Age- and experience-related user behavior differences in the use of complicated electronic devices

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Abstract

In this study, we observed the behavior of younger adults (20–29 years old) and middle-aged adults (46–59 years old) interacting with complicated electronic devices. Two recently released multi-functional multimedia devices, namely PMPs (portable multimedia players) and MP3 players were used in the observations. We examined various aspects of interaction behaviors in terms of performance, strategies, error consequences, physical operation methods, and workload. Our analysis of age-related differences included differences in background knowledge as an important independent factor. The results revealed that differences in age meaningfully affected the observed error frequency, the number of interaction steps, the rigidity of exploration, the success of physical operation methods, and subjective perception of temporal demand and performance. In contrast, trial-and-error behavior and frustration levels were influenced by background knowledge rather than age. These novel findings provide important new insights into user interaction characteristics between different age groups and may facilitate the design of age group-appropriate interfaces for complicated electronic devices.

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1. Introduction

It is generally accepted that physical, sensory, and cognitive factors decline with age (Craik and Salthouse, 2000; Hitchcock et al., 2001; Scialfa et al., 2004), with such declines accelerating after individuals reach their mid-forties (Hawthorn, 2000). Due to this trend, older people tend to have more difficulty using PCs and/or electronics, and show poorer performance with these devices compared to younger people. Older people also took longer and made more errors in computer-based work (Czaja and Sharit, 1993; Laberge and Scialfa, 2005; Sayer, 2004), showed less speed and made more slip errors in using input devices (Chaparro et al., 1999; Smith et al., 1999), and had more usability problems in the use of cellular phones (Ziefle and Bay, 2005).

Most previous studies on age-related differences in performance, however, compared younger adults aged up to about 30 years with elderly individuals over 60 years of age. Middle-aged adults have received relatively less attention in this context, even though they are important to the workforce and are widely exposed to technology in everyday life. According to OECD Statistics, in the Republic of Korea in 2006, the proportion of middle-aged adults (45–59 years of age) was 28.5%. This proportion was greater than those of younger adults aged 20–29 years (19.8%), and elderly people over 60 years of age (19.7%). In addition, 30.2% of all jobs are filled by middle-aged adults, compared to 17.5% of jobs filled by younger adults and only 10.8% of jobs held by elderly people. Similarly, in the United States, the United Kingdom, and the European Union, middle-aged adults comprise 31.5%, 30.5%, and 30.4% of total employed adults and fill 32.3%, 31.9%, and 32.5% of jobs, respectively.
However, the physical, sensory, and cognitive abilities of middle-aged adults are generally poorer than those of younger adults (Hawthorn, 2000). Middle-aged people have less knowledge of technology compared with younger adults; so middle-aged adults may experience more difficulty in using technology than younger adults. Thus, studies of technology focusing on age-related differences between younger adults and middle-aged adults will be useful in the study of HCI. Here, we examined technology interaction behavior differences between younger adults (20–29 years of age) and middle-aged adults (46–59 years of age).

1.1. Effect of background knowledge on age-related interaction differences

Besides of declines of abilities, the gap between younger and older people appears to be also at least partially due to older people tending to have less experience with technology. Previous studies found that differences in experience were an important factor in efficient computer interaction (Birdi et al., 1997; Sjölinder et al., 2005) and that practice by older adults resulted in age-related performance improvements in the use of personal digital assistants (PDAs) (Mayhorn et al., 2005; Sterns, 2005). In addition, computer use and/or training over multiple weeks was found to improve the negative attitudes of older people toward technology (Danowski and Sacks, 1980; Jay and Willis, 1992), and diminish their anxiety levels (Charness et al., 1992).

However, even when the experience gap is controlled, there is still a gap in technology use and comfort between younger and older people. For example, the time and number of interaction steps required to complete various information-processing-based computer tasks were significantly associated with differences in both age and computer experience (Czaja and Sharit, 1993). In addition, prior experience improved the performance of older people to some degree, but age-related differences remained, indicating that experience alone was unable to offset the age effect (Czaja and Sharit, 1997; Laberge and Scialfa, 2005).

