the four interface types.

It has been suggested that factors other than perceived usefulness (PU) or perceived ease of use (PEOU) may also impact technology acceptance, such as perceived newness, which is about the level of innovation (Caine et al., 2006). People are more inclined to accept the technologies that they believe are modern and fresh than they are to accept those that they believe are out of date (Gruen, 1960). Hence, the acceptance difference between the VBI and the PDI might be influenced by the factor of perceived newness. Several participants specifically commented in the open-ended questions portion of the preference questionnaire that the Visualized Button Interface (VBI) looked modern and new while the Physical Dial Interface (PDI) seemed old-fashioned and dated. Hence, older adults had negative attitudes toward new technologies employing the interaction technique they had early experiences with, and the negative attitudes were mostly because it looked old-fashioned.

Preference results showed that older adults did not prefer the physical dials although they grew up with this specific interaction technique. Actually the physical dial interface (PDI) to which older adults were exposed during their formative years received the highest number of times being selected as the "least preferred", and the visualized Button Interface (VBI) received the highest number of times being selected as the "most preferred". This result was different from the findings of Schindler & Holbrook (2003), as they found that users' preference peaked for products that were popular when they were young. The difference in findings might be because they investigated users' preferences for automobile styles (aesthetics-oriented), and this study investigated older adults' preferences for the interaction techniques of product interfaces (function-oriented). Hence, the effects of early experiences on users' preferences might be different on products that are aesthetics-oriented than they are on products that are function-oriented.

Open-ended questions in the preference questionnaire showed that older adults regarded the physical effort to be the most important factor. Touching a visualized button required the least amount of physical effort and was easy on the finger. In contrast, turning a physical dial required much more physical effort and movement. The answers to the open-ended question in the preference questionnaire were consistent with the data of physical workload measurements.

Turning a dial involved older adults to bend their elbows, twist their wrists, and reposition their fingers several times (when turning over 180 degrees), which was particularly hard to accomplish with aging hands. Older adults participating in this study were active and healthy, and did not have any severe physical impairment (only a few participants had minor arthritis). The physical dials would cause more severe problems for the general older adult population, especially for older adults who had suffered a stroke or had Parkinson's diseases, arthritis, or other nerve or musculoskeletal disorders in their upper extremities.

It has been suggested that designers may expect that users would be most fluent with the interaction style within their technology generation. However, this study found that the physical dials that today's older adults (electro-mechanical generation) grew up with caused usability problems for them due to physical aspects of aging. Hence, designers should consider that skills once well-learned and well-rehearsed by older users might have been seriously impaired by the aging process.

Physical manipulation and tactile feedback. The effect of physical manipulation and tactical feedback of interaction techniques on usability revealed different results for the button-based interfaces and the dial-based interfaces.

For the two button-based interfaces (PBI and VBI), results showed that the feature of physical manipulation and tactile feedback of the physical buttons did not improve the usability. Participants performed tasks significantly more slowly with the PBI than they did with the VBI (both groups), perceived the overall workload of using the PBI was higher than that of the VBI (younger group), and were significantly less satisfied with the PBI than they were with the VBI (both groups). Results of the structured interviews in which participants explained participants' satisfaction showed that older adults were more satisfied with the visualized button than they were with the physical button. It was mostly because activating a real physical button required more physical effort (strength) and took longer to accomplish than just tapping a visualized button on the touch-screen, which was consistent with the task completion time data and the workload data. Several participants specifically commented that losing the three-dimensional feature and tactile feedback of pressing a button was OK, as long as there was other types of feedback provided, such as a change of size or color (visual feedback) or a click sound (auditory feedback). Participants also mentioned that they were more satisfied with the VBI because it was nice and clean, and it was easier to search and to read the labels. A real physical button (three-dimensional) blocked the labels located near the button when viewed from some angles. In contrast, a visualized physical button on a flat touch-screen device did not block any labels (two-dimensional).

For the two dial-based interfaces (the PDI and the VDI), results showed that the feature of physical manipulation and tactile feedback of the physical dials was found to increase the usability. Participants performed tasks significantly more quickly with the PDI than they did with the VDI (both groups). But the PDI's feature of physical manipulation and tactical feedback did not reduce participants' overall workload or increase satisfaction. It seemed that having a real dial that participants could physically grab and manipulate facilitated participants' performance in terms of efficiency. But it might also be because turning a physical dial was well-learned and well-rehearsed by the participants, while turning a visualized dial on the touch-screen was a new method of interaction despite the short practice session prior to the tasks. Nearly all participants had never used the visualized dials before the experiment.

Hence, results suggested that the effects of the feature of physical manipulation and tactile feedback on usability depended on the type of interaction technique. For the button-based interfaces, losing the feature of physical manipulation or tactile feedback of a real button was not found to reduce usability in either age group. For the dial-based interfaces, losing the feature of physical manipulation or tactical feedback of a real dial reduced usability for both groups, but participants' greater familiarity with the PDI than with the VDI could also have played a role in this tendency.

Results of behavioral intention (BI) showed that older adults were more likely to accept technologies with the touch-screen-based interfaces (VBI and VDI) than those with the hardware-based interfaces (PBI and PDI). In addition, BI did not seem to be influenced by perceived usefulness (PU) or perceived ease of use (PEOU). The acceptance differences between the touch-screen-based interfaces and the hardware-based interfaces might have been influenced by perceived newness. The visualized buttons and visualized dials operated on a touch-screen device seemed modern and new. However, the physical dials and physical buttons seemed old-fashioned and dated.

Hence, losing the feature of physical manipulation or tactical feedback of a real button and real dial (from 3D to 2D) was not found to reduce the acceptance of new technologies. The VBI and the VDI were actually rated higher in technology acceptance, mostly because the touch-screen-based interfaces (the VBI and the VDI) seemed new and exciting.

Results of personal preferences showed that older adults preferred the touch-screen-based interfaces (the VBI and the VDI) to the hardware-based interfaces (the PBI and the PDI). Results indicated that older adults significantly preferred the VBI to the PBI, and older adults preferred the VDI to the PDI (though not to as significance a level). Out of 28 older participants, 21 older participants liked the VBI the most, 2 older participants liked the PBI the most, 4 older participants liked the VDI the most, and 1 older participant liked the PDI the most. For interpretation of friend's preferences, 22 older participants believed their friends (of similar age) would like the VBI the most, 2 older participants picked the PBI, 2 older participants picked the VDI, and 2 older participants picked the PDI.

Hence, losing the feature of physical manipulation or tactical feedback of a real button and real dial (from 3D to 2D) was not found to impair preferences. The VBI and the VDI were actually more preferred, especially the VBI.

Same appearance and operation of an old interaction technique. Results showed that the visualized dial, which kept the same appearance and operation of a physical dial (the

VDI), did not help improve the usability of a touch-screen-based interface. The visualized button interface (VBI) outperformed the visualized dial interface (VDI) in all aspects of usability measurements, including task completion time, workload, and satisfaction. Older adults' performed the tasks significantly faster with a VBI than they did with a VDI, they perceived the overall workload of using the VBI was significantly lower than that of the VDI, and they were significantly more satisfied with their interactions with the VBI than they were with their interactions with the VDI. The VBI was significantly lower than the VDI in several aspects of workload, including the mental workload, physical workload, and effort. Results of the structured interview in which participants explained their satisfaction showed that older adults were more satisfied with the visualized button than they were with the visualized dial mostly because using the visualized button required less mental and physical effort and was quicker, which was consistent with the task completion time data and the workload data. Several participants also specifically commented that keeping the visual graph of a real dial and operating it by rotating a dial on a touch-screen device was unnecessary and awkward; it would be much easier to just tap a button on a touch-screen device.

Results of behavioral intention (BI) showed there was no significant difference between the VBI and the VDI. In addition, results showed that there was no significant difference in perceived usefulness (PU) and perceived ease of use (PEOU), which were two important factors of behavioral intention (BI), according to the Technology Acceptance Model (Davis, 1989). Hence, older adults' greater familiarity with the appearance and the operation of the physical dials did not help to increase the technology acceptance of the VDI.

Results of personal preferences showed that older adults significantly preferred the VBI to the VDI, even though the VDI kept the same appearance and operation of a real dial with which they had greater familiarity. Out of 28 older participants, 21 older participants liked the VBI, and 4 older participants liked the VDI the most (the remaining 3 older participants liked the PBI or PDI). For interpretation of friend's preferences, 22 older participants believed their friends (with similar age) would like the VBI the most, and 2 older participants picked the VDI (the remaining 4 older participants liked the PBI or PDI).

Aging-related factor vs. generation-related factor. Results of simple regression showed that ability score (numerical variable) and age group (categorical variable) were significant variables to explain the age-group differences in task completion time. It implied that other significant age-group-related variables in addition to the abilities played significant roles in older adults' performances. The two age groups also belonged to two different technology generations (younger group: menu generation; older group: electro-mechanical generation). Hence, the age-group variance in task performance could be caused by the differences in age-related abilities as well as generation-related experiences and knowledge.

This finding was further supported by the data from the structured interviews. Older adults assigned 100 points between the two factors attributable to their difficulties in using the interfaces. Results showed that there was no significant difference between the aging factor and the generation factor, which implied that older adults perceived that age-related abilities and technology-generation-related experience and knowledge played equally important roles in their interactions. This result is consistent with the findings of Blackler et al. (2009), who suggested that a complex mix of cognitive abilities and prior experiences is the most important factor that affects how older people use new interfaces.

Conclusion

Older adults' early experiences with physical dials gave them some advantages with respect to task completion time, in that the age-group difference was the least pronounced for the Physical Dial Interface (PDI). However, the Visualized Button Interface (VBI) outperformed all other interface types, including the PDI, on almost all usability measurements, which was because tapping a visualized button on a touch-screen device required less physical effort and was faster than turning a real dial. It revealed that the usability benefits of the electro-mechanical style (a dial model) found by a previous study were not attributable to its interaction technique (the physical dial, per se), but rather might be attributable to its straightforward and direct interaction structure (1:1 mapping between function and control and single-layered operation). Results also showed that the VBI outperformed the PDI in technology acceptance and preference, which was mostly because the VBI looked modern, and the PDI looked old-fashioned. Hence, it would not be recommended to use the interaction technique of physical dials when developing user interfaces of new technologies for older adults.

Results showed that losing the feature of physical manipulation and tactile feedback of the electro-mechanical style were not found to cause usability problems or impair technology acceptance or preference if there was adequate feedback provided through other sensory channels. Results also showed that it was unnecessary to keep exactly the same appearance and operation of an interaction technique belonging to the electro-mechanical style on a touch-screen device.

In addition, results revealed that both the aging factor (age-related ability declines) and the generation factor (early experiences of the specific technology generation) affected older adults' interactions with new interfaces, and older adults perceived that the two factors played equally important roles in their interactions with new interfaces (interaction techniques).

CHAPTER 6
EXPERIMENT 2 (INTERACTION STRUCTURE)

Overview of Experiment

This experiment investigated the effects of early experiences with the component of interaction structure of the electro-mechanical style on usability and acceptance of new technologies by older adults.

As previously mentioned in the literature review, today's older adults (65 years and older) typically belong to the electro-mechanical generation, and the predominant interaction style they were exposed to during their formative years (10–25 years old) was the electro-mechanical style. The interaction structure of this particular interaction style featured 1:1 mapping between control and function, and single-layered operation.

In this experiment, three types of functionally equivalent interfaces were chosen to be examined: the One Control with Single Function and Single-Layered Interface (SFSLI), the One Control with Multi-Function Interface (MFI), and the Multi-Layered Interface (MLI). The only difference among the interfaces was the interaction structure.

Impacts of the feature of the 1:1 mapping between control and function would be informed by comparing the SFSLI to the MFI. Impacts of the feature of the single-layered operation would be informed by comparing the SFSLI to the MLI.

The SFSLI represented the type of interaction structure belonging to the electro-mechanical style with which older adults had early experience. The MFI and the MLI represented newer types of interaction structures over the historical changes.

Participants from two age groups were recruited in this experiment: 30 participants in a younger group (18-33 years old) and 30 participants in an older group (65-80 years old). The younger adults served as a comparison group. Each participant performed tasks with all three types of user interface twice. The order of presentations of the three user interface types was counterbalanced among the 30 participants within each age group.

The independent variables were: interface type (SFSLI, MFI, and MLI), age group (younger group and older group), and trial (trial 1 and trail 2). Both interface type and trial were within-subject. Two primary groupings of dependent variables were usability (task completion time, workload, and satisfaction) and acceptance (behavioral intention, perceived usefulness, and perceived ease of use). Also measured were reaction time and cognitive abilities (processing speed and working memory), technology experience, preferences among the three interface types, and older adults' perceived relative weights of the two factors attributable to their difficulties using new interfaces (aging factor vs. generation factor).

Methods

Participants. A total of 60 participants, including 30 younger adults (18–31 years) and 30 older adults (65–77 years) participated in this study (see Table 6.1 and Table 6.2 for an overview of the participant characteristics). All 28 younger participants and 28 older participants participated in Experiment 1 also participated in Experiment 2. The mean age of the younger group in this experiment was 22.7 years (SD = 3.84 years), and the mean age of the older group was 69.83 years (SD = 3.89). The younger group served as a comparison group to establish performance benchmarks.

Participants were recruited from North Carolina State University (NCSU) and the surrounding communities. A majority of the older adult participants were members of the Encore Program for Lifelong Enrichment of NCSU. Younger participants were undergraduate and graduate students and recent graduates of NCSU. Most of the participants received course credits or monetary compensation for participating in this study; the volunteer participants did not receive any compensation.

Participants with severe physical or cognitive impairments were excluded from participation. Participants were required to have at least a high school education, near and far vision of at least 20/40 (with or without correction), and normal hearing acuity (self-reported). Participants were also screened to ensure that they were able to follow the instructions and complete the tests in English. All 30 participants in the younger group and 29 participants in the older group were native English speakers. Only 1 participant in the older group was not a native English speaker, but the participant had lived in the United States for more than 7 years and spoke fluent English. Of the total number of participants, 27 participants in the younger group and 28 participants in the older group were righted-handed. Participants in both younger and older groups represented a wide variety of occupations or majors. All participants had at least minimal usage experiences with touch-screen devices.

Table 6.1.
Participant Demographics (Exp 2)

		Mean (Std Dev)			
	N	Age (years)	Education Level	Health	Health (Compared to age)
Younger Group	30	22.7 (3.84)	6.29 (0.6)	4.2 (0.61)	4 (0.69)
Female	17	23.24 (3.9)	6.35 (0.61)	4.18 (0.64)	4 (0.71)
Male	13	22 (3.81)	6.23 (0.6)	4.23 (0.6)	4 (0.71)
Older Group	30	69.83(3.89)	6.63 (0.85)	3.9 (0.71)	4 (0.59)
Female	19	69.47 (3.98)	6.42 (0.69)	4.11 (0.66)	4.16 (0.5)
Male	11	70.45 (3.83)	7 (1)	3.55 (0.69)	5.36 (0.5)
All Participants	60	46.27 (24.07)	6.47 (0.75)	4.05 (0.67)	4 (0.64)

Note: (1) Explanation of Scoring for Education Level:
Score 5: Some college/Associate’s degree or currently working toward a college/Associate’s degree.
Score 6: Bachelor’s degree (BA, BS) or currently working toward a Bachelor’s degree.
Score 7: Master’s degree (or other post-graduate training) or currently working toward a Master’s degree.
Score 8: Doctoral degree (PhD, MD, EdD, DDS, JD, etc.) or currently working toward a Doctoral degree.
(2) Explanation of Scoring for both Health and Health (compared to other people your own age):
Score 1: poor; Score 2: Fair; Score 3: Good; Score 4: Very good; Score 5: Excellent.

Table 6.2.
Ability Test and Technology Experience Test Sores (Exp 2)

		Mean (Std Dev)			
	N	Processing Speed	Reaction Time	Working Memory	Technology Experience
Younger Group	30	87.4 (11.58)	308.62 (32.44)	39.03 (12.82)	280.03 (20.43)
Female	17	89.29 (10.31)	315.87 (27.5)	42.65 (15.02)	283.24 (16.23)
Male	13	84.92 (13.07)	299.14 (36.91)	34.31 (7.32)	275.85 (24.97)
Older Group	30	68.63 (13.74)	365.19 (89.53)	27.47 (10.77)	287.83 (31)
Female	19	68.89 (14.17)	388 (100.35)	26.11 (10.25)	283.05 (29.71)
Male	11	68.18 (13.61)	325.79 (49.22)	29.81 (11.74)	296.09 (32.86)
All Participants	60	78.02 (15.76)	336.91 (72.6)	33.25 (13.11)	283.93 (26.32)

Note: This table showed the absolute score of the working memory.

As shown in the Table 6.3 below, a Wilconxon-Mann-Whitney test revealed marginally significant differences in education levels between the younger group and the older group (p = 0.084). But the Wilconxon-Mann-Whitney test did not identify significant differences in self-ratings of health conditions or health compared to other people of the same age between the two groups.

Table 6.3.
Wilconxon-Mann-Whitney Tests for Demographic Differences between Age Groups (Exp 2)

	Younger Group vs. Older Group	
	Z-score	P-value
Education Level	1.73	0.08*
Health Condition	-1.64	0.10
Health Compared to People with Same Age	0	1

Note: *p<0.1, **p<0.05, ***p<0.001.

The age group difference in education levels was typical of those reported in previous research (Rogers, Hertzog, & Fisk, 2002; Sharit, Hernández, Czaja, & Pirolli, 2008) in that older adults had completed more years of education than younger adults (who were still pursuing their degrees). But the nonsignificant age group difference in health conditions was not typical. Older adults often reported lower self-ratings of health than did younger adults (Rogers et al., 2002). So the older adults participating in this study might have been generally healthier than the average of the older adult population.

Participants each completed the following tests and questionnaires to assess reaction time, processing speed, working memory, and technology experience: (a) the reaction time test (Human Benchmark, 2012), (b) the Digit Symbol Substitution (Wechsler, 1981), (c) the Alphabet Span (Craik, 1986), and (d) the Technology Experience Questionnaire (Czaja et al., 2006b).

As shown in Table 6.4, an independent sample *t*-test revealed significant differences in all three abilities tested (reaction time, processing speed, and working memory) between the younger group and the older group ($p < 0.05$). But the *t*-test did not identify a significant difference in technology experience between the two groups.

Table 6.4.
T-Tests for Three Abilities and Technology Experience between Age Groups (Exp 2)

	Younger Group vs. Older Group	
	t value	P-value
Reaction Time	3.25	0.0019**
Processing Speed	-5.72	<0.0001***
Working Memory	-3.78	0.0004***
Technology Experience	1.15	0.2546

Note: *p<0.1, **p<0.05, ***p<0.001.

The age-group differences in reaction time, processing speed, and working memory were consistent with those reported in previous research (e.g., Rogers et al., 2002) in that younger adults performed better on the reaction time tests, the digital-symbol substitution tasks, and the alphabet span tasks. But the nonsignificant age-group difference in technology experience was not typical. Older adults often reported lower technology experience than did younger adults (Czaja et al., 2006a). So the older adult participants in this study might have had higher technology experience than the average of the older adult population. It has previously been reported that the technology experience between younger adults and high-technology older adults was not significantly different (O'Brien, 2010).

Setting. The experiment took place in the Research in Ergonomics and Design Laboratory (RED lab) at North Carolina State University. The room was quiet and air-conditioned and contained adequate lighting.

The participant was seated in an adjustable chair in front of a conference table. A laptop that showed task instructions was placed on the table in front of the participant, and the prototype of the user interface was placed between the participant and the laptop. The researcher was seated on the non-dominant side of the participant to monitor his or her interaction and record the task completion time.

Material. Materials in this study included prototypes, recording and computing devices, experiment instruction and task instructions, abilities tests, technology experience questionnaire, demographic information questionnaire, workload questionnaire, satisfaction questionnaire, technology acceptance questionnaire, preference questionnaire, and structured interview script.

Prototypes. Three types of user interface prototypes were made for this experiment, including the One Control with Single Function and Single-Layered Interface (SFSLI), the One Control with Multi-Function Interface (MFI), and the Multi-Layered Interface (MLI). Characteristics of the three interface types are shown in Table 6.5.

Table 6.5.
Characteristics of the Three Interface Types (Exp 2)

Interface Type	Number of Functions Per Control	Number of Layers
One Control with Single Function and Single-Layered Interface (SFSLI)	1	1
One Control with Multi-Function Interface (MFI)	3	1
Multi-Layered Interface (MLI)	1	3

The SFSLI and the MFI shared the same number of functions per control, which was one function per control (1:1 mapping). The SFSLI and the MLI shared the same number of layers, which was a single layer.

Prototypes of the three interface types (SFSLI, MFI, and MLI) varied only in the interaction structure. Prototypes of all three interface types were exactly the same in terms of interaction technique; size; background color; button and dial color; text color, font and size; and number of functions and settings. All prototypes were programmed with Xcode in iPad developer software as software applications.

The interaction technique of all prototypes was a visualized button on a touch-screen device. The size of the prototype screen was the same as a first-generation iPad (Apple Inc., 7.76 in x 5.82 in). The color of the background was blue, the color of buttons and dials was white, and the color of the text was white. All prototypes had a POWER On/Off function and 3 other functions; there were 4 settings for each of the 3 functions.

The structure of the SFSLI is shown in Figure 6.1, the structure of the MFI is shown in Figure 6.2, and the structure of the MLI is shown in Figure 6.3.

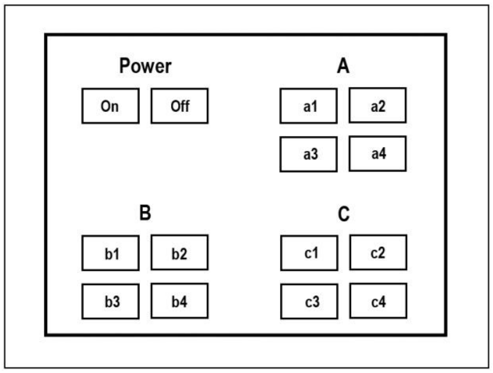

Figure 6.1. Structure of the SFSLI.

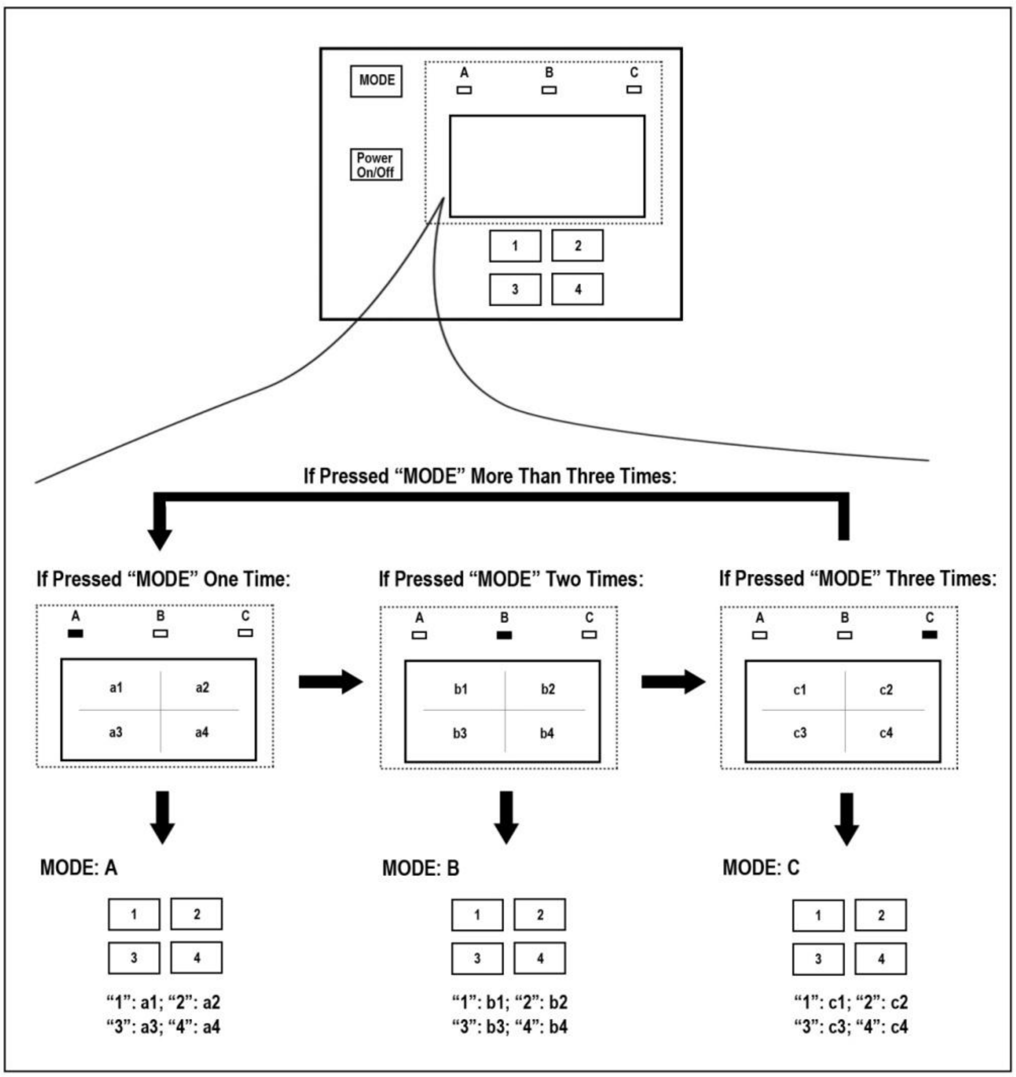

Figure 6.2. Structure of the MFI.

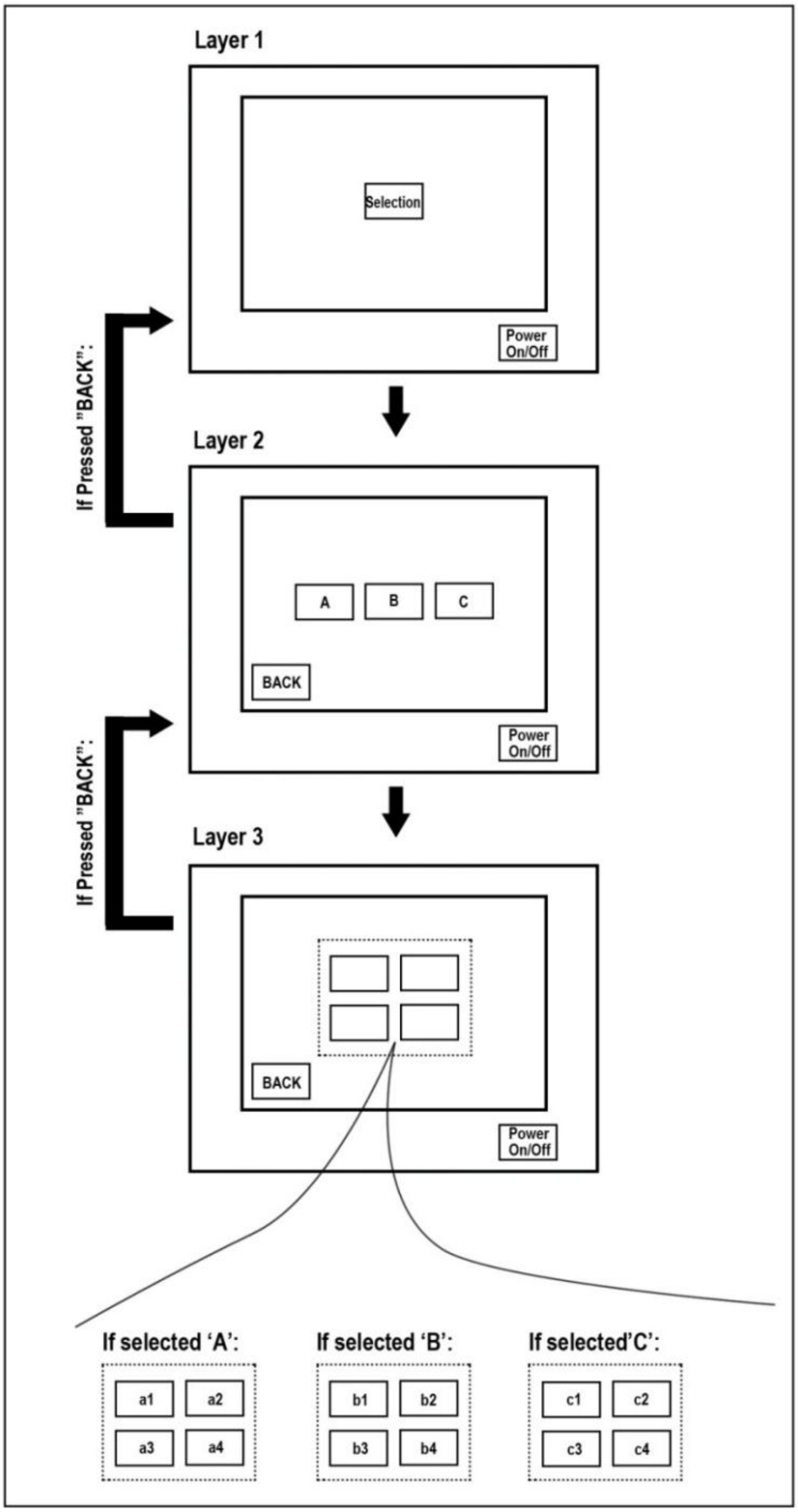

Figure 6.3. Structure of the MLI.

Because every participant was exposed to all three interface types, participants likely performed better with the interface types encountered later in the experiment because they may have remembered the text labels and locations from prior exposures. To avoid the ordering effect and to provide an insight into the effects of interaction styles on technology acceptance, three different prototypes were made for each interface type to represent three new technologies. The only difference among the three prototypes of the same interface type was the text labels (functions and settings modified in the context of the particular new technology).

The three new technologies were selected based on the following criteria:

- Both younger and older adults would be motivated to participate and use them
- The technologies were relatively new and had not been widely used as yet.
- The technologies did not have many functions.
- The technologies had interactive user interfaces.
- The technologies were normally used in a home context, not for professional use at work.
- The technologies were intended to be used with little or no instructions or assistance.
- The technologies selected were comparable in terms of functionality, complexity, and product category.

Hawthorn (2007) suggested that a test product should be perceived as relevant to motivate the participants to engage in the experiment. The three new technologies selected for this experiment all belonged to the product category of health and personal care. The three technologies included a body fat analyzer, an air cleaner and steamer, and an activity and health monitor.

For all new technologies, only the user interfaces (elements of a product used to control it and receive information) were prototyped; the functions were not prototyped. Hence, there were no actual stimuli produced as a result of interactions with the user interfaces of prototypes in this experiment.

In total, 9 prototypes (3 interface types x 3 new technologies = 9 prototypes) were made for this experiment. Pictures of the nine prototypes are shown in Figure 6.4, Figure 6.5, and Figure 6.6.

Figure 6.4. Three Prototypes of the SFSLI.

Figure 6.5. Three Prototypes of the MFI.

Figure 6.6. Three Prototypes of the MLI.

Recording and computing devices. Task completion time was recorded by a stop watch (1/100 second precision). The reaction time test was performed on a 13-in Apple MacBook Pro laptop with a mouse. The laptop accessed the Internet through the North

Carolina State University high-speed broad band connection. The system was configured with Firefox 10.0.1. The pre-recorded audio of the word lists for the alphabet span test as well as the presentation slides of experiment introduction and task instructions were also played on the laptop. The word lists were played by Windows Media Player and the presentation slides were played by PowerPoint 2010.

Experiment introduction and task instructions. The experiment introduction was introduced to the participant by the researcher using a written script coupled with a presentation slide. The written script and the presentation slides were used to ensure that the experiment introduction was consistent among participants.

Task instructions were shown as presentation slides. The task instructions were shown in black text (54 point, Arial) on a white background. The researcher controlled the playing of the slides by using a mouse.

For each task, there were five subtasks representing a series of typical interactions with the new technologies, including turning on the device, selecting several settings, and turning off the device. Each subtask was shown as an individual slide. This separation of subtasks allowed the researcher to control the start of each subtask. Asking participants to perform subtask individually rather than performing five subtasks in a row reduced participants' memory loads, especially for the older group.

Ability tests. Three ability tests were administered to each participant (see Table 6.6). The tests were chosen to indentify reaction time, processing speed, and working memory. The Reaction Time Test was used as to measure reaction time (Human Benchmark, 2012), the Digit Symbol Substitution (Wechsler, 1981) was used to measure processing speed, and the Alphabet Span (Craik, 1986) was used to measure working memory. These measurements have been widely used in the literature and have demonstrated reliability and validity. An ability score was computed for each participant by taking into account his or her performance (test scores) on all three ability tests.

Table 6.6.
Description of Ability Tests (Exp 2)

Test	**Ability**	**Description**
Reaction Time (Human Benchmark, 2012)	Reaction Time	Computer-based test. The participant is required to click the mouse as quickly as s/he can when a stimulus appears in the center of the screen.
Digit Symbol Substitution (Weschsler, 1981)	Processing speed	Paper and pencil test. The participant is presented with a series of rows that pairs each digit (from 1 to 9) with a nonsense symbol, and is then required to fill in symbols below rows of digits.
Alphabet Span (Craik, 1986)	Working memory	Paper and pencil test. The participant listens to a series of words, and then is required to write down the words in alphabetical order.

Note: For administrating the test of alphabet span, the series of words was pre-recorded and played to the participant rather than read to. The recording could ensure consistency of speaking speed and clarity among participants.

Technology experience questionnaire. A reduced version of the Computer and Technology Experience Questionnaire developed by Czaja et al. (2006b) was used to assess participants' technology experiences. The original questionnaire included questions regarding usage of technologies, computers, and the Internet. However, based on the focus and goal of this research, this experiment only used the questions regarding participants' technology familiarity and experiences, which covered usage of technology in a wide range of activities, including communication, shopping, financial transactions, healthcare-related activities, transportation, entertainment, education, home-based activities, and work. The technology experience questionnaire used this study is presented in Appendix A.

Demographic information questionnaire. A demographic questionnaire (modified from Czaja et al. (2006c) was used to get information about the participant's age, gender, hand dominance, education level, nationality, occupation, health condition, health condition compared to other people of the same age, and overall personal state (before and after the session). The demographic information questionnaire is presented in Appendix B.

Workload questionnaire. The NASA-RTLX inventory was used to measure the participant's workload of interacting with the interface types. Six aspects of workload were assessed on a 10-point scale, including mental workload, physical workload, temporal workload, effort, frustration, and success. An overall workload was computed by taking into account all six aspects of workload. The workload questionnaire is presented in Appendix C.

Satisfaction questionnaire. A satisfaction questionnaire (ISO 28202-1 (E), 2006) was used to measure the participant's satisfaction with his or her interaction with the interface types. Satisfaction was measured with a pictorial smiley scale (five faces). The satisfaction questionnaire is presented in Appendix D.

Technology acceptance questionnaire. A technology acceptance questionnaire (modified from Davis, 1989) was used to measure the participant's different attitudes toward the new technologies (different interface types). Behavioral Intention (BI), Perceived Usefulness (PU), and Perceived Ease of Use (PEOU) were assessed with a 7-point Likert scale. The technology acceptance questionnaire is presented in Appendix H.

Preference questionnaire. A preference questionnaire was used to measure participants' preference among the three different interface types. Participants were first asked to rank personal preferences among the three interface types from the most preferred to the least preferred, and also to explain why a certain interface type was the most preferred or least preferred. Then participants were also asked to select the interface type that they believed their friends would like the most. The researcher specified that friends should be of similar ages and have average education levels, health condition levels, and technology experience levels. The reason for asking such a question was to shed light on the preference of average younger adults and average older adults. The preference questionnaire is presented in Appendix I.

Structured interview script. A structured interview was conducted to ascertain the reasons for each participant's different ratings of perceived ease of use and satisfaction for the interface types, and also to find out older adults' perceptions of the relative weights of the two factors attributable to their difficulties with using the new interfaces (aging factor vs. generation factor).

During the structured interview, participants in both the younger and older groups were asked to explain their ratings for perceived ease of use and satisfaction. They were asked why particular interface types were perceived as easier to use than other types and why they were more satisfied with a particular user interface type or types.

Participants in the older group were asked additional questions regarding their difficulties in using the interface types (interaction structures) in the task. They were first asked to select the interface type they found most difficult to use. If they found the newer user interface type (MFI or MLI) difficult to use, they were then asked to provide their opinions on the relative weights of the two factors attributable to their difficulties, the aging factor vs. the generation factor (by assigning 100 points). The aging factor described the difficulties in using the MFI or the MLI that resulted from the aging-related declines in the abilities which were closely associated with their interactions with the interfaces. The generation-related factor described the difficulties in using the MFI or the MLI that resulted from incompatibility with their early experiences (being different from the interface they grew up with).

Before assigning the relative weights of the two factors, older participants were asked some priming questions to prepare and guide them to have detailed thoughts on both factors before they made the decision.

Older participants were asked to recall their early experiences with interaction structures of consumer products, to compare the interaction structures they grew up with to the newer interaction structure they found difficult in the experiment, and to elaborate how they believed the differences affected their interactions with the new interface type they found difficult in this experiment.

They were also asked to discuss the aging-related ability changes (declines) they had experienced which were closely associated with their user interface usage, and to elaborate how they believed the ability changes affected their interactions with the new interface type they found difficult in this experiment.

Then they were asked to assign 100 points between the two factors (the aging factor and the generation factor), giving the factor they perceived as playing a greater role more points than they gave the other factor.

The structured interview was audio-recorded by permissions of the participants. Notes were taken on site by the researcher. The audio recording was used as backup to verify answers. The scripts of the structured interview are presented in Appendix J.

Tasks. Each participant was asked to perform three tasks, and each task was performed with a different new technology device. Task 1 was performed with the body fat analyzer. Task 2 was performed with the air cleaner and steamer. Task 3 was performed with the activity and health monitor. There were five subtasks within each task. For each task, there were two trials. When a task was applied for the second time, a slightly modified version was used (e.g., if the participant had to set the person to “A” in the first trial, it had to set the person to “B” in the second trial.). The task instructions are shown in Table 6.7.

The emphasis of the task was on accuracy. Participants were told that the goal was to perform the tasks correctly. They were told they should try to perform the tasks as accurately as they could (as opposed to as fast as they could), and the time taken to complete the tasks successfully would be measured. The reason for instructing participants to emphasize accuracy was to ensure a same interaction strategy for the two age groups to avoid a situation in which some participants employed an interaction strategy emphasizing accuracy while other participants emphasized speed.

Table 6.7.
Task Instructions (Exp 2)

Task	Technology	Trial 1 (Sub-task)	Trial 2 (Sub-task)
1	Body Fat Analyzer	1. Turn On the Device.	1. Turn On the Device.
		2. Set the Person to A.	2. Set the Person to B.
		3. Set the Activity Level to Athlete-Female.	3. Set the Activity Level to Normal-Male.
		4. Set the Fitness Indicator to BMI.	4. Set the Fitness Indicator to Weight.
		5. Turn Off the Device.	5. Turn Off the Device.
2	Air Cleaner and Steamer	1. Turn On the Device.	1. Turn On the Device.
		2. Set the Clean Cycle to 5 Hours.	2. Set the Clean Cycle to 24 Hours.
		3. Set the Clean Speed to Fast.	3. Set the Clean Speed to Slow.
		4. Set the Volume of Mist to ' * '.	4. Set the Volume of Mist to ' * * * '.
		5. Turn Off the Device.	5. Turn Off the Device.
3	Activity and Health Monitor	1. Turn On the Device.	1. Turn On the Device.
		2. Set the Activity to Step.	2. Set the Activity to Time.
		3. Set the Health Indicator to Heart Rate.	3. Set the Health Indicator to O_2 (Percentage of Oxygen).
		4. Set the Memory to Day 1.	4. Set the Memory to Day 2.
		5. Turn Off the Device.	5. Turn Off the Device.

It is important to note that the three interface types (the SFSLI, the MFI, and the MLI) were of different difficulties. The task analysis of performing tasks on the three interface types were presented in Appendix K.

Procedure. The research took place in the Research in Ergonomics and Design Lab (RED lab) at North Carolina State University (NCSU). The whole experiment was scripted to ensure consistency among participants.

The participants were first welcomed to the lab and were provided with a brief overview of the study and reminded of the exclusion criteria (participants with severe physical or cognitive impairments were excluded from participation). These exclusion criteria were based on casual general discussions with the participants. Each participant then was given a copy of the consent form to read, and the researcher answered any questions. Participants were told before the session that they could ask the researcher to rest any time during the study as needed. They were also informed that they could stop the experiment at any time and request that all the audio recordings of the interview be deleted without any penalty.

After signing the consent form, each participant was asked to complete a demographic information questionnaire (Attachment B). Then participants each completed three ability tests (reaction time, processing speed, and working memory). Before the tests, participants were told that the tests were designed to be difficult, so that no one could achieve 100%, and they should just give their best efforts and not feel bad if they could not achieve 100%. They were told that their efforts to continue trying were highly appreciated. Participants were also told that the results of their ability assessments would not be analyzed or compared individually, but the results would instead be looked at as groups. Participants were allowed to rest for at least 3 minutes after taking the three ability tests.

After the rest period, participants performed tasks on prototypes of the three interface types. Each participant performed three tasks. For each task, there were five subtasks and two trials.

Each task was performed on a new technology. Task 1 was performed on the body fat analyzer. Task 2 was performed on the air cleaner and steamer. Task 3 was performed on the activity and health monitor. In addition, participants were presented with a different interface type for each new technology. The order of presentations of the interface types was randomized and counterbalanced among the 30 participants within each age group. All prototypes were reset and wiped clean before being presented to the next participant.

Participants were told that the goal of the task was to perform the task correctly. The time taken to successfully perform the task was recorded by the researcher.

After the two trials of each task were completed, each participant was asked to fill out a workload questionnaire (Appendix C), a satisfaction questionnaire (Appendix D), and a technology acceptance questionnaire (Appendix H). After all four tasks were completed, each participant was asked to fill out a preference questionnaire (Appendix I). Participants were allowed to rest at least 2 minutes after each task and filling out the questionnaires regarding the task.

After the rest period, the researcher then conducted a structured interview to allow participants to elaborate on their ratings for perceived ease of use and satisfaction with the interface types, and also to find out how older adults perceived the relative weights of the two factors attributable to their difficulties with using the new interfaces. The interview was audio-recorded with the permissions of the participants. Notes were also taken on site by the researcher. Each participant was allowed to rest for at least 3 minutes after the structured interview.

After the rest period, each participant was asked to fill out a technology experience questionnaire (Appendix A).

The whole experiment took approximately 1.5 hours for younger adults and approximately 2 hours for older adults.

Measurements. Primary measurements of the two experiments were usability and acceptance. Also measured were demographic information, abilities, technology experiences, preferences, and older adults' perceived relative weights of the two factors attributable to their interaction difficulties (aging factor vs. generation factor). The measurements of this experiment are shown in Table 6.8.

Table 6.8.
Measurements and Tools (Exp 2)

Measurements	**Tools**
Demographic Information	Demographic Questionnaire (modified from Czaja et al., 2006c)
Ability	
Reaction Time	Simple Reaction Time Test (Human Benchmark, 2012)
Processing Speed	Digit Symbol Substitution (Weschsler, 1981)
Working Memory	Alphabet Span (Craik, 1986)
Technology Experience	Technology Experience Questionnaire (Czaja et al., 2006b)
Usability	
Task Completion Time	Stop watch
Workload	Workload Questionnaire (NASA-RTLX)
Satisfaction	Satisfaction Questionnaire (ISO 28202-1 (E), 2006)
Technology Acceptance	
Behavioral Intention	Technology Acceptance Questionnaire (modified from Davis, 1989)
Perceived Usefulness	Technology Acceptance Questionnaire (modified from Davis, 1989)
Perceived Ease of Use	Technology Acceptance Questionnaire (modified from Davis, 1989)
Preference	
Personal Preference	Preference Questionnaire
Friend's Preference	Preference Questionnaire
Aging Factor vs. Generation Factor	Structured Interview

Usability was measured according to ISO 9241-11 (ISO, 1998). However, only the efficiency (task completion time and workload) and the satisfaction were measured. Effectiveness was not measured because the time taken to complete the tasks successfully was measured. The reason for controlling the accuracy was to ensure that all participants from the two groups used the same interaction strategy. Older adults have often reported to exploit a slow, but error-free style, while younger adults were reported to exploit a fast style with more errors (trial-and-error) (e.g., Docampo Rama, 2001; Wilkinson et al., 2010). Hence, this experiment required all participants to use the same interaction strategy.

Results

Usability. Usability was measured by task completion time (efficiency), workload (efficiency), and satisfaction.

Task completion time. A 3 (interface type) x 2 (age group) x 2 (trial) ANOVA mixed repeated measures test was carried out with the log-transformed task completion time as the dependent variable.

There were five subtasks within each task and the time to complete each subtask was recorded separately. Task completion time was the sum of completion times of all five subtasks. The original task completion time data was then log-transformed to meet the assumptions of ANOVA.

As shown in Table 6.9, there were significant interactions between the age group and interface type (F (2, 116) = 22.95, p < 0.0001), between the age group and trial (F (1, 58) = 5.65, p = 0.0208), and between the interface type and trial (F (2, 116) = 48.38, p < 0.0001).

Table 6.9.
Mixed ANOVA (Task Completion Time-Exp 2)

Effect	Num DF	Den DF	F Value	P Value
Age Group	1	58	88.84	<0.0001***
Interface Type	2	116	551.99	<0.0001***
Trial	1	58	263.55	<0.0001***
Age Group x Interface Type	2	116	22.95	<0.0001***
Age Group x Trial	1	58	5.65	0.0208**
Interface Type x Trial	2	116	48.38	<0.0001***
Age Group x Interface Type x Trial	2	116	0.89	0.4152

Note: *p<0.1, **p<0.05, ***p<0.001.

Interaction between age group and interface type. The interaction diagram of age group and interface type is illustrated in Figure 6.7.

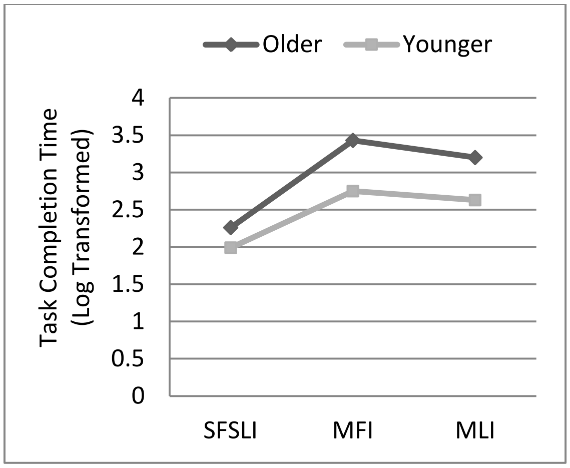

Figure 6.7. Interaction of Age Group and Interface Type.

A test of simple main effects was conducted looking at age-group differences in task completion time at each level of interface type. With a Bonferroni correction, results showed that there was a significant age group difference for each interface type. As shown in Figure 6.7 and Figure 6.8, the age-group difference in task completion time was the least pronounced in the One Control with Single Function and Single-Layered Interface (SFSLI) and the most pronounced in the One Control with Multi-Function Interface (MFI).

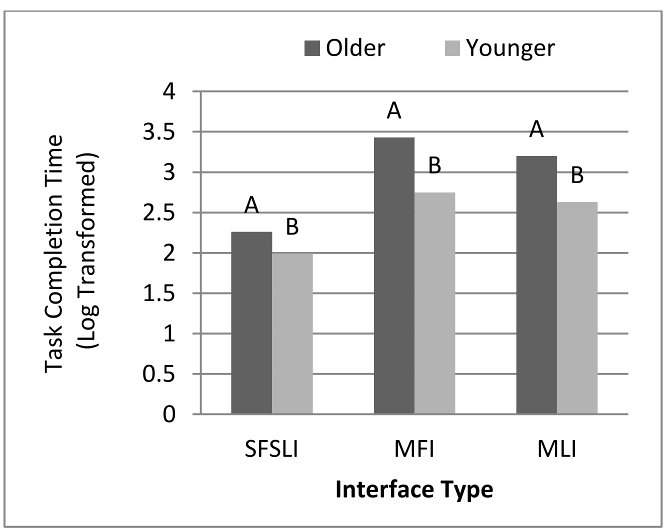

Figure 6.8. Simple Main Effect of Age Group at Each Level of Interface Type. Note: Means with same letter were not significantly different.

Another test of simple main effects was conducted looking at interface differences in task completion time at each level of age group. With a Bonferroni correction, results showed that task completion time was significantly different among the three interface types for both the younger group and older group. Tukey's HSD test was carried out to determine which conditions were significantly different for each age group. Results of the Tukey's HSD test (p < 0.05) showed different patterns for the two age groups. For the older group, task completion time of the MFI was significantly longer than that of the MLI, and the task completion time of the MLI was significantly longer than that of the SFSLI. For the younger group, task completion time of the MFI and the MLI was significantly longer than that of the SFSLI, and the task completion time of the MFI and the MLI were not significantly different from one another (Figure 6.9).