1.2. Multi-functional devices and increasing complexity

These days, various mono-function devices have been merged into single devices offering multiple functions (Lindholm et al., 2003; Pemberton, 2001). However, this increased functionality does not always guarantee increased usability. Many users find it difficult to use multi-functional devices, and those difficulties have been connected to lost sales (Gussow, 2005; Van Grinsven, 2004). In addition, the size reduction of many devices has complicated their ease of use. In small multi-functional devices, the number of functions is higher, but the UI (user interface) objects and controls tend to be limited in number and smaller than those found on single-function devices. Therefore, a given UI object or input device (i.e. button, joystick, knob, etc.) typically controls multiple functions through different operation methods. For example, the simple “on/off” button of a newer device might be pressed for various durations to enable different functions. Frequently, several buttons must be pressed in combination to achieve the desired functionality. A previous study showed that users take more time and make more errors when a single UI object provides multiple and/or dissimilar functions (Ziefle et al., 2006).

Not unexpectedly, complicated multi-functional devices tend to be more challenging for older users compared to their younger counterparts. Visual information details and useless information (e.g., advertisements, decorated text, and animation) negatively impact task completion more often in older than younger adults (Curzon et al., 2005; Kosnik et al., 1988). Thus, older adults are more likely to have difficulties in recognizing and selecting a desired function among various information items on the small screens of multi-functional devices. Hasher and Zacks (1988) found that the inhibitory function of working memory declines with age, leading to more distraction by irrelevant information; this may suggest a possible mechanism underlying the tendency of older adults to have difficulty selecting among information items. In addition, older adults often have decreased motor skills compared to younger adults (Siedler and Stelmach, 1996), making it difficult for them to operate the small, multi-functional UIs found on many devices. Although many studies have identified age-related differences in the use of computer-related appliances and the Internet (Birdi et al., 1997; Curzon et al., 2005; Sayers, 2004; Sjölinder, 2005), few studies have focused on age effects in the use of complicated electronics such as small multi-functional devices.

1.3. Motivation for the study

The study of age- and background-related differences in user behavior can provide important new insights into the fundamental characteristics of interaction behaviors between different age groups and help researchers predict users’ interaction problems based on these variables. Since electronic devices and information systems are increasingly common not only in the workplace, but also in the home, multi-functional devices are likely to become a part of everyday life. Therefore, studies identifying age- and background knowledge-related behavior differences in the use of multi-functional devices will be of significant value in the areas of HCI.

In the present study, we examined user behavior differences when using small multi-functional devices, a PMP and an MP3 player, and analyzed the effect of age and background knowledge on the identified behavior differences between the younger adults (20–29 years old) and the older adults (46–59 years old). PMPs and MP3 players are representative of small multi-functional electronic devices frequently used in many aspects of daily life, including in the home, the workplace, and while in transit.
These devices support various functions previously found in single devices (e.g., FM radio, audio player, video player), but have only a small number of UI controls because the devices are small. Moreover, the controls themselves have become more complex as devices acquire multiple operation methods. Thus, PMPs and MP3 players are suitable experimental devices with which to explore possible age-related differences in the use of small multi-functional devices.

2. Experiments

In this study, we conducted two user observations using the same procedures. In user observation I, we observed the behavior of users interacting with a PMP. In user observation II, we observed the behavior of users interacting with an MP3 player.

2.1. Observational framework

Through observations, we analyzed the user interaction behaviors in terms of performance, strategies, error consequences, physical operation methods, and workload. User strategies and error types are important factors in user interaction behaviors. Previous studies found that specific types of strategies and error consequences are related to high-level task performance (Hollnagel, 1993; Van Der Linden et al., 2001), and adoption of self-monitoring strategies can help users learn more functions of a given device (Trudel and Payne, 1996). Stronge et al. (2006) found that older adults tend to adopt more ineffective search strategies in web navigation than do younger adults, due to a lack of knowledge of effective search strategies. In terms of error types, Birdi and colleagues (1997) classified regulation error types into either higher (intellectual) or lower (sensorimotor) levels, and found that older adults made more intellectual errors than did younger adults. Morrell and colleagues (2000) examined the usage by older adults of electronic bulletin board systems, and classified error types into performance errors, motor-control problems, and intervention errors. In the present work, we examined whether older and younger adults showed differences in interaction strategy and/or error type, whether older adults had a higher likelihood of making errors that caused negative effects, and whether these differences were associated with age and/or background knowledge.