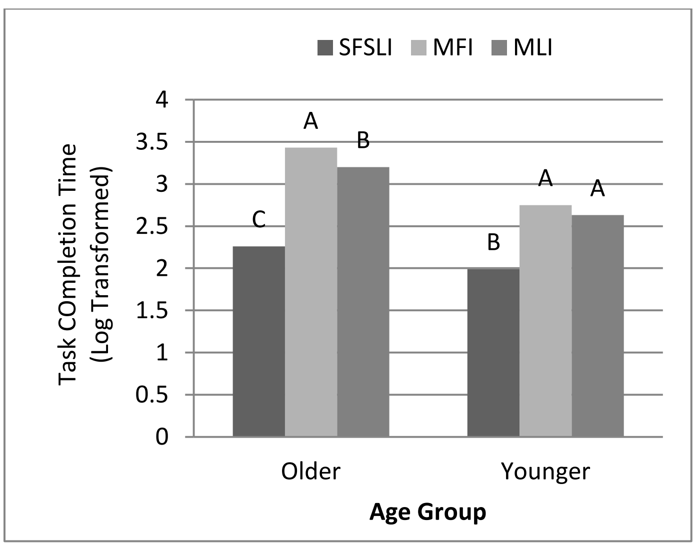

Figure 6.9. Simple Main Effect of Interface Type at Each Level of Age Group. Note: Means with same letter were not significantly different.

Interaction between age group and trial. The interaction between the age group and trial is shown in Figure 6.10.

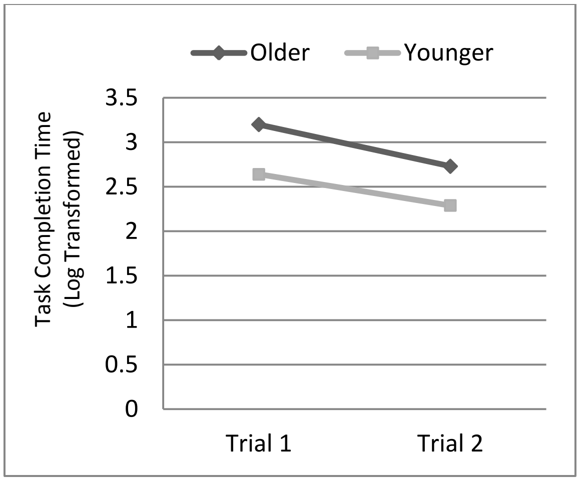

Figure 6.10. Interaction of Age Group and Trial.

A test of simple main effects was conducted looking at age group differences in task completion time at each level of trial. With a Bonferroni correction, results showed that there were significant age group differences for both trial 1 and trial 2. As shown in Figure 6.10 and Figure 6.11, the age-group difference in task completion time was more pronounced during trial 1 than during trial 2.

Figure 6.11. Simple Main Effect of Age Group at Each Level of Trial. Note: Means with same letter were not significantly different.

Another test of simple main effects was conducted looking at trial differences in task completion time at each level of age group. With a Bonferroni correction, the results showed that task completion time was significantly different between the two trials for both older group and younger group. With a Bonferroni correction, results showed that trial 2 was completed significantly faster than trial 1 for both groups. Besides, as shown in Figure 6.12, the task completion time between the two trials was more pronounced for the older group.

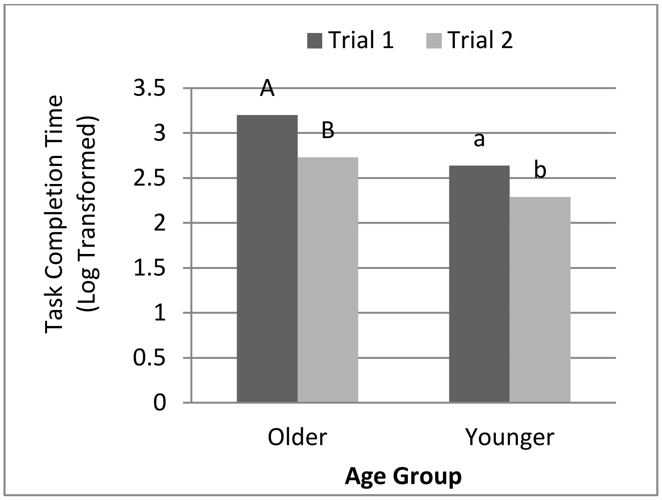

Figure 6.12. Simple Main Effect of Trial at Each Level of Age Group. Note: Means with same letter were not significantly different.

Interaction between interface type and trial. The interaction between the interface type and trial is shown in Figure 6.13.

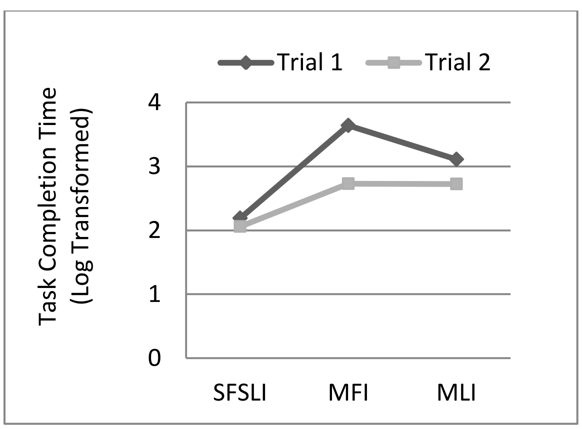

Figure 6.13. Interaction of Interface Type and Trial.

A test of simple main effects was conducted looking at trial differences in task completion time at each level of interface type. With a Bonferroni correction, results showed that trial 2 was completed significantly faster than was trial 1 for each interface type. As shown in Figure 6.13 and Figure 6.14, the task completion time difference between the two trials was the most pronounced for the MFI and the least pronounced for the SFSLI.

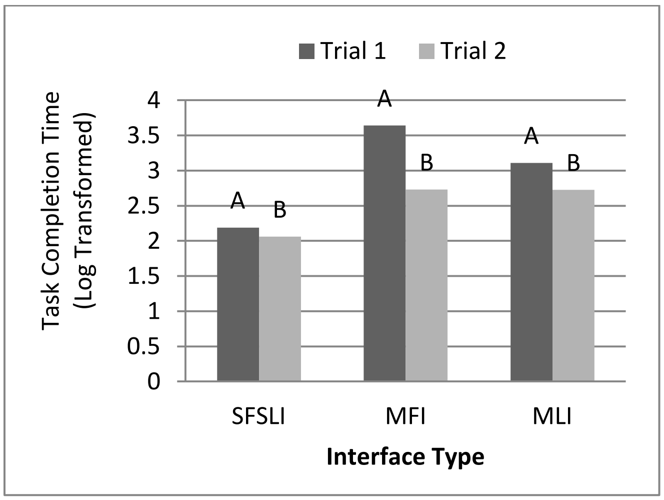

Figure 6.14. Simple Main Effect of Trial at Each Level of Interface Type. Note: Means with same letter were not significantly different.

Another test of simple main effects was conducted looking at interface differences in task completion time at each level of trial. With a Bonferroni correction, results showed that task completion time was significantly different among the three interface types for both trial 1 and trial 2. Tukey's HSD test was carried out to determine which conditions were significantly different for both trials. Results of the Tukey's HSD test ($p < 0.05$) showed different patterns for the two trials. For trial 1, task completion time of the MFI was significantly longer than that of the MLI, and the task completion time of the MLI was significantly longer than that of the SFSLI. For trial 2, the task completion time of the MFI and the MLI was significantly longer than that of the SFSLI, and the task completion time of the MFI and the MLI were not significantly different from one another (Figure 6.15).

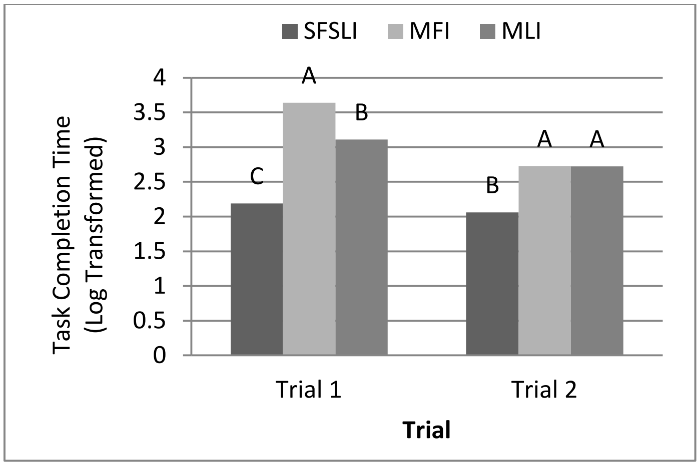

Figure 6.15. Simple Main Effect of Interface Type at Each Level of Trial. Note: Means with same letter were not significantly different.

Workload. Table 6.10 shows older adults' self-reported workload of their interactions with the three interface types, and Table 6.11 shows younger adults' self-reported workload. Six aspects were assessed in the workload questionnaire, including mental workload, physical workload, temporal workload, effort, frustration, and success. An overall workload was calculated taking into account all six aspects.

Table 6.10.
Self-Reported Workload of the Three Interface Types (Older Group)

	Older Group (n=30) Mean (Std Dev)		
	SFSLI	MFI	MLI
Overall Workload	1.73 (1.07)	4.65 (1.92)	3.7 (1.8)
Mental Workload	2.17 (1.32)	6.6 (2.31)	5.23 (2.21)
Physical Workload	1.5 (0.78)	3.03 (2.06)	2.67 (1.88)
Temporal Workload	2.27 (1.8)	4.83 (2.68)	4.23 (2.49)
Effort	1.87 (1.11)	5.63 (2.57)	4.43 (2.5)
Frustration	1.7 (1.21)	5.5 (2.96)	3.73 (2.75)
Success	9.13 (1.61)	7.7 (1.9)	8.1 (2.17)

Table 6.11.
Self-Reported Workload of the Three Interface Types (Younger Group)

	Younger Group (n=30) Mean (Std Dev)		
	SFSLI	MFI	MLI
Overall Workload	2.09 (1.13)	3.92 (1.79)	3.03 (1.32)
Mental Workload	2.9 (1.6)	5.97 (2.11)	4.7 (2.1)
Physical Workload	1.47 (0.63)	2.47 (1.94)	2.33 (1.35)
Temporal Workload	3.03 (2.22)	4.7 (2.42)	3.87 (2.27)
Effort	2.13 (1.5)	4.33 (2.22)	3.5 (1.96)
Frustration	1.73 (1.23)	3.63 (2.44)	2.37 (1.3)
Success	8.73 (1.66)	7.57 (2.24)	8.57 (1.7)

Overall workload. A Friedman's test was carried out to assess whether the overall workload was significantly different among the three interface types for each age group. Results showed that there was significant difference among the three interface types for the older group (χ^2 (2) = 48.27, $p < 0.0001$) and for the younger group (χ^2 (2) = 36.38, $p < 0.0001$).

Pairwise comparisons with Bonferroni correction were performed to determine which interface types were significantly different (with a critical alpha level at 0.05/3 = 0.0167). Results showed the same pattern for the two age groups. For both age groups, the overall workload was significantly different between the SFSLI and the MFI (younger group: $p < 0.0001$; older group: $p < 0.0001$)), the SFSLI and the MLI (younger: $p < 0.0001$; older: $p < 0.0001$), and the MFI and the MLI (younger group: $p = 0.0001$; older group: $p = 0.0027$). As shown in Figure 6.16, for both age groups, the overall workload of the MFI was significantly higher than that of the MLI, and the overall workload of the MLI was significantly higher than that of the SFSLI.

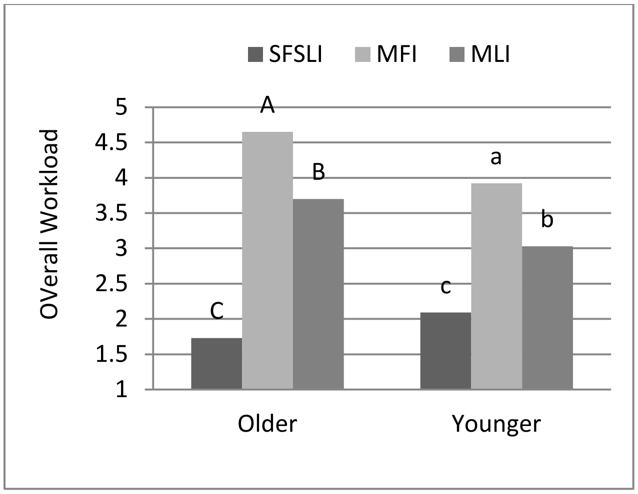

Figure 6.16. Overall Workload for the Three Interface Types. Note: Means with same letter were not significantly different.

Friedman's tests were carried out to assess each of the six items assessed in the workload questionnaire, including mental workload, physical workload, temporal workload, effort, frustration, and success. The Friedman's tests were conducted for older adult group and younger adults group separately. Pairwise comparisons with Bonferroni correction were performed to determine which conditions were significantly different (with a critical alpha level at 0.05/3 = 0.0167).

Mental workload. Results of the Friedman's test showed that mental workload was significantly different among the three interface types for the older group (χ^2 (2) = 47.53, $p <$ 0.0001) and the younger group (χ^2 (2) = 37.01, $p < 0.0001$). Results of the pairwise comparisons showed the same pattern for the two age groups. For both age groups, the mental workload was significantly different between the SFSLI and the MFI (younger group: $p < 0.0001$; older group: $p < 0.0001$), the SFSLI and the MLI (younger group: $p < 0.0001$; older group: $p < 0.0001$), and the MFI and the MLI (younger group: $p < 0.0001$; older group: $p = 0.0012$). Figure 6.17 shows the results of mental workload for both groups.

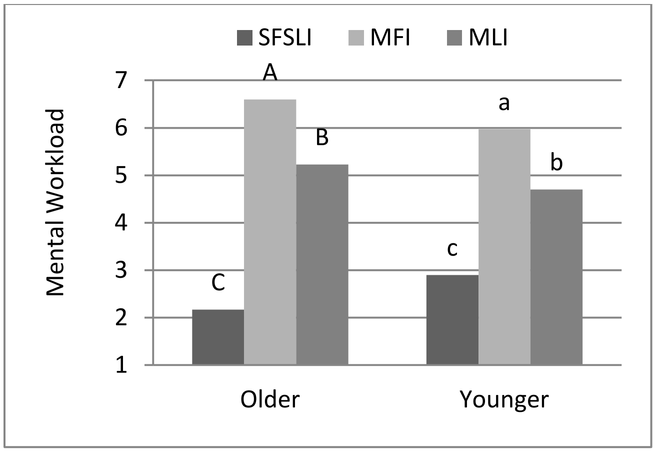

Figure 6.17. Mental Workload for the Three Interface Types. Note: Means with same letter were not significantly different.

Physical workload. Results of the Friedman's test showed that physical workload was significantly different among the three interface types for the older group (χ^2 (2) = 30.28, $p <$ 0.0001) and for the younger group (χ^2 (2) = 25.04, $p < 0.0001$). Results of the pairwise comparison showed the same pattern for the two age groups. For the older group, physical workload was significantly different between the SFSLI and the MFI (younger group: $p <$ 0.0001; older group: $p < 0.0001$), and the SFSLI and the MLI (younger group: $p = 0.0001$; older group: $p < 0.0001$). Figure 6.18 shows the results of physical workload for both groups.

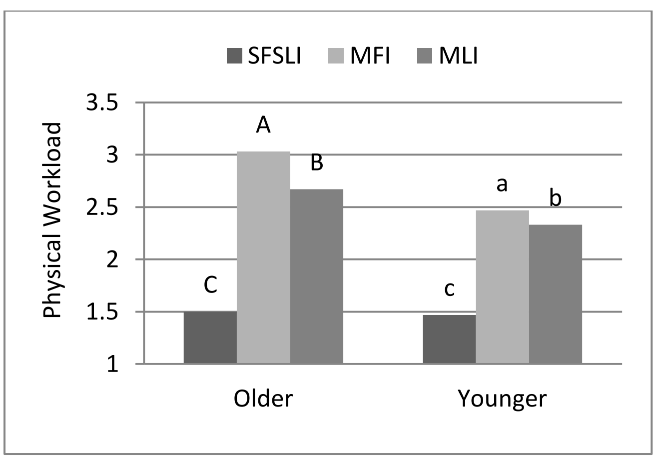

Figure 6.18. Physical Workload for the Three Interface Types. Note: Means with same letter were not significantly different.

Temporal workload. Results of the Friedman's test showed that temporal workload was significantly different for the older group (χ^2 (2) = 31.43, p < 0.0001) and for the younger group (χ^2 (2) = 26.42, p < 0.0001). However, pairwise comparison showed different patterns for the two age groups. For the older group, temporal workload was significantly different between the SFSLI and the MFI (p < 0.0001), and the SFSLI and the MLI (p < 0.0001). For the younger group, temporal workload was significantly different between the SFSLI and the MFI (p < 0.0001), the SFSLI and the MLI (p = 0.0046), and the MFI and the MLI (p = 0.007). Figure 6.19 shows the results of temporal workload for both groups.

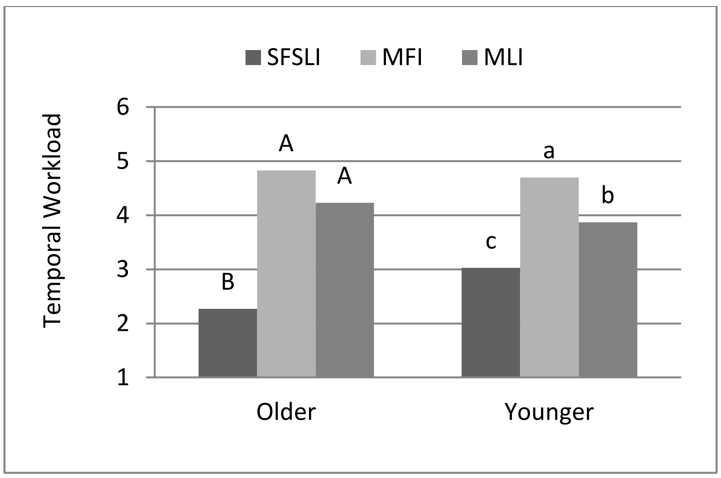

Figure 6.19. Temporal Workload for the Three Interface Types. Note: Means with same letter were not significantly different.

Effort. Results of the Friedman's test showed that effort was significantly different for the older group (χ^2 (2) = 45.31, p < 0.0001) and for the younger group (χ^2 (2) = 35.12, p < 0.0001). Pairwise comparison showed the same pattern for the two age groups. For both age groups, effort was significantly different between the SFSLI and the MFI (younger group: p < 0.0001; older group: p < 0.0001), the SFSLI and the MLI (younger group: p < 0.0001; older group: p < 0.0001), and the MFI and the MLI (younger group: p = 0.0012; older group: p = 0.0033). Figure 6.20 shows the results of effort for both groups.

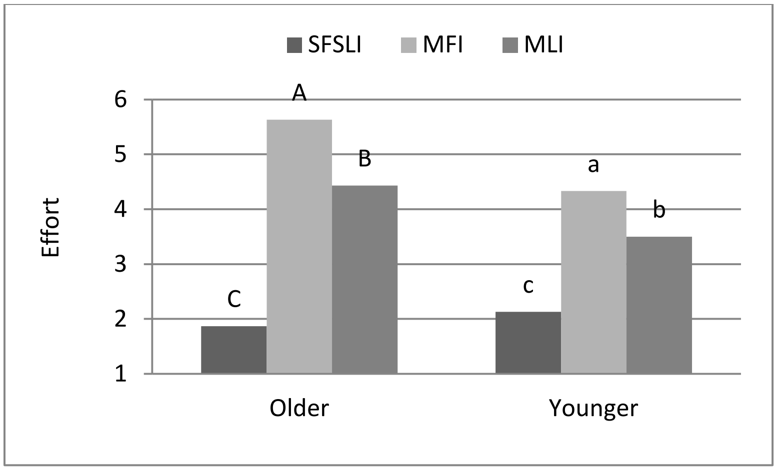

Figure 6.20. Effort for the Three Interface Types. Note: Means with same letter were not significantly different.

Frustration. Results of the Friedman's test showed that frustration was significantly different for the older group (χ^2 (2) = 33.57, p < 0.0001) and for the younger group (χ^2 (2) = 26.95, p < 0.0001). Pairwise comparison showed the same pattern for the two age groups. For both age groups, frustration was significantly different between the SFSLI and the MFI (younger group: p < 0.0001; older group: p < 0.0001), the SFSLI and the MLI (younger group: p = 0.01; older group: p < 0.0001), and the MFI and the MLI (younger group: p = 0.0002; older group: p = 0.0046). Figure 6.21 shows the results of frustration for both groups.

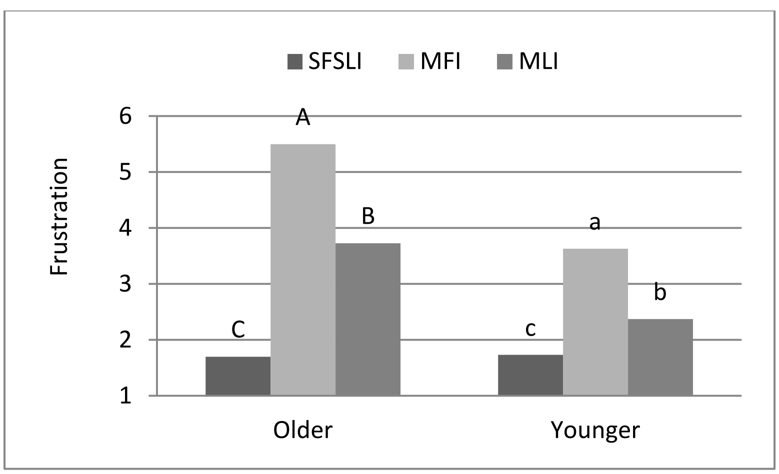

Figure 6.21. Frustration for the Three Interface Types. Note: Means with same letter were not significantly different.

Success. Results of the Friedman's test showed that success was significantly different for the older group (χ^2 (2) = 23.2, p < 0.0001) and for the younger group (χ^2 (2) = 17.72, p < 0.0001). However, pairwise comparison showed different patterns for the two age groups. For the older group, success was significantly different between the SFSLI and the MFI (p < 0.0001), and the SFSLI and the MLI (p = 0.0008). For the younger group, success was significantly different between the SFSLI and the MFI (p = 0.0002), and the MFI and the MLI (p = 0.0009). Figure 6.22 shows the results of success for both groups.

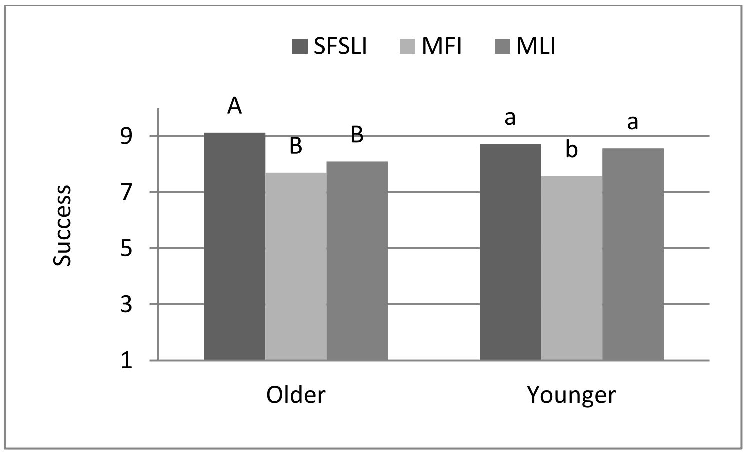

Figure 6.22. Success for the Three Interface Types. Note: Means with same letter were not significantly different.

Satisfaction. Table 6.12 shows participants' self-reported satisfaction with their interactions with the three interface types for both age groups.

Table 6.12.
Satisfaction of the Three Interface Types

	Mean (Std Dev)		
	SFSLI	MFI	MLI
Older Adults (n=30)	1.67 (0.55)	0.07 (1.17)	0.73 (1.17)
Younger Adults (n=30)	1.3 (0.79)	0.2 (1.19)	1.07 (0.98)

Friedman's test was carried out to assess whether satisfaction was significantly different among the three interface types for each age group. Results showed that satisfaction was significantly different among the three interface types for the older group ($\chi^2(2) = 36.72$, $p < 0.0001$) and for the younger group ($\chi^2(2) = 26.64$, $p < 0.0001$).

Pairwise comparisons with Bonferroni correction were performed to determine which conditions were significantly different (with a critical alpha level at 0.05/3 = 0.0167). Results showed different patterns for the two age groups. For the older group, satisfaction was significantly different between the SFSLI and the MFI ($p < 0.0001$), the SFSLI and the MLI ($p < 0.0001$), and the MFI and the MLI ($p = 0.0012$). For the younger group, satisfaction was significantly different between the SFSLI and the MFI ($p = 0.0012$), and the MFI and the MLI ($p < 0.0001$). But there was no significant difference in satisfaction between the SFSLI and the MLI for the younger group. Figure 6.23 shows the results of satisfaction for both groups.

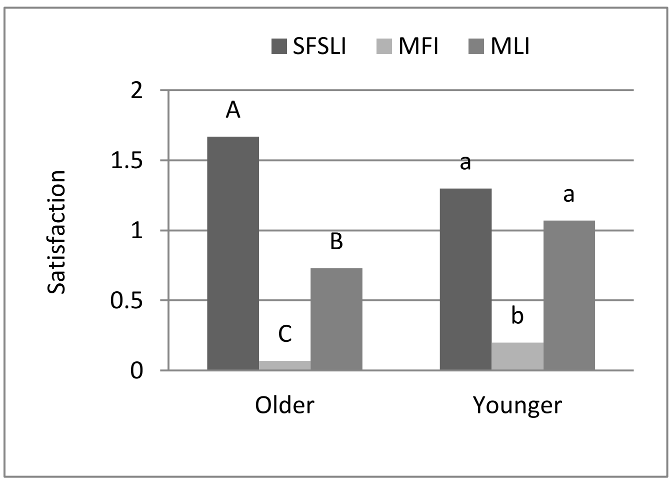

Figure 6.23. Satisfaction for the Three Interface Types. Note: Means with same letter were not significantly different.

Technology Acceptance. As the Technology Acceptance Model suggested, technology acceptance is determined by users' behavioral intention (BI) to use the technology, and the BI is influenced by users' perceived usefulness (PU) and perceived ease of use (PEOU) of the technology. In this study, BI, PU, and PEOU were measured. Cronbach's alpha was computed for each scale to ascertain internal consistency among the items. The results of the Cronbach's alpha are shown in Table 6.13.

Table 6.13.
Scale Reliability (Cronbach's Alpha)-Exp 2

Scale	**Number of Items**	**Reliability**
Behavioral Intention (BI)	2	0.96
Perceived Usefulness (PU)	4	0.97
Perceived Ease of Use (PEOU)	5	0.95

Behavioral intention. Table 6.14 shows participants' self-reported behavior intention (BI) toward the three interface types for both age groups.

Table 6.14.
Behavior Intention toward the Three Interface Types

	Mean (Std Dev)		
	SFSLI	MFI	MLI
Older Adults (n=30)	5 (1.9)	3.95 (1.89)	4.02 (2)
Younger Adults (n=30)	5.25 (1.28)	4.38 (1.21)	4.93 (1.24)

Note: Behavioral Intention (BI) was measured on 7-point Likert scales.

A Friedman's test was carried out to assess whether the Behavioral Intention (BI) was significantly different among the three interface types for each age group. Results showed that there was significant difference among the three interface types for the older group ($\chi^2(2) = 8.37$, $p = 0.015$) and for the younger group ($\chi^2(2) = 11.44$, $p = 0.003$).

Pairwise comparisons with Bonferroni correction were performed to determine which conditions were significantly different (with a critical alpha level at 0.05/3 = 0.0167). Results of the pairwise comparison showed different patterns for the two age groups. For the older group, BI was significantly different between the SFSLI and the MFI ($p = 0.0034$) and between the SFSLI and the MLI ($p = 0.0009$). For the younger group, BI was significantly different between the SFSLI and the MFI ($p = 0.0033$). Figure 6.24 shows the results of behavioral intention (BI) for both groups.

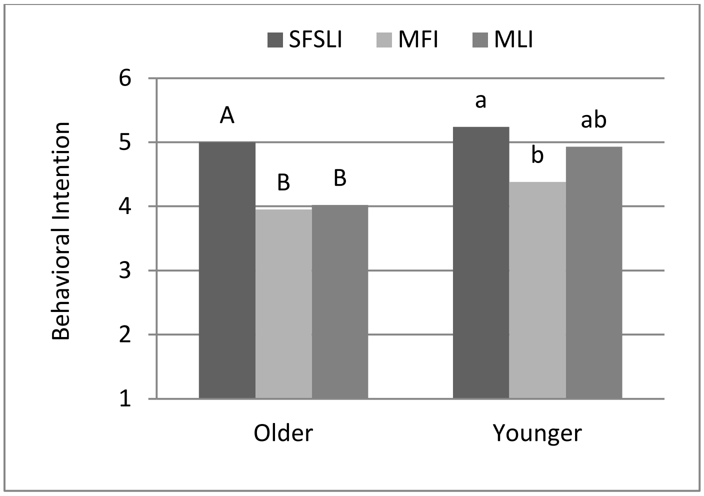

Figure 6.24. Behavioral Intention (BI) for the Three Interface Types. Note: Means with same letter were not significantly different. Score "4," Neutral Attitude; Less than "4" Negative Attitude.

One sample Wilcoxon Signed Rank test was also performed to assess whether the median of Behavioral Intention (BI) of each interface type differed significantly from 4 (a score of 4 meant neutral on the 7-point Likert scale) for both groups (null hypothesis: median of BI equaled 4). Results showed different patterns for the two age groups. For the older group, BI was significantly different from 4 for the SFSLI ($S = 82$, $p = 0.0141$), but there was not enough evidence to reject the null hypothesis for the MFI and the MLI. For the younger group, BI was significantly from 4 for the SFSLI and the MLI, but there was not enough evidence to reject the null hypothesis for the SFSLI. Hence, results revealed that older adults had significantly positive attitudes toward the SFSLI (median of BI was significantly higher than 4), and they had neutral attitudes toward the MFI and the MLI (median of BI equaled 4). Results also revealed that younger adults had significantly positive attitudes toward the SFSLI and the MLI (median of BI was significantly higher than 4), and they had neutral attitudes toward the MFI (median of BI equaled 4).

Perceived usefulness. Table 6.15 shows participants' self-reported perceived usefulness (PU) of the three interface types for both age groups.

Table 6.15.
Perceived Usefulness of the Three Interface Types

	Mean (Std Dev)		
	SFSLI	MFI	MLI
Older Adults (n=30)	5.31 (1.59)	4.63 (1.58)	4.76 (1.68)
Younger Adults (n=30)	5.15 (0.98)	5 (1.11)	5.16 (1)

Note: Perceived Usefulness (PU) was measured on 7-point Likert scales.

Friedman's test was carried out to assess whether the Perceived Usefulness (PU) was significantly different among the three interface types for each age group. Results of the Friedman's test showed that there was significant difference among the three interface types for the older group (χ^2 (2) = 7.65, p = 0.002), but no significance was found for the younger group.

Pairwise comparisons with Bonferroni correction were performed to determine which conditions were significantly different (with a critical alpha level at 0.05/3 = 0.0167). Results of the pairwise comparison showed that for the older group, there was significant difference in perceived usefulness (PU) between the SFSLI and the MFI (p = 0.014). Figure 6.25 shows the results of perceived usefulness (PU) for the older group.

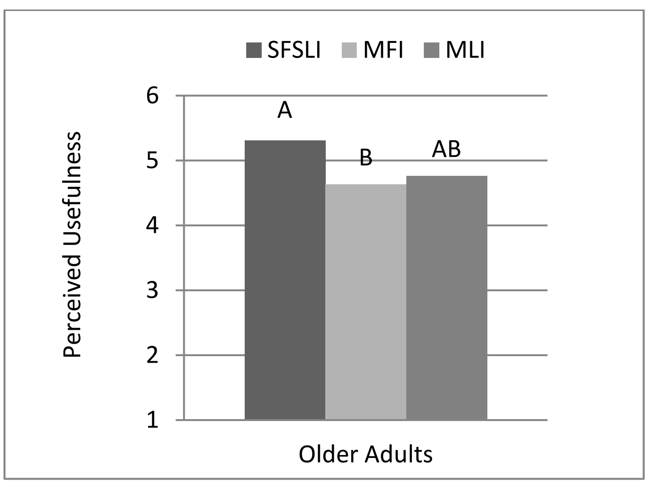

Figure 6.25. Perceived Usefulness (PU) for the Three Interface Types. Note: Means with same letter were not significantly different.

Perceived ease of use. Table 6.16 showed participants' self-reported perceived ease of use (PEOU) of the three interface types for both age groups.

Table 6.16.

Perceived Ease of Use of the Three Interface Types

	Mean (Std Dev)		
	SFSLI	MFI	MLI
Older Adults (n=30)	6.47 (0.81)	4.59 (1.36)	5.37 (1.51)
Younger Adults (n=30)	6.5 (0.74)	4.92 (1.42)	5.86 (1.34)

Note: Perceived Ease of Use (PEOU) was measured on 7-point Likert scales.

Friedman's test was carried out to assess whether the Perceived Ease of Use (PEOU) was significantly different among the three interface types for each age group. Results showed that there were significant differences among the three interface types for the older group (χ^2 (2) = 27.25, $p < 0.0001$) and for the younger group (χ^2 (2) = 31.34, $p < 0.0001$).

Pairwise comparisons with Bonferroni correction were performed to determine which conditions were significantly different (with a critical alpha level at 0.05/3 = 0.0167). Results of the pairwise comparison showed the same pattern for the two age groups. For both age groups, PEOU was significantly different between the SFSLI and the MLI (older group: $p <$ 0.0001; younger group: $p < 0.0001$), the SFSLI and the MLI (older group: $p < 0.0001$; younger group: $p = 0.0023$), and the MFI and the MLI (older group: $p = 0.01$; younger group: $p < 0.0001$). Figure 6.26 shows the results of perceived ease of use (PEOU) for both groups.

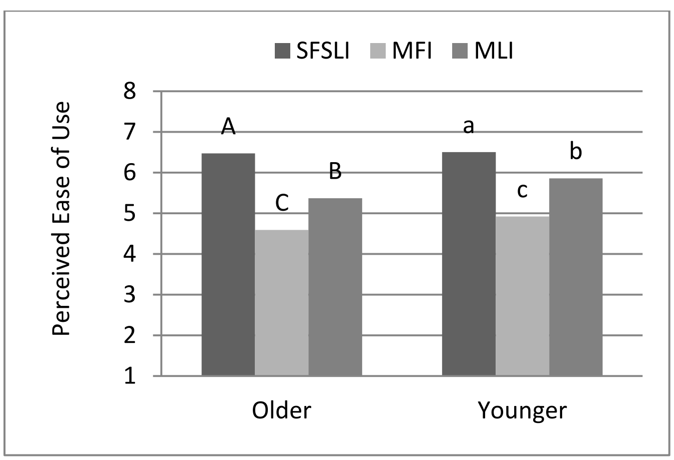

Figure 6.26. Perceived Ease of Use (PEOU) for the Three Interface Types. Note: Means with same letter were not significantly different.

Preference. Two types of preference were assessed for each age group. One type derived by asking each participant to rank his or her own preferences among the three interface types from the most preferred to the least preferred, and the choices were termed "personal preference" in this thesis. The other type was derived by asking each participant to select one interface type they believed that their friends (of similar age and average education levels, health condition levels, and technology experiences) would like the most, and the choices were termed "interpretation of friend's preference" in this thesis.

Personal preference. Table 6.17 shows participant's personal preference among the three interface types for both age groups.

Table 6.17.
Preference of the Three Interface Types

	Mean (Std Dev)		
	SFSLI	MFI	MLI
Older Adults (n=30)	1.33 (0.66)	2.53 (0.63)	2.13 (0.68)
Younger Adults (n=30)	1.37 (0.61)	2.63 (0.61)	2 (0.69)

A Kruskal-Wallis test was conducted to assess whether the preference was significantly different among the three interface types for each age group. Results of the Kruskal-Wallis test showed that preference was significantly different among the three interface types for the older group (χ^2 (2) = 33.23, $p < 0.0001$) and for the younger group (χ^2 (2) = 35.7, $p < 0.0001$).

Pairwise comparisons with Bonferroni correction were performed to determine which conditions were significantly different (with a critical alpha level at 0.05/3 = 0.0167). Results of the pairwise comparison showed different patterns for the two age groups. For the older group, preference was significantly different between the SFSLI and the MFI ($p < 0.0001$) and the SFSLI and the MLI ($p = 0.001$). For the younger group, preference was significantly different between the SFSLI and the MFI ($p < 0.0001$), the SFSLI and the MLI ($p = 0.0058$), and the MFI and the MLI ($p = 0.0058$). Figure 6.27 shows the results of preference for both groups.

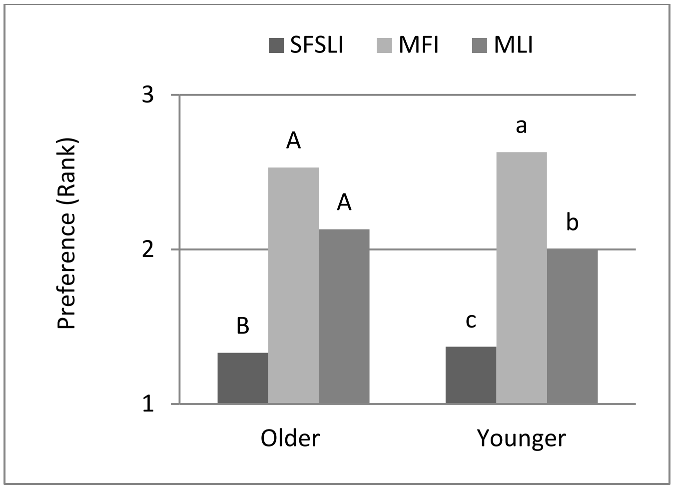

Figure 6.27. Preference for the Three Interface Types. Note: Means with same letter were not significantly different. Score "1," most preferred; "2," secondly preferred; "3," least preferred.

Most preferred. Table 6.18 shows each interface type's number of times being selected as the "most preferred" for both age groups. For both age groups, the SFSLI was selected most often as the "most preferred".

Table 6.18.
Counts of the "Most Preferred" among the Three Interface Types (Personal Preference)

	Count		
	SFSLI	MFI	MLI
Older Adults (n=30)	23	2	5
Younger Adults (n=30)	21	2	7

A Pearson Chi-square test was conducted to assess whether there was a significant relationship between age group and the interface type that was the most preferred. Results showed that there was no significant relationship between age group and the interface type that was the most preferred. In other words, there was no evidence that the two age groups favored (most preferred) the three interface types in significantly different portions.

The open-ended questions were designed to elicit why the SFSLI was the most preferred, and data compiled from responses revealed the same pattern for the two age groups. Both age groups favored the SFSLI mostly because it allowed them to see all the options at once and the interaction was very straightforward.

Least preferred. Table 6.19 shows each interface type's number of times being selected as the "least preferred" type for both age groups. For both age groups, the MFI was selected most often as the "the least preferred."

Table 6.19.
Counts of the "Least Preferred" among the Three Interface Types (Personal Preference)

	Count		
	SFSLI	MFI	MLI
Older Adults (n=30)	3	18	9
Younger Adults (n=30)	2	21	7

A Pearson Chi-square test was conducted to assess whether there was a significant relationship between age group and the interface type that was the least preferred. Results showed that there was no significant relationship between age group and the interface type that was the least preferred. In other words, there was no evidence that the two age groups disfavored (least preferred) the three interface types in significantly different portions.

The open-ended questions were designed to elicit why the MFI was the least preferred, and data compiled from responses revealed the same pattern for the two age groups. Both age groups disfavored the MFI mostly because it was confusing and required learning.

Interpretation of friend's preference. Table 6.20 shows each interface type's number of times being selected as the "most preferred" from a friend's perspective (with similar age of the participant) for both age groups. For both age groups, the SFSLI was selected most often as the "most preferred."

Table 6.20.
Counts of the "Most Preferred" among the Three Interface Types (Friend's Preference)

	Count		
	SFSLI	MFI	MLI
Older Adults (n=30)	26	3	1
Younger Adults (n=30)	18	2	10

A Pearson Chi-square test was conducted to assess whether there was a significant relationship between age group and the interface type that was the most preferred by their friends. Results showed that there was a significant relationship between age group and the interface type that participants perceived as being the most preferred by their friends (p = 0.0098). In other words, there was evidence that the two age groups favored (most preferred) the three interface types in significantly different portions.

A Pearson Chi-square tests were conducted for each pair of interface types with a Bonferroni correction for multiple comparisons (with a critical alpha level at 0.05/3 = 0.0167). Results showed evidence that the two age groups favored (most preferred) the interface types of the SFSLI and the MLI in significantly different portions (p = 0.0052). There was a significantly larger portion of favoring for the MLI in the younger group (Figure 6.28) than that in the older group (Figure 6.29). However, there was no evidence that the two age groups favored (most preferred) the interface types of the SFSLI and the MFI, or the MFI and the MLI in significantly different portions.

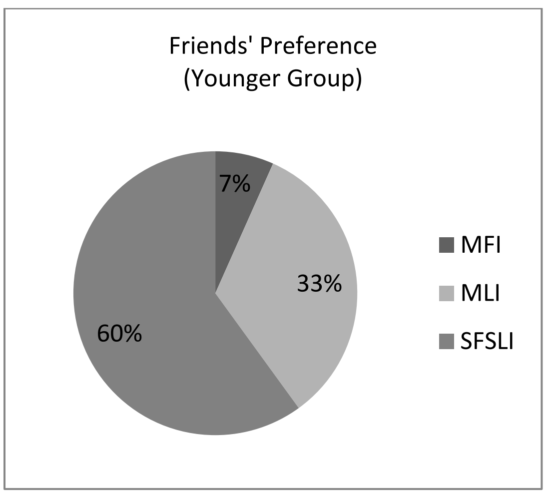

Figure 6.28. Friend’s Preference (Younger Group).

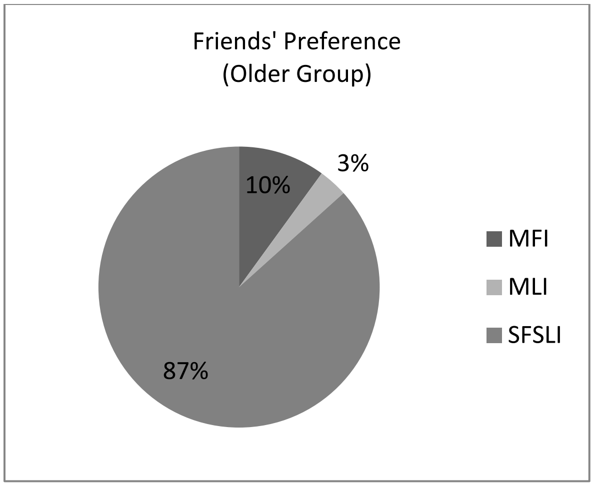

Figure 6.29. Friend’s Preference (Older Group).

Aging factor vs. generation factor. One objective measurement and one subjective measurement in this study helped to understand how the aging factor and the generation factor affected older adults’ interaction with new technologies.

This study objectively assessed whether another significant age-group variable exists other than the abilities score (reaction time, processing speed, and working memory which showed decline during the natural process of aging) to explain the age-group differences in task competion time. If there were another variable, it would imply that generation-related experiences and knowledge differneces between the two age groups also have played roles. This study also measured older adults’ subjective perceptions on how the aging factor and the generation factor affected their interactions and also determine their perceptions on the relative weights of the two factors.

Explaining task completion time. Simple regression was conducted to assess whether ability score was a significant variable to explain the age group differences in task completion time, and also whether there were other significant age group related variables besides the abilities, such as the technology generation-specific experience and knowledge.

Participants were assessed for reaction time, processing speed, and working memory. The ability score of each participant was calculated, taking into account all measurements of all three ability tests. For each participant, each one of the three test scores was converted to z-score (M = mean of the test score of the two age groups; SD = standard deviation of the test score of the two age groups), and the z-scores of the three ability tests were totaled to obtain a value for the participant's ability score.

Simple regression was conducted with ability score (numerical variable) and age group (categorical variable) as independent variables and the log-transformed task completion time as a dependent variable. The original task completion time was transformed to meet the assumptions of simple regression.

Results showed that the ability score variable was significant ($p = 0.0008$), and the age group variable was also significant ($p < 0.0001$), with R-square = 0.18. Results suggested that although a participant's ability was a significant variable, there was significant variance in task completion time that was not covered by this variable. Because the two groups also belonged to two different technology generations (younger group: menu generation; older group: electro-mechanical generation), the age group differences in task completion time could also have been caused by the differences in technology-generation-related experiences and knowledge.

Explaining older adults' difficulties with newer interaction structures (MFI and MLI). During the structured interview, older adults were asked to select the interface types they found difficult to use. If they found the newer interface type (MFI or MLI) difficult to use, they were asked to assign 100 points between the two factors attributable to their difficulties with the new interfaces (the aging factor and the generation factor).

Of all the older participants, 19 older participants had difficulties with the MFI and 5 older participants had difficulties with the MLI, so there were 24 older participants assigned 100 points between the Aging Factor and Generation Factor. Table 6.21 showed the points received by the two factors.

Two older participants did not find any interface type to be difficult. The remaining 4 older adults did not respond because they though other factors influenced their difficulties (such as patience), or they could not understand the question.

Table 6.21.
Aging Factor and Generation Factor (Exp 2)

	Mean (Std Dev)	
	Aging Factor	Generation Factor
Older Adults (n=24)	39.17 (14.35)	60.83 (14.35)

One sample *t*-test was conducted to assess whether the mean of the generation factor was equal to 50 (null hypothesis: mean = 50) and to determine whether the two factors received equal points. Results showed that the null hypothesis could be rejected. The mean of generation factor was significantly different from 50 ($t\ (23) = 3.7$, $p = 0.0012$). So there was significant difference between the aging factor and the generation factor (Figure 6.30). In other words, older adults perceived that the generation factor (incompatibility with their early experience) played a significantly more important role than the aging factor (declines in abilities during the process of aging) in causing their difficulties in using the new interfaces (with new interaction structures).

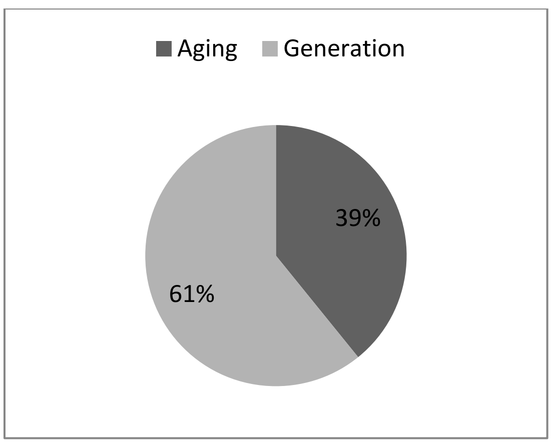

Figure 6.30. Aging Factor vs. Generation Factor (Exp 2).

Discussion

Influences of early experiences with the interaction structure. Results showed that older adults' early experiences and their corresponding great familiarity with the interaction structure of the electro-mechanical style had given them some advantages with respect to task completion time. There was a significant interaction between age group and interface type on task completion time, and the age-group difference in task completion time was the least pronounced for the SFSLI with which older adults grew up. In addition, the SFSLI outperformed the other two interface types (MFI and MLI) in all aspects of usability measurements, including task completion time, workload, and satisfaction.

Hence, older adults' early experiences with the interaction structure of the electro-mechanical style facilitated their interactions with the SFSLI and offset the ability differences from the younger adults to some extent. As shown in task analysis of the three interface types (Appendix K), older adults' better performance with the SFSLI might also partly be due to the lower perceptual and cognitive demands of this interaction structure.

Results of behavioral intention (BI) showed that older adults were more likely to accept a new technology with the SFSLI than that with the MFI and the MLI. In addition, results showed older adults perceived the SFSLI as easier to use than the MFI and MLI, and the SFSLI as more useful than the MFI. Because only the user interfaces of the new technologies were prototyped and the functions were not prototyped, there were no actual stimuli produced as a result of interactions with the new technologies. Hence, the perceived usefulness of the three interface types was expected to be the same. However, the SFSLI was perceived to be significantly more useful than the MFI by older adults, and it might have been influenced by the factor of perceived ease of use.

It has been suggested that characteristics of the technology other than PU and PEOU may also impact technology acceptance, such as perceived newness, which is about the level of innovation (Caine et al., 2006). People are more inclined to accept the technologies that they believed are modern and fresh than they are to accept those that they believe are out of date (Gruen, 1960). However, none of the older participants mentioned that the SFSLI seemed out of date, although it represented the particular interaction structure of the electro-mechanical style. It might be attributable to the fact that all interfaces were prototyped on a touch-screen device (iPad) that looked modern. Also, the interaction structure was on a purely structural level, which was harder to be discerned compared to the interaction technique.

Preference results showed that older adults most preferred the SFSLI. Out of 30 older participants, 23 selected the SFSLI as the interface type that they most preferred, and 26 older participants selected the SFSLI as the interface type that they believed that their friends of similar age would like the most.

Feature of one control with single function. The only difference between the SFSLI and the MFI was the number of functions per control. The SFSLI featured one control with single function while the MFI featured one control with multiple functions.

Results showed that the SFSLI outperformed the MFI in all aspects of usability measurements, including task completion time, workload, and satisfaction. This result was consistent with the findings of Lewis and Clarkson (2005) and Freudenthal (1999), who all also found that older adults had serious usability problems with the interface type of one control with multiple functions. The difficulties might be due to older adults being less familiar with this interaction structure and its added perceptual and cognitive demands, especially reasoning and learning abilities. In addition, in this experiment, older participants were observed to have the most difficulties with the MFI when they were asked to select a predefined setting on the new technologies for the first time (trial 1, subtask 2). For this subtask, older adults had to cycle through the "mode" button and observe the associated different feedback on the display screen to figure out the mapping relationship between a specific control and its functions under each mode.

Results of behavioral intention (BI) showed that older adults were more likely to accept the SFSLI than they were to accept the MFI. In addition, results showed that older adults perceived the SFSLI as more useful than the MFI, and the SFSLI as easier to use than the MFI.