Because small multi-functional devices tend to have small input devices with multiple operation methods, their use requires fine motor skills. While most prior works examining the impact of motor skills on technology use by older adults have focused on computer input devices, we herein examined fine motor skills in the use of various input devices of small electronics, such as touch pads, buttons, and joysticks. Regarding input devices, some studies have reported that older adults prefer direct devices to indirect devices (e.g., a touch screen over a mouse, a mouse over a keyboard) (Charness et al., 2004; Chou and Hsiao, 2007), but Rogers et al. (2005) asserted that the preference for input devices was task-dependent. In this study, we therefore explored possible preferences between direct (e.g., touchpad) and indirect (e.g., joystick and buttons) controls in adults using small multi-functional devices.

Finally, we measured workload, which encompasses user resource demands, stress, and the emotional aspects of user interaction behaviors. Workload is one of the factors that influence an individual’s task performance (Kirschnner, 2002), and the importance of evaluating workload increases as systems become more complex (Rubio et al., 2004). In this study, we used the NASA-RTLX inventory (Byers et al., 1989) to quantitatively measure subjective workload, and analyzed mental demand, physical demand, temporal demand, effort, performance, and frustration as sources of workload. The subjective and objective measures provided complementary data.

2.2. Classifications of user strategies and error consequences

User interaction behaviors were classified into four types according to the strategies they seemed to represent (Van Der Linden et al., 2001), namely systematic exploration, trial-and-error, rigid exploration, and encapsulation in information-seeking. Systematic exploration, which is a strategy that guides users to task goals with the highest probability of success (Döner and Schaub, 1994; Hollnagel, 1993), includes the behaviors of establishing, testing and evaluating hypotheses, and then making plans for next actions based on the results (Hollnagel, 1993; Van Der Linden et al., 2001). The trial-and-error strategy is a less logical and more opportunistic user behavior that involves unplanned and indiscriminate actions (Hollnagel, 1993). Rigid exploration is used to describe repetitive actions with no meaningful outcomes (Döner and Schaub, 1994; Hollnagel, 1993); this behavior is related to a confirmation bias in the formation and evaluation of hypotheses (Nisbett and Ross, 1980) or a general lack of self-reflection during exploration (Döner and Schaub, 1994). Encapsulation in information seeking, which refers to focused information searching without any progress in task flow (Döner and Schaub, 1994), is often seen when users fail to obtain required information through searching, leading to increased uncertainty and a tendency to continue searching behaviors without any useful outcome (Van Der Linden et al., 2001).

Error types were analyzed by two taxonomies. The first classification used error consequences, which could be positive, negative, or neutral (Van Der Linden et al., 2001). Errors having positive consequences are actions that do not give the desired result, but provide the user with information that will aid in achievement of the goal. In contrast, errors having negative consequences are those that lead to a dead end, invalidate previous positive actions and/or send users back to the starting point. Non-effective actions
(e.g., selection of inactive or disabled icons, menus, or buttons) are useless behaviors that have no effect on task progress. The other classification used was the Morrell error taxonomy, which classifies error types into performance errors, motor-control problems, and intervention errors (Morrell et al., 2000). Performance errors consist of commission errors, omission errors, or wrong-action errors. Commission errors refer to unnecessary and additional actions in a task procedure, while omission errors correspond to the skipping of necessary actions. Wrong-action errors are selections of incorrect functions even though the desired functions had been correctly identified. Motor-control problems are failures in physical operation of input devices. Intervention errors are delays due to interruptions from experimenters, but this type of error was not considered in this study because no interventions were made by the experimenters.