Results of personal preferences showed that older adults preferred the SFSLI to the MFI. Out of 30 older participants, 23 most preferred the SFSLI, whereas 2 older participants most preferred the MFI. For interpretation of friend's preferences, 26 older participants believed their friends (of similar age) would like the SFSLI the most, whereas only 1 older participant picked the MFI.

Hence, results suggested that losing the feature of one control with single function of the electro-mechanical style would reduce usability and acceptance of new technologies.

Feature of single-layered structure. The only difference between the SFSLI and the MLI was the number of layers. The SFSLI featured a single layer while the MLI featured multiple layers.

Results showed that the SFSLI outperformed the MLI in all aspects of usability measurements, including task completion time, workload, and satisfaction. This result is consistent with the findings of Docampo Rama (2001), who found that older adults performed the tasks more slowly and less accurately with the multi-layered interface than they did with the single-layered interface. The difficulties might be due to older adults being less familiar with this interaction structure and also its added perceptual and cognitive demands, especially working memory and learning abilities. In addition, in this experiment, older participants were observed to have the most difficulties with the MLI when they were asked to select a predefined setting on the new technologies which involved returning to an upper level for the first time (trial 1, subtask 3). Older adults were also observed to have fewer difficulties with going down to deeper levels than they did with going up and returning to previous levels along the same path in the hierarchical menu structure of the MLI.

However, for the younger group, the task completion time of the SFSLI was not significantly different from that of the MLI, the perceived success (one aspect of workload) of the SFSLI was not significantly different from that of the MLI, and the satisfaction of the SFSLI was not significantly different from the MLI. It might have been because the younger group (menu generation) grew up with the multi-layered operation (the interaction structure of the menu style), and they had acquired the skills of interacting with this particular interaction structure.

Results of behavioral intention (BI) showed that older adults were more likely to accept the SFSLI than they were to accept the MLI. In addition, results showed that older adults perceived the SFSLI as more useful than the MLI, and the SFSLI as easier to use than the MLI. However, for the younger group, the behavioral intention (BI) of the SFSLI was not significantly different from that of the MLI. It also might have been because the younger group (menu generation) grew up with the multi-layered operation.

Results of personal preferences showed that older adults preferred the SFSLI to the MFI. Out of 30 older participants, 23 most preferred the SFSLI, whereas only 5 older participants most preferred the MFI. For interpretation of friend's preference, 26 older participants believed their friends (of similar age) would like the SFSLI the most, whereas only 1 older participant picked the MLI. However, for the younger group's interpretation of friend's preference, 18 participants believed their friends (of similar age) would like the SFSLI the most, and 10 participants picked the MLI. In addition, the results revealed that there was a significant relationship between age group and the interface type that was the most preferred. In other words, the two groups favored the SFSLI and the MLI in significantly different portions, whereby the younger group significantly more portions of the MLI.

Hence, losing the feature of single-layered structure of the electro-mechanical style would reduce usability and acceptance of new technologies.

One control with single function vs. single-layered structure. Results indicated that both the feature of one control with single function and the feature of single-layered interaction of an electro-mechanical style had influenced the usability, acceptance, and preference of new technologies by older adults.

Results showed that the task completion time of the MFI was significantly longer than that of the MLI. However, for the younger group, the task completion time of the MFI and the MLI was not significantly different. Results showed that the workload of the MFI was significantly higher than that of the MLI. Results also showed that the satisfaction of the MFI was significantly lower than that of the MLI.

Results of the behavioral intention (BI) showed that the MFI and the MLI were not significantly different from each other. The perceived usefulness (PU) of the MFI and the MLI were also not significantly different from each other. The perceived ease of use (PEOU) of the MFI was significantly lower than that of the MLI.

Results of personal preferences showed that the MFI and the MLI were not significantly different from each other.

Hence, losing the feature of one control with single function would impair usability and acceptance of new technologies by older adults to a greater extent than would losing the feature of single-layered structure.

Aging-related factor vs. generation-related factor. Results of simple regression showed that ability score (numerical variable) and age group (categorical variable) were significant variables to explain the age-group differences in task completion time. It implied that other significant age-group related variables in addition to the abilities played significant roles in older adults' performances. The two age groups also belonged to two different technology generations (younger group: menu generation; older group: electro-mechanical generation). Hence, the age-group variance in task performance could be caused by the differences in age-related abilities, as well as generation-related experiences and knowledge.

This finding was further reported by the data from the structured interviews. Older adults assigned 100 points between the two factors attributable to their difficulties in using the interfaces (the age factor and the generation factor). Results showed that the generation factor received significantly more points than the aging factor received, which implied that the older adults perceived that the generation-related experiences and knowledge played a more important role than the age-related abilities in their interactions with the new interfaces.

This result is consistent with the findings of Blackler et al. (2009), who suggested that a complex mix of cognitive abilities and prior experiences is the most important factor that affects how older people use new interfaces.

Conclusion

Older adults' early experiences with the one control with single function and single-layered operation gave them some advantages with respect to task completion time, in that the age group difference was the least pronounced for the SFSLI. The SFSLI outperformed the other interface types (the MFI and the MLI) in terms of usability, acceptance, and preference. It might be because of older adults' familiarity with this particular interaction structure but may also be partly due to its lower perceptual and cognitive demands. Hence, it was recommended that the 1:1 mapping between function and control and the single-layered operation be used when developing user interfaces of new technologies for older adults.

In addition, results revealed that both the aging factor (age-related ability declines) and the generation factor (early experiences of the specific technology generation) affected how older adults interacted with new interfaces; older adults perceived that the generation factor played a greater role than the aging factor did in their interactions with new interfaces (interaction structures).

CHAPTER 7

DISCUSSION OF EXPERIMENT 1 AND EXPERIMENT 2

Comparison of Results of Experiment 1 and Experiment 2

This research investigated the effects of older adults' early experiences with interaction style on usability and acceptance of new technologies. Historical analysis has indentified that today's older adults typically belong to the electro-mechanical generation and were exposed to the electro-mechanical style during their formative years (10–25 years old). The two experiments in this research focused on two different components of the electro-mechanical style. Experiment 1 focused on the interaction technique, and Experiment 2 focused on the interaction structure.

Experiment 1 assessed four interface types with different interaction techniques across historical changes, including the Physical Dial Interface (PDI), the Physical Button Interface (PBI), the Visualized Button Interface (VBI), and the Visualized Dial Interface (VDI). The PDI represented the interaction technique of the electro-mechanical style.

Experiment 2 assessed three interface types with different interaction structures across historical changes, including the One Control with Single Function and Single-Layered Interface (SFSLI), the One Control with Multi-Function Interface (MFI), and the Multi-Layered Interface (MLI). The SFSLI represented the interaction structure of the electro-mechanical style.

Similarity. Results of the two experiments were similar in the effects of early experiences with the two components of the electro-mechanical style on task completion time. Results were also similar in the mixed effects of the aging factor and the generation factor on older adults' interactions with new interfaces.

Task completion time. Results showed that older adults' early experiences with the two components of an electro-mechanical style (the interaction technique and the interaction structure) both positively influenced their task completion time. In Experiment 1, the age-group differences in task completion time were the least pronounced for the PDI among all the interaction techniques assessed. In Experiment 2, the age-group differences in task completion time were the least pronounced for the SFSLI among all the interaction structures assessed. It implied that older adults' early experiences with the electro-mechanical style offset the age-related ability difference to some extent.

Aging factor and generation factor. Results showed that both declines in age-related ability and technology-generation-related experience differences played important roles in older adults' interactions with interfaces. In both experiments, ability score was not the only significant variable to explain the age group difference in task completion time. There were other age-group differences that were not explained by the ability score, which suggested that the technology-generation-related knowledge and experiences could also have played significant roles. Older adults confirmed in the structure interviews in both experiments that both the aging factor and the generation factor affected their interactions with new interface types.

Differences. Results of the two experiments were different in the effects of early experiences with the two components of the electro-mechanical style on usability and acceptance. Results were also different in the relative weights of two factors (the aging factor and the generation factor) were attributable to older adults' interaction difficulties with new interface types.

Usability. Results showed that the impact of older adults' early experiences with the interaction structure of the electro-mechanical style on usability was greater than that with the interaction technique of the electro-mechanical style. Older adults had more difficulties adapting to newer interaction structures than they did adapting to newer interaction techniques beyond their technology generation.

Results of Experiment 1 showed that although older adults grew up with physical dials, and turning a physical dial was well-learned and well-rehearsed, they would benefit more from using a recent and newer interaction technique, the visualized button on a touch-screen device. Tapping a visualized button required much less physical effort and involved much less movement. The aging characteristics of older adults, especially the physical aspects of aging, made turning the dials more difficult, which could override their early experiences with physical dials.

Results of Experiment 2 showed that older adults would benefit the most from the interaction structure that they grew up with (SFSLI). Older adults were exposed to products featuring one control with one function and single-layered interface during their formative years, during which time they formed their most established knowledge about the interaction structure of products. Unlike the younger generation who grew up using computers, digital music players, cell phones, and products of the digital age featuring menu structure, older adults typically were not trained and did not have adequate skills of understanding and interacting with a user interface of a hierarchical structure.

Acceptance. Results showed that older adults were more likely to reject new technologies employing the interaction technique of the electro-mechanical style, while they were more likely to accept new technologies employing the interaction structure of the electro-mechanical style.

Results of Experiment 1 showed that older adults had significantly negative attitudes toward new technologies employing the interaction technique they grew up with (PDI), and they had neutral attitudes toward technologies employing the VBI and the VDI. In addition, it seemed to be influenced by the factor of perceived newness, rather than by perceived usefulness or perceived ease of use. Several older adults specifically commented that the PDI seemed old-fashioned and dated.

Results of Experiment 2 showed that older adults had significantly positive attitudes toward new technologies employing the interaction structure they grew up with (SFSLI), and they had neutral attitudes toward the MFI and the MLI. In addition, it seemed to be influenced by the factors of perceived usefulness and perceived ease of use. None of the older adults commented that the SFSLI seemed old-fashioned or dated.

Aging factor vs. generation factor. Results of Experiment 1 revealed that older adults perceived the aging factor (ability declines) and the generation factor (incompatibility with early experiences) to play equally important roles in causing their difficulties in interacting with new interaction techniques. Results of Experiment 2 revealed that older adults perceived the generation factor (incompatibility with early experience) to play a significantly more important role than that of the aging factor (ability declines) in causing their difficulties in interacting with new interaction structures.

Early experiences with interaction technique vs. early experiences with interaction structure. Results of Experiment 1 and Experiment 2 showed that the impact of older adults' early experiences with the interaction structure of the electro-mechanical style was greater than that of the interaction technique on their future interactions with technologies with respect to usability and technology acceptance. It implied that although the interaction technique of the electro-mechanical style was more pronounced (it comprised the appearance of a user interface), the interaction structure of the electro-mechanical style (the straightforward 1:1 mapping between control and function and the direct single-layered operation) on a purely structural level of a user interface was the essence of electro-mechanical style.

Implications of Proposed Framework

This research has several implications for the proposed framework of guiding interface design (in Chapter 3) for older adults.

First, the two experiments in this research showed that both the aging factor and the generation factor affected older adults' interactions with new interfaces. It empirically supported the proposed framework concerning the necessity of taking into account of both older adults' aging-related ability changes and their prior knowledge and experience as an older generation (by applying both the aging-oriented approach and the generation-oriented approach) during the process of interface design for older adults.

Second, the results of this research also supported the proposed framework concerning the necessity of comparison dialogue between the two preliminary products generated from the aging-oriented approach and the generation-oriented approach because the two preliminary products from the two approaches are not necessarily the same. For Experiment 1, focusing on designing interaction technique for older adults, the aging-oriented approach would recommend the VBI, because it required the least physical effort for the aging hand, while the generation-oriented approach would recommend the PDI, because it was the type of interaction technique that older adults grew up with and had great familiarity with. Hence, the two preliminary products generated from the two approaches for Experiment 1 were different. For Experiment 2, focusing on designing interaction structure for older adults, the aging-oriented approach would recommend the SFSLI, because it required the least cognitive and physical effort for older adults, and the generation-oriented approach would also recommend the SFSLI, because it was the type of interaction structure that older adults grew up with and had great familiarity with. Hence, the two preliminary products generated from the two approaches for Experiment 2 were the same.

Third, this research investigated one aspect of older adults' generation-specific knowledge and experiences listed in the proposed framework of guiding interface design for older adults, which was about their knowledge on a tools level. More specifically, it was about older adults' early experiences with the predominant interaction style of consumer products that was collectively acquired during their formative years. This research documented the whole process of investigation. This study started with collecting resources to study and understand older adults' generation-specific knowledge and experiences with interaction style by reviewing historical overview and analysis on the development of interaction style. Then this study designed experiments and developed prototypes to assess how older adults prior knowledge and experiences with each main component of the electro-mechanical style affected usability and acceptance of new technologies. Finally this research provided design recommendations and insights based on research finding. This research would encourage more studies to investigate other aspects of older adults' generation-specific knowledge and experiences listed in the proposed framework using similar approaches to this investigation.

Fourth, this research also investigated the issue of technology acceptance, which was not addressed in the proposed framework. The proposed framework attempted to assist designers for maximum usability for older adults. However, it is crucial to ensure that older adults are not only able to use the interfaces, but also willing to use them. This research suggested that high usability did not always guarantee high technology acceptance, which might be influenced by the factor of perceived newness. For example, although the age difference in task completion time was the least pronounced for the Physical Dial Interface

(PDI), older adults had significantly negative attitudes toward new technologies with the PDI because it looked old-fashioned. Hence, it would be important to consider both the usability and acceptance issues, especially when applying the generation-oriented approach that leverages older adults' prior knowledge and experiences.

CHAPTER 8
GENERAL CONCLUSIONS

Major Findings

Effects of early experiences on usability. Results from Experiment 1 and Experiment 2 revealed that older adults' early experiences with both of the two components of the electro-mechanical style had positive effects on usability. The age-group differences in task completion time were the least pronounced for the PDI (Experiment 1) and the SFSLI (Experiment 2). It suggested that older adults' knowledge and skills developed during their formative years had given them some advantages in operating the particular interaction technique and the particular interaction structure of the electro-mechanical style.

However, it is important to note that a skill once well-learned and well-rehearsed during one's formative years could be impaired to some extent by aging. In Experiment 1, decline in strength, dexterity, and hand-eye coordination due to the natural process of aging made it difficult for older adults to achieve the movement of turning a physical dial. The operation of turning a physical dial is a good example to show and emphasize that designers should not set expectations or assume that older adults would not have usability problems with the products and interfaces they had used during their formative years. As suggested in the proposed framework, a holistic view of taking both aging perspective and generation perspective is crucial.

Effects of early experiences on acceptance. Results of the two experiments showed that older adults' early experiences with interaction style affected acceptance of new technologies in two ways.

First, older adults had negative attitudes toward new technologies employing features that they could easily discern belonged to the past (the features were function-related but not aesthetics-related). In Experiment 1, older adults had less behavioral intention to use and were less satisfied with new technologies employing the interaction technique belonged to the electro-mechanical style (physical dial interface) mostly because it seemed old-fashioned and dated. However, in Experiment 2, older adults did not have negative attitudes toward new technologies employing the interaction structure belonging to the electro-mechanical style (1:1 mapping and single-layered operation) and did not consider it old-fashioned. It might be because the component of the interaction structure of the electro-mechanical style is on a purely structural level and harder to be discerned than the component of the interaction technique (comprised the appearance of a user interface). Hence, older adults were found to be less likely to accept new technologies that employed features with a visible tag of "the past". However, we expected that there might be other mediating variables in this relationship, such as technology experience, technology anxiety, and personality. For example, older adults with lower technology experiences and higher technology anxiety might place a lighter emphasis on the importance of perceived newness on accepting new technologies, and they therefore might not have significantly negative attitudes toward new technologies employing features that they could discern belonged to their formative years.

Second, by combining data of the two age groups (technology generations), we found that early experiences also affected technology acceptance by influencing expectations. More specifically, one's early experiences regarding the demands of user interface might shape a critical threshold or critical level of tolerance of interface demands, which might have an impact on one's future acceptance of new technologies. As shown in Figure 8.1, demands of different interfaces could be put in a continuum, where D_{min} represents a theoretical value of the minimum interface demands, D_{max} represents a theoretical value of the maximum interface demands, and D_{ee} represents the demands of the interface that one was exposed to during early experience (D_{ee} locates between D_{min} and D_{max}). With other characteristics of the new technologies remaining constant (including the perceived usefulness, perceived newness, and so forth), if the demands of the interface type of the new technology are lower than the D_{ee}, the interface is more likely to receive neutral to positive attitudes. However, if the demands of the interface type are higher than the D_{ee}, the interface is more likely to receive neutral to negative attitudes. This relationship was termed "Demands-Acceptance Relationship (Early Experience)" in this thesis.

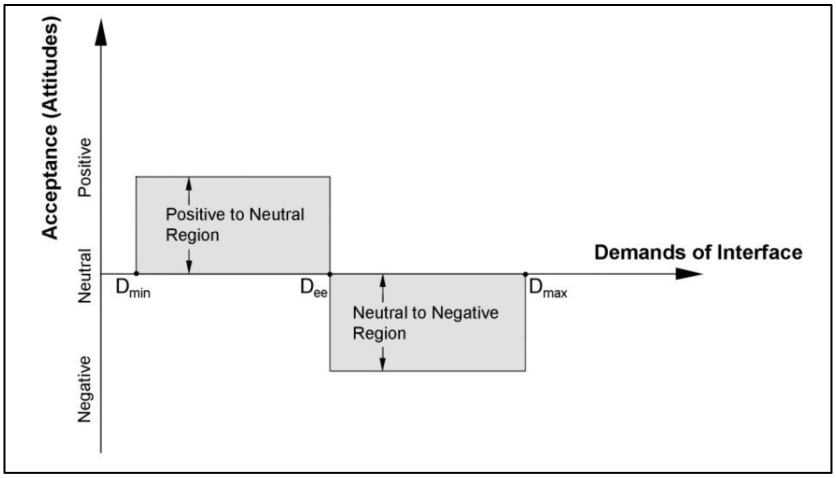

Figure 8.1. Demands-Acceptance Relationship (Early Experience). Note: Other characteristics of the new technologies are held constant.

Figure 8.2 further illustrates the Demands-Acceptance Relationship (Early Experience) by using the results of Experiment 2 as an example.

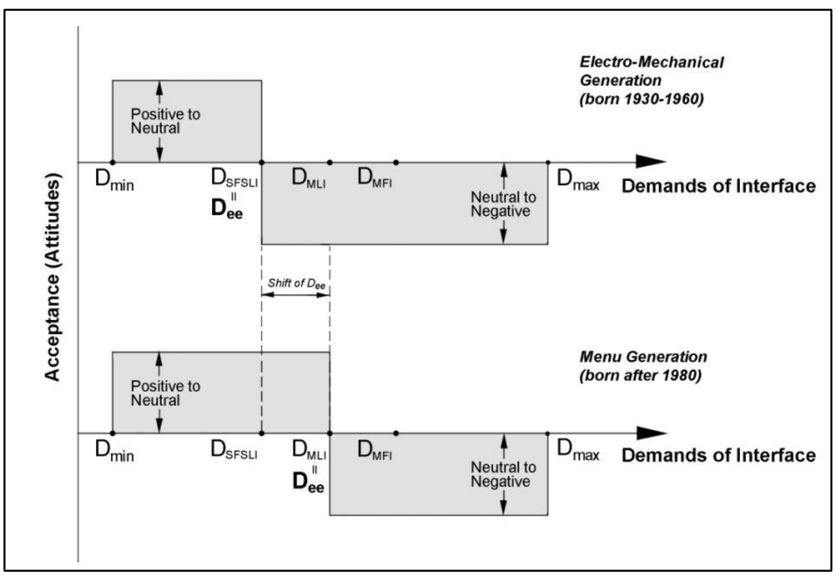

Figure 8.2. Demands-Acceptance Relationship (Electro-Mechanical Generation vs. Menu Generation). Note: Other characteristics of the new technologies are held constant.

There were three interface types assessed in Experiment 2. From lower to higher interface demands, there were SFSLI, MLI, and MFI. Participants in the older group (electro-mechanical generation) were exposed to electro-mechanical style during their formative years, and the interaction structure then was the SFSLI. So for the older group, the D_{ee} (demands of interface during one's early experience) is the demands of the SFSLI. In contrast, the participants in the younger group (menu generation) were exposed to menu style during their formative years, and the interaction structure of that time was the MLI. So for the younger group, the D_{ee} (demands of interface during one's early experience) is the demands of the MLI. As shown in Figure 8.2, there was a shift of D_{ee} to the higher interface demands from the electro-mechanical generation to the menu generation.

For the older group (D_{ee}=D_{SFSLI}), both the demands of the MLI and the MFI were higher than the demands of the SFSLI (D_{ee}). Older adults were found to have positive attitudes toward the SFSLI and neutral attitudes toward the MLI and the MFI (which were in the neutral to negative region).

For the younger group (D_{ee}=D_{MLI}), the demand of the SFSLI was lower than the demand of the MLI (D_{ee}), while the demand of the MFI was higher than the demand of the MLI (D_{ee}). Younger adults were found to have positive attitudes toward the MLI and the SFSLI (which was in the positive to neutral region) and neutral attitudes toward the MFI (which was in the neutral to negative region).

Early experiences with interaction technique vs. interaction structure. Comparison of results in Experiment 1 and Experiment 2 showed that older adults' early experiences with the interaction structure of the electro-mechanical style had a greater influence than their experiences with the interaction technique. It was easier for older adults to learn to use a new type of interaction technique than it was for them to learn a new type of interaction structure. Learning a new interaction structure involves understanding the interaction on a structural level and remembering a new sequence of operation steps, which would be difficult due to the age-related declines in procedural memory regarding learning new procedures.

Results of Experiment 1 revealed that older adults perceived the incompatibility with early experiences and the ability declines to play equally important roles in causing their difficulties in interactions with new interaction techniques. Results of Experiment 2 revealed that older adults perceived the incompatibility with early experiences played a significantly more important role than the ability declines in causing their difficulties in interactions with new interaction structures. It also suggested that their early experiences with the interaction structure had a greater influence than their early experiences with the interaction technique.

Results of the two experiments implied the essence of the electro-mechanical style or the essence of the older adults' early experiences with this interaction style was its interaction structure (one control with one function and single-layered operation) rather than its interaction technique (hardware-based input and output devices with physical manipulation and tactile feedback).

Aging factor vs. generation factor. Results showed that both age-related ability declines and technology-generation-related experience differences played important roles in older adults' interactions with interfaces. In both experiments, both ability score (numerical variable) and age group (categorical variable) were significant variables to explain the age-group difference in task completion time. It implied that the age-group difference was not explained only by the ability score; other age-group differences, such as the technology-generation-related knowledge and experiences, could also be significant variables.

The results were further supported by the structured interview data. Older adults believed that the aging factor and the generation factor played equally important roles in their performances with newer interaction techniques, while the generation factor played a significantly more important role than did the aging factor in their performances with newer interaction structures.

Recommendations on Reshaping the Electro-Mechanical Style

This research experimentally isolated the effects of older adults' early experiences with the interaction technique (Experiment 1) and early experiences with the interaction structure (Experiment 2) of the electro-mechanical style. Based on the results of the two experiments, recommendations on reshaping the electro-mechanical style for today's older adults are as follows:

1. Keep the interaction structure of the electro-mechanical style (one control with one function and single-layered operation).

1a. Keep the 1:1 mapping between control and function. If there are not enough spaces, make sure the most frequently used or most important functions employ one control with one function and avoid one control with multi-functions.

1b. Keep the single-layered operation. If there are not enough spaces, make sure the most frequently used or most important functions and available options are placed on the first layer of the interface and can be seen at once (not hidden behind the layers).

2. Replace the interaction technique of the electro-mechanical (hardware-based input and output device) with newer types of interaction technique that are more direct and require less physical and cognitive effort (such as touch-screen and voice recognition).

2a. It is OK to discard the feature of physical manipulation and tactile feedback of the interaction technique of the electro-mechanical style, if adequate feedback through other sensory channels (such as visual and auditory channels) is provided.

2b. It is unnecessary to keep exactly the same appearance and operation method of an old interaction technique. (For example, a visualized dial on a touch-screen device, which kept the appearance and operation method of a physical dial did not help increase usability or acceptance more than did a visualized button on touch screen device).

Recommendations on Designing New Interaction Styles for Older Adults Highlighting their Early Experience

Based on the results of the two experiments, recommendations on designing new interaction styles tailored to the early experiences of today's older adults are as follows:

1. Highlight the interaction structure of the electro-mechanical style. The essence of the electro-mechanical style was found to be its interaction structure (1:1 mapping between control and function and also single-layered operation). It had a very high level of directness and straightforwardness, and it was very similar to our everyday interaction with the physical world.