2.3. Participants

Sixty participants, including 30 younger adults and 30 older adults participated in each observation. In user observation I, the younger adults were between 21 and 29 years ($M = 25, SD = 2.1$; 20 males and 10 females) and the older adults were between 46 and 59 years ($M = 52, SD = 4.6$; 19 males and 11 females). In user observation II, the younger adults were aged between 20 and 27 years ($M = 25, SD = 1.8$; 21 males and 9 females) and the older adults were aged between 46 and 59 years ($M = 54, SD = 4.5$; 20 males and 10 females). All participants were citizens of the Republic of Korea, and they had various occupations. Students, researchers, teachers, engineers, clerks, mechanics, businessmen, and housewives were all included in the study. All participants had either normal eyesight, or eyesight fully corrected with glasses. All participants could easily see information on the displays of the tested devices. In each case, the participants were novice users of the given device. All participants selected were educated beyond the high school level to reduce any effects of educational level.

Before user observations, the participants were given questionnaires surveying their education level and their background knowledge of representative technologies (e.g., PCs, the Internet, cellular phones, and electronic devices) that might affect user behavior when interacting with the test devices (Fig. 1). Education level was determined using that might affect user behavior when interacting with the PCs, the Internet, cellular phones, and electronic devices) background knowledge of representative technologies (e.g., questionnaires surveying their education level and their effects of educational level. were educated beyond the high school level to reduce any of the tested devices. In each case, the participants could easily see information on the displays

maximal PC background knowledge score of 15 points. Internet background knowledge was assessed in a similar manner, except that the usage period was rated from “less than 1 year” to “more than 10 years.” Cellular phone experience was measured in terms of usage period (five-point scale ranging from “less than 1 year” to “more than 10 years”), frequency (five-point scale ranging from “less than three times per week” to “more than ten times per day”), and number of functions used (five-point scale). Background knowledge of electronic devices was scored from 1 to 5, with 1 point given for knowledge of each device category (such as TVs and radios; CD players and audio systems; VCRs, DVD players and DVD recorders; digital cameras and camcorders; and PDAs).

The PMP used in this study offered functions and UIs that were similar to those found in PC programs. Since large differences in PC knowledge could have obscured the effects of other background knowledge types, we controlled the background knowledge of PCs.

Our t-test results showed that all background knowledge types differed significantly ($p < .05$) between the two age groups, except for the background knowledge of PCs in user observation I and education levels in both observations, which were strictly controlled. These differences in background knowledge were taken to reflect the general generation gap, indicating that the user behavior differences observed in this study are likely to reflect general
differences between younger and older adult users of the tested devices.

2.4. Tested electronic devices

The test devices consisted of an i-STATION PMP 1000 and an iRiver IFP-180T MP3 player. The appearances of the test devices and the specifications of input devices are shown in Figs. 2 and 3.

The PMP may be manipulated by three types of UI controls, namely a touchpad, a mini-joystick, and two buttons. A touch pen is used to click the menu items or icons on the screen, and the functions of some items are differentiated by the application of a short click versus a long click. The mini-joystick responds to either short pushes or long pushes (the term “push” refers to the directions of up, down, right, or left) for navigation among items or icons, and short presses and long presses (the term “press” refers to the direction perpendicular to the screen) to select items or icons. Sometimes, the push of the joystick operates hidden functions such as forward or rewind of music or video files. The two buttons (left and right) are also used for navigation and selection of various functions (menu items). The participants can operate all provided functions with any of the input devices, but the efficiency of each input device differs depending on the function.

The MP3 player offers three buttons operating with both short- and long-press methods, and a mini-joystick that provides different functions according to short- or long-duration push, short- or long-duration press, and combinations thereof. In contrast to the PMP, most functions of the MP3 player depend on hidden physical operation methods of the joystick and buttons rather than selection of on-screen menu items.

2.5. Procedure

Before the observations, the experimenter explained the purpose of the experiment and the basic functions of the apparatus. The detailed operation methods of the UI controls were not mentioned, because we wanted to observe the natural behaviors that came from the expectations and intentions of each participant. The participants performed seven tasks in each observation (Tables 1 and 2).

No time limits were imposed, but the participants were asked to perform the tasks as accurately and as quickly as possible. Interaction behaviors were recorded by two experimenters during the observation, and the observation was videotaped for later review. The experimenters were Ph.D. candidate students, who had majored in HCI, and who had more than four years of experience in projects involving user tests, user observations, usability evaluations, and interface designs.

After each task was completed, workload and detail interaction behaviors were examined. Workload was assessed using the NASA-RTLX inventory, whereby participants were asked to assess six aspects of workload (mental demand, physical demand, temporal demand, performance, effort, and frustration) along a 100-point scale divided in increments of 10. The participants were

![Fig. 2. Experimental PMP.](image)

![Fig. 3. Experimental MP3 player: front view (left) and side view (right).](image)
Strategies selected all the icons, singly, in a random manner. In contrast, participants adopting trial-and-error (ending point-confirm) and tried to find corresponding hypothetical task sequences (set starting point-confirm-set playing). Some participants assumed the tests were completed. Participants' explanations and viewing video records after coding the strategy and error types independently during or press/push actions using UI input devices).

The number of interaction steps was measured as the percentage of successful tasks among total tasks, and the error rate was measured as the percentage of erroneous actions among total actions. The task completion rate was measured as the number of keystrokes (e.g., clicking of UI objects on a touch screen, or press/push actions using UI input devices).

To analyze strategies and error types, two experimenters coded the strategy and error types independently during the tests, and rechecked their decisions by listening to participants' explanations and viewing video records after the tests were completed.

An example of systematic exploration in the task of replaying a specific section of a song would be the user's planning of task procedures. Some participants assumed hypothetical task sequences (set starting point-confirm-set ending point-confirm) and tried to find corresponding icons. In contrast, participants adopting trial-and-error strategies selected all the icons, singly, in a random manner. Actions choosing the same icon more than three times were categorized as rigid explorations, and repeated searches of a help menu without any outcomes were categorized as encapsulations. The four strategy categories were mutually exclusive.

An example of a positive error consequence is the pushing of the joystick in the up direction to change the radio frequency, after pushing in a wrong direction (to the right), which had increased the volume. Deletion of a pre-selected music file, while adding a music file to the playlist, is a negative error consequence. Selection of inactive menus, without recognizing that they are ineffective, is an example of a non-effective action. An example of a commission error is an attempt to set a starting point in the task of replaying a specific section of a song, even though the step is not required. In contrast, leaving out necessary steps, such as stopping the currently playing movie before starting a new movie, is an omission error. An example of a wrong-action error is selection of the “repeat whole song” icon instead of the “repeat specific section” icon. A failure to press or push the joystick for a long duration, because of poor motor skills, is a motor-control problem.

The inter-rater reliabilities (κ) for logging of strategy types, error types by consequences, and error types by the Morrell error taxonomy, were 0.90, 0.88, and 0.91, respectively, in observation I, and 0.84, 0.87, and 0.88 in observation II.

### 3. Experimental results

Three dependent variables were used to assess performance. These were the task completion rate, the error rate, and the number of interaction steps. The task completion rate was measured as the percentage of successful tasks among total tasks, and the error rate was measured as the percentage of erroneous actions among total actions. The number of interaction steps was measured as the number of keystrokes (e.g., clicking of UI objects on a touch screen, or press/push actions using UI input devices).

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### 3.1. Observation I: interacting with the PMP

#### 3.1.1. Performance

The older adults showed lower task completion rates ($M = 86.5\%$) than the younger adults ($M = 90.5\%$), but this difference was not statistically significant ($p > .05$). The older adults made more erroneous actions ($M = 45.5\%$), however, compared to the younger adults ($M = 28.8\%$), and required more interaction steps ($M = 9.0$) than the younger adults ($M = 6.7$). These differences were statistically significant (error rate: $t(58) = 5.16, p < .001$; number of interaction steps: $t(58) = 3.27, p = .002$).

To examine whether these differences were related to age or background knowledge, we conducted ANCOVAs that included age as a factor and background knowledge types (education and PC, Internet, cellular phone and electronic device experience) as covariates. For the task completion rate, neither the main effect of age nor the tested background knowledge covariates were significant ($p > .05$). Regarding the error rate and the number of interaction steps, the effect of age was significant (error rate: $F(1,53) = 12.48, p < .001$; number of interaction steps: $F(1,53) = 8.62, p = .005$), but the background knowledge types were not.