2. Keep the demands of the new interaction styles no higher than the demands of the electro-mechanical style. As the Demands-Acceptance Relationship (Early Experience) suggested, when other characteristics of the new technologies are held constant, interface demands of new technologies which exceed those of older adults' early experiences (the

electro-mechanical style) are more likely to receive negative attitudes toward accepting the new technologies.

3. Take into account the age-related changes in sensory, physical, and cognitive abilities. Make sure the demands of the new interaction styles do not exceed the capabilities of older adults.

Theoretical Contributions

Findings from this study provided empirical support for explaining the differences in using and accepting new technologies from a generation perspective, more specifically, the knowledge and experience gained during the formative years. This study contributed to the knowledge regarding the effects of early experiences with the interaction style of consumer products on usability and acceptance of new technologies by older adults. More specifically, it improved the understanding of and insights into the effects attributable to two different components of interaction style—the interaction technique and the interaction structure. In addition, it improved the understanding of how aging-related abilities and generation-specific knowledge and experiences come into play in older adults' interactions with new interfaces. Furthermore, the results of this study provided design recommendations for reshaping the electro-mechanical style and designing new interaction styles highlighting older adults' early experiences. This study also proposed a theoretical framework of guiding interface design for older adults, which combined the aging-oriented approach and the generation-oriented approach, as well as a Demands-Acceptance Relationship (Early Experience), which could be generalized to the design of other aspects of user interfaces.

Practical Contributions

Findings of this study helped to inform designers on how the design choices of interaction style would affect the usability and acceptance of older adults. It provided guidance on how to reshape the electro-mechanical style to increase the usability and acceptance of new technologies, and also on how to design new interaction styles to highlight older adults' early experiences by taking into account older adults' familiarity and expectations and aging characteristics. In addition, the proposed framework of guiding interface design for older adults would support usability specialists, product designers, interaction designers, product manufacturers and others involved in the design and development of user interfaces of modern technologies for older adults.

Research Limitations

The limitations of this study were as follows:

1. Most of the older adults participating in this study had attained Bachelor degrees or higher. The education level of the older adults participating in this study was higher than that of the general older adult population. We expected that participants with lower education levels might yield different results in performance and attitude.

2. Technology experiences of the older adults participating in this study were higher than those of the general older adult population. Participants with lower technology experiences might have had different levels of performance and attitude. We expected that the influence of early experiences with interaction style would be stronger for older adults with low technology experience.

3. Self-reported health conditions of the older adults participating in this study were higher than that of the general older adult population. We expected that participants with lower health conditions might have had different levels of performance and attitude, especially for Experiment 1. Participants with hand problems might have more difficulties using the Physical Dial Interface (PDI).

4. The older adults participating in this study were all residents of the United States. We expected that culture could play a role in this study. People in different countries and regions might develop different early experiences with interaction styles based on the products available to them (different rates in diffusion of an interaction style) and might also have different attitudes toward accepting new technologies.

5. This study only assessed simple products with a small number of functions. We expected that the number of functions could play a role in this study, especially for Experiment 2.

6. This study was a cross-sectional study and comprised an older group and a younger group. Carefully structured longitudinal research could further examine the research question of this study and establish whether the explanations are valid.

Future Studies

Additional studies, including various types of devices and a broad range of older adult participants would obtain more general results. Future studies could test the retention of each interface type and assess the usability and acceptance after one day, one week, or even longer periods of time. Future studies could investigate gender differences as well as individual differences in the influence of early experiences. Future studies could also investigate other aspects of older adults' generation-specific knowledge and experience with products and interfaces, such as mental models. Future studies could also investigate older adults' knowledge and experiences gained after their formative years, the periods in their lifetime when they encountered important design innovations and social changes that were influential for the target generation.

REFERENCES

Ackerman, P. L. (1996). A theory of adult intellectual development: Process, personality, interests, and knowledge. *Intelligence, 22*(2), 227-257.

Ajzen, I. & Fishbein, M. (1980). *Understanding attitudes and predicting social behavior*. Englewood Cliffs, NJ: Prentice-Hall.

Anderson, J. R. (1983). *The architecture of cognition*. Cambridge, MA: Harvard University Press.

Ansari, S. (2011). Designing interactive pill reminders for older adults: A formative study. In C. Stephanidis (Ed.), *Universal Access in Human-Computer Interaction* (pp.121-130). Berlin, Germany: Springer.

Arning, K., & Ziefle, M. (2007). Barriers of information access in small screen device applications: The relevance of user characteristics for a transgenerational design. In C. Stephanidis & M. Pieper (Ed.), *User Interfaces for All: Universal Access in Ambient Intelligence Environments* (pp.117-136). Heidelberg, Germany: Springer

Baltes, P. B. (1997). On the incomplete architecture of human ontogeny: selection, optimization, and compensation as foundation of developmental theory. *American Psychologist*, *52*(4), 366-380.

Baltes, P. B., Staudinger, U. M., & Lindenberger, U. (1999). Life span psychology: theory and application to intellectual functioning. *Annual Review of Psychology*, *50*, 471-507.

Bandua, A. (1986). *Social foundations of thought and action: a social cognitive theory*. Englewood Cliffs, NJ: Prentice-Hall.

Batu, Y., Kim, Y., & Cheng, H. (2010). Senior-friendly icon design for the mobile phone. In 6th International Conference on Digital Content, Multimedia Technology and its Applications (IDA), Seoul, Korea.

Birdi, K., Pennington, J., & Zapf, D. (1997). Ageing and errors in computer-based work: An observational field study. *Journal of Occupational & Organizational Psychology*, *70*(1), 35-47.

Blackler, A. (2006). *Intuitive interaction with complex artefacts.* Unpublished dissertation. Brisbane, Australia: Queensland University of Technology.

Blackler, A., & Hurtienne, J. (2007). Towards a unified view of intuitive interaction: definitions, models and tools across the world. *MMI-Interaktiv*, *13*, 37-55.

Blackler, A., Popovic, V., & Mahar, D. (2009). *Intuitive interaction, prior experience and ageing: an empirical study*. Paper presented at the HCI 2009, Churchill College, Cambridge, UK.

Blackler, A., Popovic, V., & Mahar, D. (2010). Investigating users' intuitive interaction with complex artefacts. *Applied Ergonomics*, *41*(1), 72-92.

Caine, K. E., O'Brien, M. A., Park, S., Rogers, W. A., Fisk, A. D., Van Ittersum, K., Capar, M., & Parsons, L. J. (2006). Understanding acceptance of high technology products: 50 years of research. *Proceedings of the Human Factors and Ergonomics Society 50th Annual Meeting*, 2148-2152.

Cardoso, C., Keates. S., & Clarkson, P. J. (2004). Comparing product assessment methods for inclusive design. In S. Keates, J. Clarkson, P., Langdon, & P. Robinson (Ed.), *Designing a More Inclusive World* (pp.31-40). London, UK: Springer.

Charness, N, & Boot, W. R. (2009). Aging and information technology use: Potential and barriers. *Current Directions in Psychological Science*, *18*, 253-258.

Charness, N., Holley, P., Feddon, J., & Jastrzembski, T. (2004). Light pen use and practice minimize age and hand performance differences in pointing tasks. *Human Factors*, *46*(3), 373-384.

Chou, J. R., & Hsiao, S. W. (2007). A usability study on human–computer interface for middle-aged learners. *Computers in Human Behavior*, *23*, 2040-2063.

Chung, J., Park, N., Wang, H., Fulk, J., & McLaughlin, M. (2010). Age differences in perceptions of online community participation among non-users: an extension of the Technology Acceptance Model. *Computers in Human Behavior*, *26*(6), 1674-1684.

Craik, F. (1986). A functional account of age differences in memory. In F. Klix & H. Hagendorf. (Eds.), *Human memory and cognitive abilities* (pp.409-422). Amsterdam: Elsevier.

Czaja, S. J., Charness, N., Fisk, A. D., Hertzog, C., Nair, S. N., & Rogers, W. A. (2006a). Factors predicting the use of technology: Findings from the center for research and education on aging and technology enhancement (CREATE). *Psychology and Aging*, *21*(2), 333-352.

Czaja, S.J., Charness, N., Dijkstra, K., Fisk, A.D., Rogers, W.A., & Sharit, J. (2006b). Computer and Technology Experience Questionnaire. (CREATE Technical Rep. CREATE-2006-03).

Czaja, S.J., Charness, N., Dijkstra, K., Fisk, A.D., Rogers, W.A., & Sharit, J. (2006c). Demographic and Background Questionnaire. (CREATE Technical Rep. CREATE-2006-02).

Czaja, S. J., Sharit, J., Ownby, R., Roth, D., & Nair, S. N. (2001). Examining age differences in performance of a complex information search and retrieval task. *Psychology and Aging*, *16*, 564-579.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, *13*(3), 319-342.

DiDomenico, A., & Nussbam, M. A. (2003). Measurement and prediction of single and multi-digit finger strength. *Ergonomics*, *46*(15), 1531-1548.

Dixon, P., & Gabrys, G. (1991). Learning to operate complex devices: Effects of conceptual and operational similarity. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 33*(1), 103-103.

Dixon, P. & O'Reilly, T. (2002). Appearance, form, and the retrieval of prior knowledge. In J. Frascara (Ed.), *Design and the Social Sciences: Making Connections* (pp.166-177). London: Taylor and Francis

Docampo Rama, M. (2001). Technology generations: handling complex user interfaces. Unpublished dissertation. Eindhoven, the Netherlands: Technical University of Eindhoven.

Duggan, M. & Rainie, L. (2012). Cell phone activities 2012. Pew Research Center's Internet & American Life Project. Retrieved from http://pewinternet.org/Reports/2012/Cell-Activities.aspx

Gruen, W. (1960). Preference for new products and its relationship to different measures of conformity. *Journal of Applied Psychology, 44*, 361-364.

Fischer, G. (1991) The importance of models in making complex systems comprehensible. In Tauber, M. J. & Ackermann, D. (Eds.), *Mental Models and Human Computer Interaction 2* (pp.23-33). North-Holland: Elsevier Science Publishers.

Fisk, A. D., Rogers, W. A., Charness, N., Czaja, S. J. & Sharit, J. (2004). *Designing for Older Adults: Principles and Creative Human Factors Approaches*. Boca Raton, FL: CRC Press.

Fisk, A. D., Rogers, W. A., & Giambra, L. M. (1990). Consistent and varied memory/visual search: Is there an interaction between age and response-set effects*? Journal of Gerontology: Psychological Sciences*, *45*, 81-87.

Freudenthal, A. (1999). *The design of home appliances for young and old consumers*. Delft, Holland: Delft University Press.

Freudenthal, D. (2001). The role of age, foreknowledge and complexity in learning to operate a complex device. *Behaviour & Information Technology, 20*(1), 23-35.

Freudenthal, T. D. (1998). *Learning to use interactive devices: age differences in the reasoning process.* Unpublished dissertation. Eindhoven, the Netherlands: Eindhoven University of Technology.

Gefen, D. (2000). E-commerce: the role of familiarity and trust. *Omega*, *28*, 725–737.

Goodhue, D. L., & Thompson, R. L. (1995). Task-technology fit and individual performance. *MIS Quarterly*, *19*(2), 213-233.

Hackbarth, G., Grover, V., & Yi, M.Y. (2003). Computer playfulness and anxiety: positive and negative mediators of the system experience effect on perceived ease of use. *Information & Management*, *40*(3), 221–232.

Häikiö, J., Isomursu, M., Matinmikko, T., Wallin, A., Ailisto, H., & Huomo, T. (2007). Touch-based User Interface for Elderly Users. *Proceedings of 9th International Conference on Human Computer Interaction with Mobile Devices and Services,* 289-296.

Halasz, F. G., & Moran, T. P. (1983). Mental models and problem solving in using a calculator. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,* 212-216.

Hasan, B., & Ahmed, M. U. (2007). Effects of interface style on user perceptions and behavioral intention to use computer systems. *Computers in Human Behavior*, *23*(6), 3025-3037.

Hawthorn, D. (2000). Possible implications of aging for interface designers. *Interacting with Computers, 12*, 507-528.

Hawthorn, D. (2007). Interface design and engagement with older people. *Behaviour & Information Technology*, *26*(4), 333-341.

He, W., Sengupta, M., Velkoff, V. A., & DeBarros, K. A. (2005). *65+ in the United States: 2005.* Washington, DC: US Census Bureau.

Hisham, S., & Edwards, A. (2007). Incorporating culture in user-interface: a case study of older adults in Malaysia, Papers presented at the Proceedings of the 18th Conference on Hypertext and Hypermedia, Manchester, UK.

Holbrook, M. B., & Schindler, R. M. (1989). Some exploratory findings on the development of musical tastes. *Journal of Consumer Research*, *16*(June), 119-24.

Holzinger, A., Searle, G., & Wernbacher, M. (2011). The effect of previous exposure to technology on acceptance and its importance in usability and accessibility engineering. *Universal Access in the Information Society*, *10*(3), 245-260.

Hong, W.Y., Thong, J. Y. L., Wong, W. M., & Tam, K.Y. (2001). Determinants of user acceptance of digital libraries: an empirical examination of individual differences and system characteristics. *Journal of Management Information Systems*, *18*(3), 97-124.

Huang, H. M., & Liaw, S. S. (2005). Exploring users' attitudes and intentions toward the Web as a survey tool. *Computers in Human Behavior*, *21*(5), 729-743.

Human Benchmark (2012). Reaction Time Test. retrieved from http://www.humanbenchmark.com/tests/reactiontime/

Hurtienne, J., Horn, A. M., & Langdon, P. M. (2010). Facets of prior experience and their impact on product usability for older users. In Langdon, P. M., Clarkson, P. J. & Robinson, P. (Eds.), *Designing Inclusive Interactions* (pp.123-132). London, UK: Springer.

Hurtienne, J., & Israel, J. H. (2007). Image schemas and their metaphorical extensions-intuitive patterns for tangible interaction. Papers presented at the Proceedings of the 1st International Conference on Tangible and Embedded Interaction, New York, US.

Hurtienne, J., Langdon, P., & Clarkson, P. J. (2009). Toward an account of sensorimotor knowledge in inclusive product design. Paper presented the Proceedings of the 5th

International Conference on Universal Access in Human-Computer Interaction (Part I), San Diego, USA.

Hurtienne, J., Weber, K., & Blessing, L. (2008). Prior experience and intuitive use: image schemas in user centred design. In: P. Langdon & P. Robinson (Eds.) *Designing Inclusive Futures* (pp.107-116). London, UK: Springer.

Ibrahim, Y. K., & Hadidi, M. M. (2006). Design of language independent speech interfaces. *Directory of Open Access Journals*, *5*(6), 1140-1142.

Igbaria, M. (1993). User acceptance of microcomputer technology: An empirical test. *Omega*, *21*(1), 73-90.

Igbaria, M., & Chakrabarti, A. (1990). Computer anxiety and attitudes towards microcomputer use. *Behavior and Information Technology*, *9*, 229-241.

Igbaria, M, & Iivari, J. (1995). The effects of self-efficacy on computer usage. *Omega*, *23*(6), 587-605.

International Standard Organization. (1998). Ergonomic requirements for office work with visual display terminals (VDTs) – Part 11: guidance on usability [ISO 9241-11]. Geneva: International Organization for Standardization.

International Standards Organization. (2006). Ease of operation of everyday products –Part 1: Design requirements for context of use and user characteristics [ISO Standard 20282-1:2006(E)]. Geneva: International Standards Organization.

Jacko, J. A., Scott, I. U., Sainfort, F., Moloney, K. P., Kongnakorn, T., Zorich, B. S., & Emery, V. K. (2003). Effects of Multimodal Feedback on the Performance of Older Adults with Normal and Impaired Vision. In Carbonell, N., & Stephanidis, C. (Ed.), *Universal Access Theoretical Perspectives, Practice, and Experience* (pp.3-22). Berlin, Germany: Springer.

Jin, Z., Plocher, T., & Kiff, L. (2007). Touch screen user interfaces for older adults: Button size and spacing. In C. Stephanidis (Ed.), *Universal Access in Human Computer Interaction* (pp.933-941). Berlin, Germany: Springer.

Jones, L. A., & Sarter, N. B. (2008). Tactile Displays: Guidance for Their Design and Application. *Human Factors*, *50*(1), 90-111.

Jones, S., & Fox, S. (2009). Generations online in 2009. Retrieved from http://www.pewInternet.org/PPF/r/275/report_display.asp

Kanfer, R., & Ackerman, P. L. (1989). Dynamics of skill acquisition: Building a bridge between intelligence and motivation. In R. J. Sternberg (Ed.), *Advances in the psychology of human intelligence* (pp.83-136). Mahwah, NJ: Erlbaum.

Kanfer, R., Ackerman, P. L., Murtha, T. C., Dugdate, B., & Nelson, L. (1994). Goal setting, conditions of practice, and task performance: a resource allocation perspective. *Journal of Applied Psychology*, *79*(6), 826-835.

Kang, N. E., & Yoon, W. C. (2008). Age- and experience-related user behavior differences in the use of complicated electronic devices. *International Journal of Human-Computer Studies*, *66*(6), 425-437.

Keates, S., & Clarkson, J. (2003). *Countering Design Exclusion: An Introduction to Inclusive Design.* London, UK: Springer.

Kieras, D., & Bovair, S. (1984). The role of a mental model in learning to operate a device. *Cognitive Science*, *8*, 255-273.

Kim, J., Kim, H., & Han, K. (2011). Color image effect of online community on age: focusing on self-expression. In C. Stephanidis (Ed.), *HCI International 2011 – Posters' Extended Abstracts* (pp.445-448). Berlin, Germany: Springer.

Kinzie, M. B., Delcourt, M. A. B., & Powers, S. M. (1994). Computer technologies: attitudes and self efficacy across undergraduate disciplines. *Research in Higher Education*, *35*(6), 745-768.

Kliegl, R., Smith, J., & Baltes, P. B. (1989). Testing-the-limits and the study of age differences in cognitive plasticity of a mnemonic skill. *Developmental Psychology*, *25*, 247-256.

Kwon, H. S., & Chidambaram, L. (2000). A test of the Technology Acceptance Model: the case of cellular telephone adoption. *Proceedings of the 33rd Hawaii International Conference on System Sciences.*

Langdon, P. M., Lewis, T., & Clarkson, P. J. (2007). The effects of prior experience on the use of consumer products. *Universal Access in the Information Society*, *6*(2), 179-191.

Langdon, P. M., Lewis, T., & Clarkson, P. J. (2010). Prior experience in the use of domestic product interfaces. *Universal Access in the Information Society, 9*(3), 209-225.

Lawry, S., Popovic, V., & Blackler, A. (2009). Investigating Familiarity in Older Adults to Facilitate Intuitive Interaction. *Proceedings of the International Association of Societies of Design Research Conference*, 18-22.

Legris, P., Ingham, J., & Collerette, P. (2003). Why do people use information technology? A critical review of the technology acceptance model. *Information and Management*, *40*, 191-204.

Lewis, T., & Clarkson, P. J. (2005). A user study into customizing for inclusive design. *Universal Access in the Information Society*. *6*(2), 179-191.

Lewis, T., Langdon, P. M., & Clarkson, P. J. (2006). Investigating the role of experience in the use of consumer products. In P. M. Langdon, J. Clarkson & P. Robinson (Eds.), *Designing Inclusive Futures* (pp.189-198). London, UK: Springer.

Lewis, T., Langdon, P., & Clarkson, P. (2007). Cognitive aspects of ageing and product interfaces: Interface type. *Universal Access in Human Computer Interaction. Coping with Diversity* (pp.731-740). Berlin, Germany: Springer.

Lewis, T., Langdon, P. M., & Clarkson, P. J. (2008). Prior experience of domestic microwave cooker interfaces: a user study. In P. M. Langdon, P. J. Clarkson, & P. Robinson (Eds.), *Designing Inclusive Futures* (pp.95-106). London, UK: Springer.

Lloyd-Sherlock, P. (2000). Population ageing in developed and developing regions: Implications for health policy. *Social Science & Medicine, 51*(6), 887-895.

Mead, S. E., Batsakes, P., Fisk, A. D., & Mykityshyn, A. (1999). Application of cognitive theory to training and design solutions for age-related computer use. *International Journal of Behavioral Development, 23*(3), 553-573.

Melenhorst, A., Rogers, W. A., & Caylor, E. C. (2001). The use of communication technologies by older adults: Exploring the benefits from the user's perspective. *Human Factors and Ergonomics Society Annual Meeting Proceedings*, *45*(3), 221-221.

Mitzner, T. L., Boron, J. B., Fausset, C. B., Adams, A. E., Charness, N., Czaja, S. J., Dijkstra, K., Fisk, A. D., Rogers, W. A., & Sharit, J. (2010). Older adults talk technology: technology usage and attitudes. *Computers in Human Behavior, 26*, 1710-1721.

Mollenkopf, H. (2003). Assistive Technology: Potential and Preconditions of Useful Applications. In: N. Charness & K. W. Schaie (Eds.), *Impact of Technology on Successful Aging*. (pp.203-214). New York: Springer.

Morris, J. M. (1994). User interface design for older adults. *Interacting with Computers, 6*(4), 373-393.

Naumann, A. Wechsung, I., & Hurtienne, J. (2009). Multimodality, inclusive design, and intuitive use. *Proceedings of the 23rd British Computer Society Human Computer Interaction Workshop and Conference (HCI 2009).*

Necessary, J. R. & Parish, T. S. (1996). The relationships between computer usage and computer-related attitudes and behaviors. *Education, 116*(3). 384-386.

Norman, D. (1993). *Things that Make Us Smart.* New York: Addison Wesley.

O'Brien M. (2010). *Understanding human-technology interaction: the role of prior experience and age.* Unpublished dissertation. Georgia, USA: Georgia Institute of Technology.

Ofcom, (2009). Accessing the Internet at home: a quantitative and qualitative study among people without the Internet at home. Retrieved from http://www.ofcom.org.uk/research/telecoms/reports/bbresearch/bbathome.pdf

Ogata, K., Kumada, T., Suto, S., Watanabe, K., & Ifukube, T. (2011). Interface design of a central monitoring device taking cognitive aging into account. In 2011 IEEE International Conference on Systems, Man, and Cybernetics (SMS), Anchorage, Alaska, US.

Okeye, H. (1999). *Metaphor mental model approach to intuitive graphical user interface design.* PhD Thesis, Cleveland, USA: Cleveland State University.

Pak, R., & McLaughlin, A. (2011). *Designing Display for Older Adults.* Boca Raton, FL: CRC Press.

Pattison, W., & Stedmon, A. (2006). Inclusive design and human factors: designing mobile phones for older users. *Psychology Journal, 4(*3), 267-284.

Persad, U., Langdon, P. M., & Clarkson, P. J. (2006). Inclusive design evaluation and the capability-demand relationship in Designing accessible technology. In: P. J. Clarkson, P.

Langdon, & P. Robinson (Ed.), *Designing Accessible Technology* (pp.177-188). London, UK: Springer.

Pirolli, P. (1999). Cognitive Engineering Models and Cognitive Architectures in Human-Computer Interaction. In Durso, F. T. et al., (Ed.). *Handbook of Applied Cognition* (pp.443-477). Chichester, UK: John Wiley & Sons Ltd.

Potosky, D. (2002). A field study of computer efficacy beliefs as anoutcome of training: the role of computer playfulness, computer knowledge, and performance during training, *Computers in Human Behavior, 18*(3), 241-255.

Raskin, J., (1994). Intuitive Equals Familiar. *Communications of the ACM, 37*(9), 17-18.

Rau, P., & Hsu, J. (2002). A Study of Interaction Devices and WWW User Interface Design for Older Adults. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 46*(2), 219-223.

Reddy, R. G., Blackler, A. L., Popovic, V., & Mahar, D. P. (2009). Redundancy in interface design and its impact on intuitive use of a product in older users. *Proceedings of IASDR 2009: International Association of Societies of Design Research Conference Seoul*.

Renaud, K., & van Biljon, J. (2008). Predicting technology acceptance and adoption by the elderly: A qualitative study. *Proceedings of the 2008 Annual Research Conference of the South African institute of Computer Scientists and information Technologists on IT Research in Developing Countries: Riding the Wave of Technology*, 210-219.

Rogers, W. A., & Fisk, A. D. (1991). Are age differences in consistent-mapping visual search due to feature learning or attention training? *Psychology and Aging, 6,* 542-550.

Rogers, W. A., Fisk, A. D., & Hertzog, C. (1994). Do ability–performance relationships differentiate age and practice effects in visual search? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20*(3), 710 -738.

Rogers, W. A., Fisk, A. D., McLaughlin, A. C., & Park, R. (2005). Touch a screen or turn a knob: choosing the best device for the job. *Human Factors, 47*(2), 271-288.

Rogers, W. A., Hertzog, C., & Fisk, A. D. (2000). An individual differences analysis of ability and strategy influences: age-related differences in associative learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26*, 359-394.

Rubin, D. C., Rahhal, T. A., & Poon, L. W. (1998). Things learned in early adulthood are remembered best. *Memory & Cognition, 26,* 3-19.

Schindler, R. M., & Holbrook, M. B. (2003). Nostalgia for early experience as a determinant of consumer preferences. *Psychology and Marketing, 20*(4), 275-302.