#### 3.1.2. Strategy

The older adults showed less systematic exploration ($M = 54.6\%$), more trial-and-error efforts ($M = 14.3\%$),
more rigid exploration ($M = 7.2\%$), and more encapsulation ($M = 0.5\%$), than the younger adults (systematic exploration: $M = 71.6\%$; trial-and-error: $M = 5.9\%$; rigid exploration: $M = 4.2\%$; encapsulation: $M = 0.2\%$). The differences between the two age groups were significant ($p < .05$), except for encapsulation. Regarding adoption of systematic exploration and encapsulation, neither the effect of age nor the effect of background knowledge was significant. The effect of background knowledge of electronic devices was significant in the adoption of trial-and-error strategies ($F(1,53) = 5.68, p = .021$), and the effect of age was significant for adoption of rigid exploration ($F(1,53) = 5.23; p = .026$).

3.1.3. Error types

Each error type is represented as a percentage of total actions (thus, the sum of all error types is not unity). Analysis of error type according to error consequences showed that the older adults had fewer positive error consequences ($M = 8.2\%$), experienced more negative error consequences ($M = 7.4\%$), and made more non-effective actions ($M = 29.9\%$) compared to the younger adults (positive error consequences: $M = 9.1\%$; negative error consequences: $M = 3.5\%$; non-effective actions: $M = 16.2\%$). The differences in error consequences between the two age groups were significant ($p < .05$) except for positive error consequences. For positive and negative error consequences, neither the effect of age nor the effect of background knowledge type was significant. However, the effect of age was significant in accounting for non-effective actions ($F(1,53) = 15.37, p < .001$).

Regarding the Morrell error taxonomy, commission errors, omission errors, wrong-action errors, and motor-control problems, were shown by 5.6\%, 5.3\%, 32.2\%, and 2.4\%, respectively, of older adults, and 4.1\%, 4.4\%, 19.6\%, and 0.7\%, respectively, of younger adults. The difference was significant only for the wrong-action errors ($F(1,58) = 4.10, p < .001$). ANCOVA analyses showed that background knowledge of PCs was significant in reducing omission errors ($F(1,53) = 6.19, p = .016$), and older age was significant in increasing wrong-action errors ($F(1,53) = 15.35, p < .001$).

3.1.4. Physical operation of input devices

3.1.4.1. Discrimination of short and long operation methods. The younger group was better able to perform long versus short click and push operations compared to the older group. For touchpad use, 80% of the younger adults differentiated long and short click operations, whereas only 53% of the older adults were able to distinguish between these operations. The difference between the two age groups was significant ($\chi^2(1, N = 60) = 4.80, p = .029$).

To identify factors affecting the ability to efficiently distinguish between long and short operations, we conducted logistic regression analysis. Whether a participant efficiently distinguished long operations from short operations was treated as a dependent variable (e.g., a value of 0 or 1 was assigned), and age and background knowledge parameters were treated as independent variables. Results showed that only age significantly affected the distinct use of long and short click on the touchpad ($LR(53) = 59.77, \chi^2(1) = 4.61, p = .032$). For joystick push operations, 33% of the younger adults and 7% of the older adults successfully used both long push and short push operations; in this context, the difference between the two age groups was significant ($\chi^2(1, N = 60) = 6.67, p = .001$) and age was an influential factor ($LR(53) = 49.23, \chi^2(1) = 6.13, p = .013$) but background knowledge was not.

3.1.4.2. Utilization of familiar operation methods used in other devices. All participants of the PMP observation had PC experience and thus were familiar with the double click, and drag and drop operation methods. However, the younger adults utilized these operations better than the older adults. Only 23% of the older adults utilized the double click or drag and drop methods, whereas 60% of the younger adults utilized those methods. The difference between the two age groups was significant ($\chi^2(1, N = 60) = 8.30, p = .004$), and only age was significantly related to the difference ($LR(53) = 70.30, \chi^2(1) = 6.48, p = .011$).

3.1.5. Preference for input devices

The touchpad was the most preferred input device for both age groups (90% of the younger group, 77% of the older group). However, the reasons for this preference differed between the two groups; the highest ranked reason among younger users (47%) was efficiency factors such as time and distance to access and select functions, whereas the older group considered physical effort (43%), and familiarity with the input devices (33%), to be the most important factors. For instance, some of the older adults preferred the touchpad because they found it difficult to simultaneously operate an input device (joystick or button) while searching functions (e.g., viewing menu items on the screen) and other older adults said that holding the touch pen required additional physical labor, so they preferred the joystick or buttons. Some older adults also preferred touchpads operated by touch pens because the input resembled the familiar writing device.

3.1.6. Workload

The older adults reported higher workloads than the younger adults (Table 3). Age was only found to be significant for temporal demand ($F(1,53) = 4.01, p = .049$) and performance ($F(1,53) = 11.56, p < .001$). Older adults reported more difficulty with temporal demands ($M = 39.7$) and performance ($M = 47.8$) than younger adults ($M = 29.5$ and 25.6, respectively). The ANCOVA revealed that a lack of knowledge about PCs lead to increased ratings of effort ($F(1,53) = 4.20, p = .046$) and a lack of knowledge about PCs and the Internet increased levels of frustration ($F(1,53) = 6.04, p < .017$ and $F(1,53) = 6.57, p = .013$, respectively).
3.2. Observation II: interacting with the MP3 player

3.2.1. Performance

The completion rate was not significantly different between younger (M = 66.7%) and older (M = 61.0%) adults. However, the older adults showed poorer performance than the younger adults regarding the number of errors and the number of interaction steps. The older adults made more errors (M = 54.7%) than the younger adults (M = 43.2%), and the ANCOVA revealed that age was the only factor that significantly explained the difference (F(1,53) = 4.97, p = .030). Regarding the number of interaction steps, the older adults made more interaction steps (M = 9.4) than the younger adults (M = 7.8). Only age effect was significant with regard to this difference (F(1,53) = 4.51, p = .038).

3.2.2. Strategy

The older adults showed less systematic exploration (M = 45.1%) than the younger adults (M = 56.5%), but showed more trial-and-error (M = 12.3%), rigid exploration (M = 12.7%), and encapsulation (M = 3.5%) than the younger adults (trial-and-error: M = 7.8%; rigid exploration: M = 4.7%; encapsulation: M = 1.3%). The ANCOVA revealed that neither age nor background knowledge significantly affected the likelihood of adopting systematic exploration (p > .05). Age was only found to be significant for adoption of rigid exploration; so the older adults used more rigid exploration than the younger adults (F(1,53) = 8.39, p = .006). A lack of knowledge about electronic devices led to increased adoption of trial-and-error strategy (F(1,53) = 4.39, p = .041) and a lack of knowledge about cellular phones led to increased encapsulation (F(1,53) = 5.01, p = .030).

3.2.3. Error types

The older adults had fewer positive error consequences (M = 10.4%), and made more negative error consequences (M = 12.6%) and non-effective actions (M = 31.3%) than the younger adults (positive error consequences: M = 13.4%; negative error consequences: M = 3.9%; non-effective actions: M = 25.9%). The effect of age was significant only regarding the negative error consequences (F(1,53) = 10.56, p = .002) and none of the background knowledge types affected those types of errors. For positive error consequences and non-effective actions, neither the effect of age nor the effect of background knowledge was significant.

When the data for the Morrell error taxonomy were examined, the older adults made more errors than the younger adults, over all error types. The average rates of commission errors, omission errors, wrong-action errors, and motor-control problems, were 3.6%, 2.2%, 39.7%, and 9.2%, respectively, for older adults, and 2.3%, 1.9%, 33.3%, and 2.3%, respectively, for younger adults. The ANCOVA revealed that age was the only significant variable explaining the increase of wrong-action errors (F(1,53) = 10.64, p = .002) and motor-control problems (F(1,53) = 15.24, p < .001). With commission errors and omission errors, neither the effect of age nor the effect of background knowledge explained the differences between the two age groups.