Sharit, J., Hernandez, M. A., Czaja, S. J., & Pirolli, P. L. (2008). Investigating the roles of knowledge and cognitive abilities in older adult information seeking on the Web. *ACM Transactions on Computer-Human Interaction, 15*(1), 3-28.

Smith, M.W., Sharit, J., & Czaja, S.J. (1999). Aging, motor control, and the performance of computer mouse tasks. *Human Factors, 41*(3), 389-396.

Spool, J. M. (2005). What makes a design seem 'intuitive'. Retrieved from http://uie.com/articles/design_intuitive/

Tacken, M., Marcellini, F., Mollenkopf, H., Ruoppilam, I., & Szeman, Z. (2005). Use and acceptance of new technology by older people. Findings of the international mobilate survey: enhancing mobility in later life. *Journal of Gerontechnology, 3*(3), 126-137.

Taylor, S. & Todd., P. A. (1995). Assessing IT usage: the role of prior experience. *Management Information Systems Quarterly, 19*(4), 561-570.

Tremayne, P., Burdett, J., & Utecht, C. (2011). Simulation suit aids tailored care. *Nursing Older People, 23*(7), 19-22.

Tsai, W., & Lee, C. (2011). A study on the icon feedback types of small touch screen for the elderly. In C. Stephanidis (Ed.), *Universal Access in Human-Computer Interaction* (pp.422-431). Berlin, Germany: Springer.

Venkatesh, V., & Davis, F. D. (2000). A theoretical extension of the technology acceptance model: four longitudinal field studies. *Management Science, 46*(2), 186–204.

Vet, J. De, & Ruyter, B. De. (1996). An inventory of interaction styles. Report no. 1113. Eindhoven. The Netherlands: Institute for Perception Research (IPO).

Vincent, G.K., & Velkoff, V.A. (2010). The next four decades the older population of the United States: 2010–2050. Retrieved from *www.census.gov/prod/2010pubs/p25-1138.pdf*

Vines, J., & Thompson, S. (2007). Aging futures: toward an inclusive cognitive interaction design. Papers presented at the 4th International Conference for Inclusive Design, London, UK.

Waldherr, S., Romero, R., & Thrun, S. (2000). A gesture based control interface for human – robot interaction. *Autonomous Robots, 9*,151-173.

Wechsler D. (1987). *Weschsler Memory Scaled—Revised*. New York: The Psychological Corporation.

Werner, C. A. (2011). The Older Population: 2010. Retrieved from http://www.census.gov/prod/cen2010/briefs/c2010br-09.pdf

Wiedenbeck, S., & Davis, S. (1997). The influence of interaction style and experience on user perceptions of software packages. *International Journal of Human-Computer Studies, 46*(5), 563-588.

Wilkinson, C., Langdon P. M., & Clarkson, P. J. (2010). Prior experience and learning: Generational effects upon interaction. In P. Langdon, P. J. Clarkson, & P. Robinson (Eds.), *Designing Inclusive Interactions* (pp.145-154). London, UK: Springer.

Wilkinson, C., Langdon, P. M., & Clarkson, P. J. (2011). Evaluating the design, use and learnability of household products for older individuals. In C. Stephanidis (Ed.), Universal Access in Human-Computer Interaction. *Users Diversity* (pp.250-259). Berlin, Germany: Springer.

Zajicek, M. (2001a). Interface design for older adults. Papers presented at the Proceedings of the 2001 EC/NSF workshop on Universal accessibility of ubiquitous computing: providing for the elderly, Alcácer do Sal, Portugal.

Zajicek, M. (2001b). Making World Wide Web interfaces usable for elderly and/or visually impaired people. Papers presented at the 15th Annual Conference of the Human Computer Interaction Group of the British Computer Society IHMHCI, Toulouse, France.

Zhang, B., Rau, P. P., & Salvendy, G. (2009). Design and evaluation of smart home user interface: effects of age, tasks and intelligence level. *Behaviour & Information Technology, 28*(3), 239-249.

Ziefle, M. (2002). The influence of user expertise and phone complexity on performance, ease of use and learnability of different mobile phones. *Behaviour & Information Technology, 21*(5), 303-311.

Ziefle, M., & Bay, S. (2005). How older adults meet complexity: Aging effects on the usability of different mobile phones. *Behaviour and Information Technology, 24*, 375-389.

Ziefle, M., Bay, S., & Schwade, A. (2006). On keys meanings and modes: the impact of navigation key solutions on children's efficiency using a mobile phone. *Behaviour and Information Technology, 25*, 413-431.

APPENDICES

Appendix A

Technology Experience Questionnaire

The purpose of this set of questions is to assess your familiarity and experience with technology. Please answer all questions by placing a check mark at the appropriate response.

1. How often do you communicate with other people (e.g., family members, friends, doctors, customer service representatives)?

□$_1$Daily
□$_2$Weekly
□$_3$Monthly
□$_4$Yearly
□$_5$ Never

2. Within the last year, which of the following methods have you used for communication?
(Please use the following scale:
Not sure what it is:1, Never: 2, Once in a while: 3, Some of the time: 4, Most of the time: 5, Always: 6.)

(   ) 1. Answering machine
(   ) 2. Cell phone
(   ) 3. Fax machine
(   ) 4. Internet (e.g., e-mail, chat room, video conferencing)
(   ) 5. Telephone
(   ) 6. Videophone

3. How often do you go shopping?

□$_1$Daily
□$_2$Weekly
□$_3$Monthly
□$_4$Yearly
□$_5$ Never

4. Within the last year, which of the following have you used for shopping?
(Please use the following scale:
Not sure what it is:1, Never: 2, Once in a while: 3, Some of the time: 4, Most of the time: 5, Always: 6.)

(   ) 1. Credit card
(   ) 2. Debit card
(   ) 3. In-store automated kiosk (e.g., self checkout, price scanner, item locator)
(   ) 4. Internet (e.g., online purchasing, online product evaluation)
(   ) 5. Telephone
(   ) 6. Television shopping

5. How often do you use customer service functions (e.g., technical support, product assistance, reservations)?

□1Daily
□2Weekly
□3Monthly
□4Yearly
□5 Never

6. Within the last year, which of the following have you used for customer service (e.g., technical support, product assistance, reservations)?

(Please use the following scale:
Not sure what it is:1, Never: 2, Once in a while: 3, Some of the time: 4, Most of the time: 5, Always: 6.)

( ) 1. Automated telephone menu system
( ) 2. CD/DVD
( ) 3. E-mail
( ) 4. Fax machine
( ) 5. Internet (e.g., online manuals, online interactive support, web site)
( ) 6. Person on the telephone

7. How often do you make financial transactions (e.g., bill paying, banking, investing/ financial planning, tax preparation)?

□1Daily
□2Weekly
□3Monthly
□4Yearly
□5 Never

8. Within the last year, which of the following have you used for financial transactions (e.g., bill paying, banking, investing/financial planning, tax preparation)?

(Please use the following scale:
Not sure what it is:1, Never: 2, Once in a while: 3, Some of the time: 4, Most of the time: 5, Always: 6.)

( ) 1. Automated telephone menu system (e.g., banking, credit card information)
( ) 2. Automatic teller machine (ATM)
( ) 3. Drive-through banking
( ) 4. Internet (e.g., online banking, online bill paying, online investing)
( ) 5. Person on the telephone
( ) 6. Software (e.g., Quicken, spreadsheet, MS Money, TurboTax)

9. How often do you engage in healthcare related activities for yourself or others (e.g., going to see a doctor, checking blood pressure, finding information about a disease or medication)?

□1Daily
□2Weekly
□3Monthly
□4Yearly
□5 Never

10. Within the last year, which of the following have you used for healthcare related activities for yourself or others?
(Please use the following scale:
Not sure what it is:1, Never: 2, Once in a while: 3, Some of the time: 4, Most of the time: 5, Always: 6.)
(   ) 1. Automated telephone menu system
(   ) 2. Health information searching on the Internet
(   ) 3. Internet communication (e.g., e-mail, computer support groups)
(   ) 4. Medical-related Internet purchasing (e.g., medication or medical supplies)
(   ) 5. Person on the telephone
(   ) 6. Telemedicine (e.g., videoconferencing with doctors or nurses)

11. How often do you use healthcare devices at home for yourself or others (e.g., glucose monitor, blood pressure monitor)?
□1 Daily
□2 Weekly
□3 Monthly
□4 Yearly
□5 Never

12. Within the last year, which of the following healthcare devices have you used in your home?
(Please use the following scale:
Not sure what it is:1, Never: 2, Once in a while: 3, Some of the time: 4, Most of the time: 5, Always: 6.)
(   ) 1. Blood pressure measurement device
(   ) 2. Digital thermometer
(   ) 3. Electronic dental hygiene system (e.g., electric toothbrush, Waterpik)
(   ) 4. Emergency call system (e.g., Lifeline)
(   ) 5. Heating pads
(   ) 6. Infusion pump
(   ) 7. Monitoring device (e.g., glucose, apnea, cardiac)
(   ) 8. Nebulizers
(   ) 9. Oxygen equipment

13. How often do you use public transportation (e.g., train, bus, subway)?
□1 Daily
□2 Weekly
□3 Monthly
□4 Yearly
□5 Never

14. How often do you drive?
□1 Daily
□2 Weekly
□3 Monthly
□4 Yearly
□5 Never

15. How often do you travel by airplane?

□1Daily
□2Weekly
□3Monthly
□4Yearly
□5 Never

16. Within the last year, which of the following transportation-related systems have you used?

(Please use the following scale:
Not sure what it is:1, Never: 2, Once in a while: 3, Some of the time: 4, Most of the time: 5, Always: 6.)

( ) 1. Automated telephone menu system
( ) 2. Automatic check-in station
( ) 3. Automatic parking payment station
( ) 4. Automatic ticket purchase station
( ) 5. Cruise control in your car
( ) 6. In-car navigation system (e.g., GPS, OnStar, Neverlost)
( ) 7. On-line travel schedule
( ) 8. Personal digital assistant (PDA)
( ) 9. Person on the phone
( ) 10. Remote control to start the car
( ) 11. Travel direction/ map software (e.g., MapQuest, Streets &Trips, keyhole)

17. How often do you engage in leisure/hobby/entertainment-related activities?

□1Daily
□2Weekly
□3Monthly
□4Yearly
□5 Never

18. Within the last year, which of the following leisure/hobby/entertainment-related systems have you used?

(Please use the following scale:
Not sure what it is:1, Never: 2, Once in a while: 3, Some of the time: 4, Most of the time: 5, Always: 6.)

( ) 1. Books on tape (audio book)
( ) 2. Computer/Video game (e.g., Gameboy, PlayStation, Nintendo, GameCube, X-Box)
( ) 3. Digital photography (e.g., camera, camcorder)
( ) 4. Fitness device (e.g., pedometer, pulsemeter, golf swing enhancer, treadmill)
( ) 5. Hobby-specific computer usage (e.g., Internet, Photoshop, genealogy software, patterns)
( ) 6. MP3/IPOD
( ) 7. Personal digital assistant (PDA)
( ) 8. Recording and playback device (e.g., CD, DVD, VCR)
( ) 9. TV set-top box (e.g., program TV, pay-per view movies, music stations, TiVo)

19. How often do you engage in learning/educational/self-help activities?
□$_1$Daily
□$_2$Weekly
□$_3$Monthly
□$_4$Yearly
□$_5$ Never

20. Within the last year, which of the following learning/educational/self-help-related systems have you used?
(Please use the following scale:
Not sure what it is:1, Never: 2, Once in a while: 3, Some of the time: 4, Most of the time: 5, Always: 6.)
(   ) 1. Computer-based instruction (e.g., CD, DVD, VCR)
(   ) 2. Computer support group (e.g., chat room, discussion forum)
(   ) 3. Digital or tape recorder
(   ) 4. Internet searching (e.g., Google, directories, URLs, newspapers)
(   ) 5. Language learning and translation systems
(   ) 6. Online library database/catalog

21. On average, how many hours per day do you spend at home?
□$_1$ Less than 8 hours
□$_2$ 8-11 hours
□$_3$ 12-15 hours
□$_4$ 16-19 hours
□$_5$ 20-24 hours

22. Within the last year, which of the following home-based systems have you used?
(Please use the following scale:
Not sure what it is:1, Never: 2, Once in a while: 3, Some of the time: 4, Most of the time: 5, Always: 6.)
(   ) 1. Garage door opener
(   ) 2. Microwave oven
(   ) 3. Home security system (e.g., visitor entry directory system, home alarm, gate access)
(   ) 4. Personal computer
(   ) 5. Programmable device (e.g., lights, thermostat, sprinkler, programmable food processor, programmable coffee maker)
(   ) 6. Robot (e.g., vacuum cleaner, lawn mower)

23. On average, how many hours per week do you work (including volunteer work) in or out of the home? (For the purpose of this question you should not consider activities such as homemaking or family caregiving)
□$_1$ 0
□$_2$ 1 – 10 hours
□$_3$ 11 – 20 hours
□$_4$ 21 – 30 hours
□$_5$ 31 – 40 hours
□$_6$ More than 40 hours

24. Within the last year, which of the following technologies have you used in the context of your work?

(Please use the following scale:

Not sure what it is:1, Never: 2, Once in a while: 3, Some of the time: 4, Most of the time: 5, Always: 6.)

( ) 1. Bar code scanner
( ) 2. Cell phone
( ) 3. Computer
( ) 4. Copier/scanner
( ) 5. Recording or playback device (e.g., CD, DVD, VCR)
( ) 6. Electronic cash register (point of sale terminal)
( ) 7. E-mail
( ) 8. Fax machine
( ) 9. Internet
( ) 10. LCD projector
( ) 11. Multifunction telephone system (e.g., with conferencing, speaker, transfer capabilities)
( ) 12. Pager/Beeper
( ) 13. Personal digital assistant (PDA)
( ) 14. Voice recorder (e.g., dictaphone, digital recording system, handheld tape recorder)

Appendix B

Demographics Questionnaire

(Modified from CREATE Background Questionnaire)

1. Participant Number: _____

2. Gender: Male □1 **Female** □2

3. Age: _____

4. What is your highest level of education?

□1 No formal education
□2 Less than high school graduate
□3 High school graduate/GED
□4 Vocational training
□5 Some college/Associate's degree
□6 Bachelor's degree (BA, BS)
□7 Master's degree (or other post-graduate training)
□8 Doctoral degree (PhD, MD, EdD, DDS, JD, etc.)

5. Nationality: _____
If your nationality is not the U.S., how long you have lived in the U.S.? _____

6. What is your primary occupation? _____
If you are retired, what was your primary occupation? _____

7. In general, would you say your health is: _____

□1	□2	□3	□4	□5
Poor	Fair	Good	Very Good	Excellent

8. Compared to other people your own age, would you say our health is: _____

□1	□2	□3	□4	□5
Poor	Fair	Good	Very Good	Excellent

9. Pertinent Health Information: ____
____

10. Overall Personal State (Initial):

Please indicate whether you agree or disagree with this statement "I feel comfortable".

□1	□2	□3	□4	□5	□6
Strongly Disagree	Disagree	Tend to Disagree	Tend to Agree	Agree	Strongly Agree

---

**This part is to be filled at the end of session*

11. Overall Personal State (End of Session):

Please indicate whether you agree or disagree with this statement "I feel comfortable".

□1	□2	□3	□4	□5	□6
Strongly Disagree	Disagree	Tend to Disagree	Tend to Agree	Agree	Strongly Agree

Appendix C

Workload Questionnaire

Participant Number: _____ Interface Type: ______

Instruction: Circle your rating at the point that best indicates your experience with the task you just performed.

1. Mental Demand: How much mental and perceptual activity was required?

1 2 3 4 5 6 7 8 9 10
Low High

2. Physical Demand: How much physical activity was required?

1 2 3 4 5 6 7 8 9 10
Low High

3. Temporal Demand: How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred?

1 2 3 4 5 6 7 8 9 10
Low High

4. Effort: How hard did you have to work (mentally and physically) to accomplish your level of performance?

1 2 3 4 5 6 7 8 9 10
Low High

5. Frustration Level: How insecure, discouraged, irritated, stressed and annoyed did you feel during the task?

1 2 3 4 5 6 7 8 9 10
Low High

6. Performance: How successful do you think you were in accomplishing the goals of the task?

1 2 3 4 5 6 7 8 9 10
Low High

Appendix D

Satisfaction Questionnaire

Participant Number: _____ Interface Type: ______

Instruction: Please tick the face that corresponds most closely with your degree of satisfaction with the operation of the interface you just tried.

Appendix E

Technology Acceptance Questionnaire (Exp 1)
(Modified from Technology Acceptance Model, Davis, 1989)

Participant Number: _____ Interface Type: ______

Task 1: Sound Conditioner
Please indicate whether you agree or disagree with the following statement using a scale from 1 to 7.
(1: Strongly Disagree, 2: Disagree, 3: Tend to disagree, 4: Neutral, 5: Tend to agree, 6: Agree, 7: Strongly Agree)

Section 1: Perceived Usefulness (PU)	Strongly Disagree			Neutral			Strongly Agree
PU1: Using the Sound Conditioner would improve my sleep quality (sleep better).	1	2	3	4	5	6	7
PU2: Using the Sound Conditioner would enhance my effectiveness in falling asleep.	1	2	3	4	5	6	7
PU3: Using the Sound Conditioner would make it easier for me to fall asleep.	1	2	3	4	5	6	7
PU4: Over all, I would find the Sound Conditioner useful in my home.	1	2	3	4	5	6	7
Section 2: Perceived Ease of Use (PEOU)							
PEOU1: Learning to use the Sound Conditioner was easy for me.	1	2	3	4	5	6	7
PEOU2: I think finding what I want via the Sound Conditioner was easy.	1	2	3	4	5	6	7
PEOU3: My interaction with the Sound Conditioner was clear and understandable.	1	2	3	4	5	6	7
PEOU4: It would be easy for me to become skillful at using the Sound Conditioner.	1	2	3	4	5	6	7
PEOU5: Over all, I think the Sound Conditioner is easy to use.	1	2	3	4	5	6	7
Section 3: Behavioral Intention (BI)							
BI1: Assuming I had access to the Sound Conditioner, I intend to use it.	1	2	3	4	5	6	7
BI2: Given that I had access to the Sound Conditioner, I predict that I would use it.	1	2	3	4	5	6	7

Participant Number: _____ Interface Type: ______

Task 2: Personal Biofeedback Device

Please indicate whether you agree or disagree with the following statement using a scale from 1 to 7. (1: Strongly Disagree, 2: Disagree, 3: Tend to disagree, 4: Neutral, 5: Tend to agree, 6: Agree, 7: Strongly Agree)

Section 1: Perceived Usefulness (PU)	Strongly Disagree			Neutral			Strongly Agree
PU1: Using the Personal Biofeedback Device would improve my relaxation and stress relief.	1	2	3	4	5	6	7
PU2: Using the Personal Biofeedback Device would enhance my effectiveness in relaxing and relieving stress.	1	2	3	4	5	6	7
PU3: Using the Personal Biofeedback Device would make it easier for me to relax and relieve stress.	1	2	3	4	5	6	7
PU4: Over all, I would find the Personal Biofeedback Device useful in my home.	1	2	3	4	5	6	7
Section 2: Perceived Ease of Use (PEOU)							
PEOU1: Learning to use the Personal Biofeedback Device was easy for me.	1	2	3	4	5	6	7
PEOU2: I think finding what I want via the Personal Biofeedback Device was easy.	1	2	3	4	5	6	7
PEOU3: My interaction with the Personal Biofeedback Device was clear and understandable.	1	2	3	4	5	6	7
PEOU4: It would be easy for me to become skillful at using the Personal Biofeedback Device.	1	2	3	4	5	6	7
PEOU5: Over all, I think using the Personal Biofeedback Device is easy to use.	1	2	3	4	5	6	7
Section 3: Behavioral Intention (BI)							
BI1: Assuming I had access to the Personal Biofeedback Device, I intend to use it.	1	2	3	4	5	6	7
BI2: Given that I had access to the Personal Biofeedback Device, I predict that I would use it.	1	2	3	4	5	6	7

Participant Number: _____ Interface Type: ______

Task 3: Herbal Vaporizer

Please indicate whether you agree or disagree with the following statement using a scale from 1 to 7.
(1: Strongly Disagree, 2: Disagree, 3: Tend to disagree, 4: Neutral, 5: Tend to agree, 6: Agree, 7: Strongly Agree)

<u>Section 1: Perceived Usefulness (PU)</u>	Strongly Disagree			Neutral			Strongly Agree
PU1: Using the Herbal Vaporizer would improve my lung health.	1	2	3	4	5	6	7
PU2: Using the Herbal Vaporizer would enhance effectiveness in breathing air that is good for lung health.	1	2	3	4	5	6	7
PU3: Using the Herbal Vaporizer would make it easier to breathe air that is good for lung health.	1	2	3	4	5	6	7
PU4: Over all, I would find the Herbal Vaporizer useful in my home.	1	2	3	4	5	6	7
<u>Section 2: Perceived Ease of Use (PEOU)</u>							
PEOU1: Learning to use the Herbal Vaporizer was easy for me.	1	2	3	4	5	6	7
PEOU2: I think finding what I want via the Herbal Vaporizer was easy.	1	2	3	4	5	6	7
PEOU3: My interaction with the Herbal Vaporizer was clear and understandable.	1	2	3	4	5	6	7
PEOU4: It would be easy for me to become skillful at using the Herbal Vaporizer.	1	2	3	4	5	6	7
PEOU5: Over all, I think using the Herbal Vaporizer is easy to use.	1	2	3	4	5	6	7
<u>Section 3: Behavioral Intention (BI)</u>							
BI1: Assuming I had access to the Herbal Vaporizer, I intend to use it.	1	2	3	4	5	6	7
BI2: Given that I had access to the Herbal Vaporizer, I predict that I would use it.	1	2	3	4	5	6	7

Participant Number: _____ Interface Type: ______

Task 4: Air Humidifier & Freshener

Please indicate whether you agree or disagree with the following statement using a scale from 1 to 7.
(1: Strongly Disagree, 2: Disagree, 3: Tend to disagree, 4: Neutral, 5: Tend to agree, 6: Agree, 7: Strongly Agree)

Section 1: Perceived Usefulness (PU)	Strongly Disagree			Neutral			Strongly Agree
PU1: Using the Air Humidifier & Freshener would improve the humidity and scents of indoor air.	1	2	3	4	5	6	7
PU2: Using the Air Humidifier & Freshener would enhance effectiveness in keeping the room humid and fresh.	1	2	3	4	5	6	7
PU3: Using the Air Humidifier & Freshener would make it easier to keep the room humid and fresh.	1	2	3	4	5	6	7
PU4: Over all, I would find the Air Humidifier & Freshener useful in my home.	1	2	3	4	5	6	7
Section 2: Perceived Ease of Use (PEOU)							
PEOU1: Learning to use the Air Humidifier & Freshener was easy for me.	1	2	3	4	5	6	7
PEOU2: I think finding what I want via the Air Humidifier & Freshener was easy.	1	2	3	4	5	6	7
PEOU3: My interaction with the Air Humidifier & Freshener was clear and understandable.	1	2	3	4	5	6	7
PEOU4: It would be easy for me to become skillful at using the Air Humidifier & Freshener.	1	2	3	4	5	6	7
PEOU5: Over all, I think using the Air Humidifier & Freshener is easy to use.	1	2	3	4	5	6	7
Section 3: Behavioral Intention (BI)							
BI1: Assuming I had access to the Air Humidifier & Freshener, I intend to use it.	1	2	3	4	5	6	7
BI2: Given that I had access to the Air Humidifier & Freshener, I predict that I would use it.	1	2	3	4	5	6	7

Appendix F

Preference Questionnaire (Exp 1)

Participant Number: _____

1. Please rank the 4 different types of user interface based on your preference.
(1: most preferred; 2: secondly preferred; 3: thirdly preferred; 4: least preferred)

User Interface Type	**Preference**
Physical Button Interface (PBI)	
Physical Dial Interface (PDI)	
Visualized Button Interface (VBI)	
Visualized Dial Interface (VDI)	

2. Please explain your choices for the most preferred and the least preferred interface types.
(A) Please explain why the user interface type of________________ is the most preferred.
____
____
____
____

(B) Please explain why the user interface type of________________ is the least preferred.
____
____
____
____

3. Please choose one interface type that you think your friends (similar age, average education level, health condition level, and technology experience level) would like the most. _____________
Please explain why____
____
____
____

Appendix G

Structured Interview Script and Data Collection Sheet (Exp 1)

Participant Number: _____ Interface Type: ______

Now that you have operated all the interface types in this study, we would like you to answer a few questions regarding your interaction with the four interface types. There are no right or wrong answers, please just provide your opinion.

Section 1. Explanations of Subjective Ratings on Perceived Ease of Use
You rated that ___________________________ is/are easier to use than others.
Could you tell me why do you think the interface(s) is/are easier to use?

____
____
____
____
____

Section 2. Explanations of Subjective Ratings on Satisfaction
You rated that ___________________________ is/are more satisfactory than others.
Could you tell me why you are most satisfied with the interface(s)?

____
____
____
____
____

**** Section 3 is for Older Adult Group Only.***

Section 3. Generation-related Early Experience vs. Age-related Ability Changes
1. You have tried four different controls today in the tasks, the physical buttons, the physical dials, the visualized buttons on iPad, and the visualized dials on iPad. Which control(s) you used today in the tasks was/were difficult to you? You may choose more than one.

____
____

2. I would like to understand what made your interaction difficult, whether it is because the control(s) you found difficult to use in the tasks today are different from the controls that you used when you grew up, or whether it is because your ability changes during the process of aging.

2(a). Let's talk about the early experiences of your generation first. I would like you to take some time and try to remember your experiences with the controls (and control panel) of some consumer products when you were about 10-25 years old (you grew up with). For example, you may think of the controls of the TV sets, radios, washers, phones, and recall what the controls on these products looked like and how they felt like when you were using them. Would you please share with me your memory about the controls (and control panels) that you grew up with?

____

I would like you to compare your memory (early experiences) of controls (and control panels) that you grew up with to the control(s) that you found difficult in the tasks today. How different are those? How do you think it affected you using the control(s) in the tasks today?

2(b). Next, let's talk about the age-related ability changes. As we get older, some aspects of our abilities change or decline in the natural process of aging. I would like you to think about the age related ability changes you experienced which you think made your using the control(s) difficult. For example, your ability to press, push, think, remember, and search? How do you think these changes affected you using the control(s)?

3. Now we have discussed the two factors which might make your usage difficult, the difference from the early experiences of your generation, and the age-related ability changes. Please express the relative contribution of these two things by dividing 100 points between generation-related early experience and age-related ability changes.

For example, if my difficulties had nothing to do with my age-related changes, I might divide the points: generation-related early experiences for 100 points and age-related changes for 0 points.

For example, if my difficulties had little to do with my early experiences, I might divide the points: generation-related early experiences for 20 points and age-related changes for 80 points.

Remember the total number of points must add to 100.

Overall, how would you divide the 100 points?

Factors	**Points**
Generation-related early experience	
Aging-related ability changes	

4. Do you have other comments about early experiences vs. aging?

Appendix H

Technology Acceptance Questionnaire (Exp 2)

(Modified from Technology Acceptance Model, Davis, 1989)

Participant Number: _____ Interface Type: ______

Task 1: Body Fat Analyzer

Please indicate whether you agree or disagree with the following statement using a scale from 1 to 7. (1: Strongly Disagree, 2: Disagree, 3: Tend to disagree, 4: Neutral, 5: Tend to agree, 6: Agree, 7: Strongly Agree)

Section 1: Perceived Usefulness (PU)	Strongly Disagree			Neutral			Strongly Agree
PU1: Using the Body Fat Analyzer would improve my ability to analyze my body fat and stay healthy.	1	2	3	4	5	6	7
PU2: Using the Body Fat Analyzer would enhance my effectiveness in analyzing my body fat and staying healthy.	1	2	3	4	5	6	7
PU3: Using the Body Fat Analyzer would make it easier for me to analyze my body fat and stay healthy.	1	2	3	4	5	6	7
PU4: Over all, I would find the Body Fat Analyzer useful in my home.	1	2	3	4	5	6	7
Section 2: Perceived Ease of Use (PEOU)							
PEOU1: Learning to use the Body Fat Analyzer was easy for me.	1	2	3	4	5	6	7
PEOU2: I think finding what I want via the Body Fat Analyzer was easy.	1	2	3	4	5	6	7
PEOU3: My interaction with the Body Fat Analyzer was clear and understandable.	1	2	3	4	5	6	7
PEOU4: It would be easy for me to become skillful at using the Body Fat Analyzer.	1	2	3	4	5	6	7
PEOU5: Over all, I think using the Body Fat Analyzer is easy to use.	1	2	3	4	5	6	7
Section 3: Behavioral Intention (BI)							
BI1: Assuming I had access to the Body Fat Analyzer, I intend to use it.	1	2	3	4	5	6	7
BI2: Given that I had access to the Body Fat Analyzer, I predict that I would use it.	1	2	3	4	5	6	7

Participant Number: _____ Interface Type: ______

Task 2: Air Cleaner & Steamer

Please indicate whether you agree or disagree with the following statement using a scale from 1 to 7.
(1: Strongly Disagree, 2: Disagree, 3: Tend to disagree, 4: Neutral, 5: Tend to agree, 6: Agree, 7: Strongly Agree)

Section 1: Perceived Usefulness (PU)	Strongly Disagree			Neutral			Strongly Agree
PU1: Using the Air Cleaner & Steamer would improve the cleanness and humidity of indoor air.	1	2	3	4	5	6	7
PU2: Using the Air Cleaner & Steamer would enhance my effectiveness in keeping the room clean and humid.	1	2	3	4	5	6	7
PU3: Using the Air Cleaner & Steamer would make it easier for me to keep the room clean and humid.	1	2	3	4	5	6	7
PU4: Over all, I would find the Air Cleaner & Steamer useful in my home.	1	2	3	4	5	6	7
Section 2: Perceived Ease of Use (PEOU)							
PEOU1: Learning to use the Air Cleaner & Steamer was easy for me.	1	2	3	4	5	6	7
PEOU2: I think finding what I want via the Air Cleaner & Steamer was easy.	1	2	3	4	5	6	7
PEOU3: My interaction with the Air Cleaner & Steamer was clear and understandable.	1	2	3	4	5	6	7
PEOU4: It would be easy for me to become skillful at using the Air Cleaner & Steamer.	1	2	3	4	5	6	7
PEOU5: Over all, I think using the Air Cleaner & Steamer is easy to use.	1	2	3	4	5	6	7
Section 3: Behavioral Intention (BI)							
BI1: Assuming I had access to the Air Cleaner & Steamer, I intend to use it.	1	2	3	4	5	6	7
BI2: Given that I had access to the Air Cleaner & Steamer, I predict that I would use it.	1	2	3	4	5	6	7

Participant Number: _____ Interface Type: ______

Task 3: Activity & Health Monitor

Please indicate whether you agree or disagree with the following statement using a scale from 1 to 7.
(1: Strongly Disagree, 2: Disagree, 3: Tend to disagree, 4: Neutral, 5: Tend to agree, 6: Agree, 7: Strongly Agree)

	Strongly Disagree 1	2	3	Neutral 4	5	6	Strongly Agree 7
Section 1: Perceived Usefulness (PU)							
PU1: Using the Activity & Health Monitor would improve my ability to monitor my daily activity and health.	1	2	3	4	5	6	7
PU2: Using the Activity & Health Monitor would enhance my effectiveness in monitoring my daily activity and health.	1	2	3	4	5	6	7
PU3: Using the Activity & Health Monitor would make it easier for me to monitor my daily activity and health	1	2	3	4	5	6	7
PU4: Over all, I would find the Activity & Health Monitor useful in my home.	1	2	3	4	5	6	7
Section 2: Perceived Ease of Use (PEOU)							
PEOU1: Learning to use the Activity & Health Monitor was easy for me.	1	2	3	4	5	6	7
PEOU2: I think finding what I want via the Activity & Health Monitor was easy.	1	2	3	4	5	6	7
PEOU3: My interaction with the Activity & Health Monitor was clear and understandable.	1	2	3	4	5	6	7
PEOU4: It would be easy for me to become skillful at using the Activity & Health Monitor.	1	2	3	4	5	6	7
PEOU5: Over all, I think using the Activity & Health Monitor is easy to use.	1	2	3	4	5	6	7
Section 3: Behavioral Intention (BI)							
BI1: Assuming I had access to the Activity & Health Monitor, I intend to use it.	1	2	3	4	5	6	7
BI2: Given that I had access to the Activity & Health Monitor, I predict that I would use it.	1	2	3	4	5	6	7

Appendix I

Preference Questionnaire (Exp 2)

Participant Number: _____

1. Please rank the 3 different types of user interface based on your preference.
(1: most preferred; 2: secondly preferred; 3: least preferred)

User Interface Type	**Preference**
One Control with Single Function and Single-Layered Interface (SFSLI)	
One Control with Multi-Function Interface (MFI)	
Multi-Layered Interface (MLI)	

2. Please explain your choices for the most preferred and the least preferred interface types.
(A) Please explain why the user interface type of________________ is the most preferred.

(B) Please explain why the user interface type of________________ is the least preferred.

3. Please choose one interface type that you think your friends (similar age, average education level, health condition level, and technology experience level) would like the most. _____________
Please explain why____

Appendix J

Structured Interview Script and Data Collection Sheet (Exp 2)

Participant Number: _____ Interface Type: ______

Now that you have operated all the interface types in this study, we would like you to answer a few questions regarding your interaction with the four interface types. There are no right or wrong answers, please just provide your opinion.

Section 1. Explanations of Subjective Ratings on Perceived Ease of Use
You rated that ___________________________ is/are easier to use than others.
Could you tell me why do you think the interface(s) is/are easier to use?

____
____
____
____
____

Section 2. Explanations of Subjective Ratings on Satisfaction
You rated that ___________________________ is/are more satisfactory than others.
Could you tell me why you are most satisfied with the interface(s)?

____
____
____
____
____

**** Section 3 is for Older Adult Group Only.***

Section 3. Generation-related Early Experiences vs. Age-related Ability Changes
1. You have tried three ways of function structures in the tasks. You have tried each function has its own control and functions were placed on one layer (the SFSLI), three functions shared one control (the MFI), and functions were allocated on three layers (the MLI). Which way(s) of function organization you used today in the tasks are was/were difficult to you? You may choose more than one.

____
____

2. I would like to understand what made your interaction difficult, whether it is because function structure you found difficult to use in the tasks today are very different from the interface design(s)/the ways that functions were structured that you used when you grew up, or whether it is because your ability changes during the process of aging.

2(a). Let's talk about the early experience first. I would like you to take some time and try to remember your experience with function structure of consumer products when you were about 10-25 years old (you grew up with). For example, you may think the ways that functions were structured in the TV sets, radios, washers, phones, whether the functions were all on one-layer (flat) or allocated on multiple-layers (hidden functions behind the layer), whether each function has its own control or multiple functions have to share one control (mode). Would you please share with me your memory about the function organization that you grew up with?

____
____
____
____

I would like you to compare your memory (early experiences) of user interface (function structure) at that time to the user interface design that you found the most difficult in the task today. How different are those? How it affected your usage (interaction)?

____
____
____
____

2(b). Next, let's talk about the age-related ability changes. As we get older, some aspects of our abilities change or decline during the natural process of aging. I would like you to think about the age related ability changes you experienced which you think made your usage difficult. For example, your ability to press, control, think, remember, and search? How these changes affected your usage (interaction)?

____
____
____
____

3. Now we have discussed the two factors which might make your usage difficult, the difference from the early experiences of your generation, and the age-related ability changes. Please express the relative contribution of these two things by dividing 100 points between generation-related early experience and age-related ability changes.
For example, if my difficulties had nothing to do with my age-related changes, I might divide the points: generation-related early experiences for 100 points and age-related changes for 0 points.
For example, if my difficulties had little to do with my early experiences, I might divide the points: generation-related early experiences for 20 points and age-related changes for 80 points.
Remember the total number of points must add to 100.
Overall, how would you divide the 100 points?

Factors	**Points**
Generation related early experience	
Aging-related ability changes	

4. Do you have other comments about early experiences vs. aging?

____
____
____

Appendix K

Task Analysis (Exp 2)

Interface Type: One Control with Single Function and Single-Layered Interface (SFSLI)
(Example: Air Cleaner and Steamer)

Task	**Cue for Initiation** (What Participants Saw and Knew About the Situation)	**Reasoning or Decision**	**Control Used**	**Feedback**
1. Turn On the Device				
1.1 Locate and touch the *Power On* button.	A headline of "Power" located in the upper left corner of the iPad screen. A group of 2 buttons located under the headline of "Power," with one button labeled "On."		Touch the button labeled "On."	After the "On" button was touched, the color of the word "On" on the button changed from white to blue, while all the other buttons on the iPad screen remained unchanged.
2. Set the Clean Cycle to 5 hours				
2.1 Locate the setting of Clean Cycle.	A headline of "Clean Cycle (hr)" located in the upper right corner of the iPad screen.			
2.2 Locate and Select the option of *5 Hours* in the mode of *Clean Cycle*.	A group of 4 buttons located under the headline of "Clean Cycle (hr)," with one button labeled "5."		Touch the button labeled "5."	After the "5" button was touched, the color of the number "5" on the button changed from white to blue, while all the other buttons on the iPad screen remained unchanged.
3. Set the Clean Speed to Fast				
3.1 Locate the setting of Clean Speed.	A headline of "Clean Speed" located in the bottom left corner of the iPad screen.			
3.2 Locate and Select the option of *Fast* in the mode of *Clean Speed*.	A group of 4 buttons located under the headline of "Clean Speed," with one button labeled "Fast."		Touch the button labeled "Fast."	After the "Fast" button was touched, the color of the word "Fast" on the button changed from white to blue, while all the other buttons on the iPad screen remained unchanged.
4. Set the Mist Volume to "*"				
4.1 Locate the setting of Mist Volume.	A headline of "Mist Volume" located in the bottom right corner of the iPad screen.			
4.2 Locate and Select the option of "*" in the mode of *Mist Volume*.	A group of 4 buttons located under the headline of "Mist Volume," with one button labeled "*."		Touch the button labeled "*."	After the "*" button was touched, the color of the symbol "*" on the button changed from white to blue, while all the other buttons on the iPad screen remained unchanged.

5. Turn Off the Device				
5.1 Locate and touch the *Power Off* button.	A headline of "Power" located in the upper left corner of the iPad screen. A group of 2 buttons located under it, with one button labeled "Off."		Touch the button labeled "Off."	After the "Off" button was touched, the color of all numbers, words, and symbols on all previously selected buttons changed from blue to white.

Interface Type: One Control with Multi-Function Interface (MFI)
(Example: Air Cleaner and Steamer)

Task	Cue for Initiation (What Participants Saw and Knew About the Situation)	Reasoning or Decision	Control Used	Feedback
1. Turn On the Device				
1.1 Locate and touch the *Power On* button.	A button labeled "POWER On/OFF" located on the left of the iPad screen.		Touch the button labeled "POWER On/Off."	After the "POWER On/Off" button was touched, the display screen (a smaller screen within the iPad screen) changed from dark to being lit blue. At the same time, a cross figure appeared in the center of the display screen which divided the display screen evenly into 4 squares. The "MODE" button, which was located on the left side of the iPad screen remained unchanged. The group of 4 buttons ("1" button, "2" button, "3" button, and "4" button), which was located at the bottom of the iPad screen also remained unchanged.
2. Set the Clean Cycle to 5 hours				
2.1 Set the *Mode* to *Clean Cycle*.	A button labeled "MODE" located in the upper left corner of the iPad screen. Three indicator lights under the labeling of "Clean Cycle (hr)," "Clean Speed," and "Mist Volume" were turned off (gray).	Decide whether the present display shows it is in the right mode. If it is, continue. If not, change the mode.	Touch the button labeled "MODE" once.	After the "MODE" button was touched, the indicator light directly under the labeling of "Clean Cycle (hr)" turned from gray to being lit red, with the other 2 indicator lights unchanged. At the same time, 4 numbers appeared in the display screen (in 4 separate squares, which were labeled "1," "5," "12," and "24." The "POWER On/Off" button, the "MODE" button, and the group of 4 buttons ("1" button, "2" button, "3" button, and "4" button) remained unchanged.

2.2 Select the option of *5 Hours* in the mode of *Clean Cycle*.	Four squares in the display screen showed 4 different numbers with one square showing "5." A group of 4 buttons labeled "1," "2," "3," and "4," with button "2" shared the same location of the square of "5" (mapping and correspondence), they both located in the upper right corner.	Decide the associated functions of the 4 buttons ("1" button, "2" button, "3" button, and "4" button) in this particular mode.	Touch the button labeled "2".	After the "2" button was touched, the color of the number "5" in the square changed from white to blue, while the other 3 numbers "1", "12, and "24" in the 3 other squares remained unchanged. The "POWER On/Off" button, the "MODE" button, and the group of 4 buttons ("1" button, "2" button", "3" button, and "4" button) remained unchanged.
3. Set the Clean Speed to Fast				
3.1 Set the *Mode* to *Clean Speed*.	A button labeled "MODE" located in the upper left corner of the iPad screen. The indicator light under the labeling of "Clean Cycle (hr)" was turned on (red), while the other 2 indicator lights under the labeling of "Clean Speed," and "Mist Volume" were turned off (gray).	Decide whether the present display shows it is in the right mode. If it is, continue. If not, change the mode.	Touch the button labeled "MODE" once.	After the "MODE" button was touched, the indicator light directly under the labeling of "Clean Speed" turned from gray to being lit red, with the other 2 indicator lights unchanged. At the same time, 4 words appeared in the display screen (in 4 different squares: "Slow," "Med," "Fast," and "Off." The "POWER On/Off" button, the "MODE" button, and the group of 4 buttons ("1" button, "2" button, "3" button, and "4" button) remained unchanged.
3.3 Select the option of *Fast* within the setting of *Clean Speed*.	Four squares in the display screen showed 4 different numbers with one square showed "Fast". A group of 4 buttons labeled "1," "2," "3," and "4," with button "2" shared the same location of the square of "Fast" (mapping and correspondence), they both located in the bottom left corner.	Decide the associated functions of the 4 buttons ("1" button, "2" button, "3" button, and "4" button) in this particular mode.	Touch the button labeled "3".	After the "3" button was touched, the color of the word "Fast" in the square changed from white to blue, while the other 3 numbers "1," "12," and "24" in the other 3 squares remained unchanged. The "POWER On/Off" button, the "MODE" button, and the group of 4 buttons ("1" button, "2" button, "3" button, and "4" button) remained unchanged.
4. Set the Mist Volume to "*"				
4.1 Set the *Mode* to *Mist Volume*.	A button labeled "MODE" located in the upper left corner of the iPad screen. The indicator light under the labeling of "Mist Volume" was turned on (red), while the other 2 indicator	Decide whether the present display shows it is in the right mode. If it is, continue. If not, change the mode.	Touch the button labeled "MODE" once.	After the "MODE" button was touched, the indicator light directly under the labeling of "Mist Volume" turned from gray to being lit red, with the other 2 indicator lights unchanged. At the same time, 4 symbols appeared in the display screen (in 4 different squares), "*,""* *," "* * *," and "* * * *."

	lights under the labeling of "Clean Cycle (hr)" and "Clean Speed" were turned off (gray).			The "POWER On/Off" button, the "MODE" button, and the group of 4 buttons ("1" button, "2" button, "3" button, and "4" button) remained unchanged.
4.2 Select the option of "*" within the setting of *Mist Volume.*	Four squares in the display screen showed 4 different numbers with one square showing "*." A group of 4 buttons labeled "1," "2," "3," and "4," with button "1" shared the same location of the square of "*" (mapping and correspondence), they both located in the upper left corner.	Decide the associated functions of the 4 buttons ("1" button, "2" button, "3" button, and "4" button) in this particular mode.	Touch the button labeled "1."	After the "1" button was touched, the color of the symbol "*" in the square changed from white to blue, while the other 3 symbols "* *," "* * *," and "* * * *" in the other 3 squares remained unchanged. The "POWER On/Off" button, the "MODE" button, and the group of 4 buttons ("1" button, "2" button, "3" button, and "4" button) remained unchanged.
5. Turn Off the Device				
5.1 Locate and touch the *Power Off* button.	A button labeled "POWER On/OFF" located in the bottom right corner of the iPad screen.		Touch the button labeled "POWER On/Off".	After the "POWER On/Off" button was touched, all the buttons on the display screen disappeared and the display screen turned dark. The "MODE" button, and the group of 4 buttons ("1" button, "2" button, "3" button, and "4" button) remained unchanged.

Interface Type: Multi-Layered Interface (MLI)
(Example: Air Cleaner and Steamer)

Task	Cue for Initiation (What Participants Saw and Knew About the Situation)	Reasoning or Decision	Control Used	Feedback
1. Turn On the Device				
1.1 Locate and touch the *Power On* button.	A button labeled "POWER On/OFF" located on the bottom right corner of the iPad screen.		Touch the button labeled "POWER On/Off."	After the "POWER On/Off" button was touched, the display screen (a smaller screen within the iPad screen) changed from dark to being lit blue. At the same time, a button labeled "Selection" appeared in the center of the display screen.
2. Set the Clean Cycle to 5 hours				
2.1 Find the setting of *Clean Cycle*.	A button labeled "Selection" located in the center of the display screen (a smaller screen within the iPad screen).	Decide whether it is the right choice to go to a deeper layer.	Touch the button labeled "Selection."	After the "Selection" button was touched, the display on the display screen changed to a group of 4 buttons labeled "Clean Cycle (hr)," "Clean Speed," "Mist Volume," and "BACK" appeared on the display screen. The "BACK" button was located on the bottom left corner of the display screen

				while the other 3 buttons were located in the center of the display screen. "POWER On/Off" remained unchanged.
2.2 Select the setting of *Clean Cycle*.	A group of 3 buttons located in the center of the display screen with one button labeled "Clean Cycle".	Decide whether it is the right choice to go to a deeper layer.	Touch the button labeled "Clean Cycle (hr)."	After the "Clean Cycle (hr)" button was touched, the display in the center of the display screen changed to a group of 4 buttons labeled "1," "5," "12," and "24." "BACK" button and "POWER On/Off" button remained unchanged.
2.3 Select the option of *5 Hours* within the setting of *Clean Cycle*.	A group of 4 buttons located in the center of the display screen with one button labeled "5".		Touch the button labeled "5."	After the "5" button was touched, the color of the number "5" on the button changed from white to blue, while the other 3 buttons labeled "1", "12," and "24" remained unchanged. "BACK" button and "POWER On/Off" button remained unchanged.
3. Set the Clean Speed to Fast				
3.1 Go back to previous layer with the setting of *Clean Speed*.	A button labeled "BACK" in left bottom corner of the display screen. Knowledge from previous encounter of the button labeled "Clean Speed" on the upper layer.	Decide whether it is the right choice to go to an upper layer.	Touch the button labeled "BACK."	After the "BACK" button was touched, the display in the display screen changed to a group of 3 buttons labeled "Clean Cycle (hr)", "Clean Speed", and "Mist Volume" as seen before. "BACK" button and "POWER On/Off" button remained unchanged.
3.2 Select the setting of *Clean Speed*.	A group of 3 buttons located in the center of the display screen with one button labeled "Clean Speed".	Decide whether it is the right choice to go to a deeper layer.	Touch the button labeled "Clean Speed."	After the "Clean Speed" button was touched, the display in the center of the display screen changed to a group of 4 buttons labeled "Slow," "Med," "Fast," and "Off." "BACK" button and "POWER On/Off" button remained unchanged.
3.3 Select the option of *Fast* within the setting of *Clean Speed*.	A group of 4 buttons located in the center of the display screen with one button labeled "Fast".		Touch the button labeled "Fast."	After the "Fast" button was touched, the color of the word "Fast" on the button changed from white to blue, while the other 3 buttons labeled "Slow," "Med," and "Off" remained unchanged. "BACK" button and "POWER On/Off" button remained unchanged.
4. Set the Mist Volume to "*"				
4.1 Go back to previous layer with the setting of *Mist Volume*.	A button labeled "BACK" in left bottom corner of the display screen.	Decide whether it is the right choice to go	Touch the button labeled "BACK."	After the "BACK" button was touched, the display on the display screen changed to a group of 3 buttons labeled "Clean Cycle (hr),"

	Knowledge from previous encounter with the button labeled “Mist Volume” on the upper layer.	to an upper layer.		“Clean Speed,” and “Mist Volume” as seen before. “BACK” button and “POWER On/Off” button remained unchanged.
4.2 Select the setting of *Mist Volume*.	A group of 3 buttons located in the center of the display screen with one button labeled “Mist Volume”.	Decide whether it is the right choice to go to a deeper layer.	Touch the button labeled “Mist Volume.”	After the “Mist Volume” button was touched, the display in the center of the display screen changed to a group 4 buttons labeled “*,” “* *,” “* * *,” and “* * * *”. “BACK” button and “POWER On/Off” button remained unchanged.
4.3 Select the option of “*” within the setting of *Clean Speed*.	A group of 4 buttons located in the center of the display screen with one button labeled “*”.		Touch the button labeled “*.”	After the “*” button was touched, the color of the symbol “*” on the button changed from white to blue, while the other 3 buttons labeled “* *,” “* * *,” and “* * * *” remained unchanged. “BACK” button and “POWER On/Off” button remained unchanged.
5. Turn Off the Device				
5.1 Locate and touch the *Power Off* button.	A button labeled “POWER On/OFF” located on the bottom right corner of the iPad screen.		Touch the button labeled “POWER On/Off.”	After the “POWER On/Off” button was touched, all the buttons on the display screen disappeared and the display screen turned dark.