3.2.4. Physical operations of input devices

3.2.4.1. Discrimination of short and long operation methods.

In dealing with the joystick, 80% of the younger adults and 53% of the older adults successfully used both long and short presses and the difference between the two age groups was significant ($\chi^2(1, N = 60) = 4.80, p = .029$). Logistic regression analysis showed that the effect of age was significant (LR(53) = 59.77, $\chi^2(1) = 5.72, p = .017$), whereas none of the effect of background knowledge types were significant regarding this difference. For press operations of the joystick, 90% of the younger adults and 67% of the older adults successfully used long and short presses. The difference between the two age groups was significant ($\chi^2(1, N = 60) = 4.81, p = .028$) and only age affected the distinct use of short and long press of the joystick (LR(53) = 51.08, $\chi^2(1) = 4.46, p = .035$). Regarding long press and short press of buttons, the younger adults (M = 87%) more successfully differentiated long press from short press than the older adults (M = 60%), and the difference was significant ($\chi^2(1, N = 60) = 5.45, p = .020$). Only effect of age was

Table 3

<table>
<thead>
<tr>
<th>Workload aspects</th>
<th>Mean (and standard deviation)</th>
<th>ANCOVA</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Younger adults</td>
<td>Older adults</td>
</tr>
<tr>
<td>Mental demand</td>
<td>37.7 (14.6)</td>
<td>49.4 (17.1)</td>
</tr>
<tr>
<td>Physical demand</td>
<td>30.0 (17.0)</td>
<td>36.1 (16.5)</td>
</tr>
<tr>
<td>Temporal demand</td>
<td>29.5 (17.9)</td>
<td>39.7 (15.2)</td>
</tr>
<tr>
<td>Performance</td>
<td>25.6 (15.9)</td>
<td>47.8 (16.2)</td>
</tr>
<tr>
<td>Effort</td>
<td>35.7 (15.0)</td>
<td>42.1 (15.5)</td>
</tr>
<tr>
<td>Frustration</td>
<td>26.8 (16.0)</td>
<td>35.5 (14.1)</td>
</tr>
<tr>
<td>Total workload</td>
<td>30.9 (13.8)</td>
<td>41.9 (12.6)</td>
</tr>
<tr>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
significant \( LR(53) = 53.35, \chi^2(1) = 4.05, \ p = .041 \), whereas none of the effect of background knowledge types were significant regarding this difference. Based on the participants’ explanations of their detailed interaction behaviors, we found that 30% of older adults failed to hold an adequate duration of long push or press, even though they intended to conduct long operations.

3.2.4.2. Combined operation methods. Regardless of age, most participants failed to successfully use combined operation methods, such as combinations of short and long operations or simultaneous selection of more than one input device. For example, the task of playing the first music in the next folder required a combined joystick operation of short push followed by long push. Only 13% of the younger adults and 7% of the older adults successfully performed the combined operation. In addition, few participants were successful in simultaneously selecting more than one button or one button and the joystick. The 23% of the younger adults and 10% of the older adults tried concurrent selection of more than one input device.

3.2.5. Workload

The older adults had higher workloads than the younger adults for all aspects of workload (Table 4). Significant differences between the age groups were observed for mental demand, temporal demand, performance, frustration, and total workload. Only the effect of age was significant regarding the temporal demand and performance aspect, whereas the effect of background knowledge of cellular phones was significant for the aspects of frustration. For total workload, the effects of age and the background knowledge of cellular phones were significant.

4. Discussion

The findings in the experiments show that the effect of age or background knowledge accounted for different aspects of the observed user interaction behaviors. In the following, we will explain the interaction characteristics by distinguishing the effect of age and background knowledge, and suggest some design implications for devices aimed at older adults.

4.1. Behavioral differences related to age

4.1.1. Relationships of interaction steps with strategies and error types

Previous studies in the domains of computer appliances (Sjölinder et al., 2005), the Internet (Kubeck et al., 1999; Mead et al., 1997), and cellular phones (Ziefle and Bay, 2005) indicated that older adults use more interaction steps than younger adults when dealing with technological devices. Consistent with these findings, we found that older and younger adults showed a similar level of task completion rates when using small multi-functional devices, but the older adults had more interaction steps. Thus, the results of the present study and previous works suggest that older adults tend to require more interaction steps than younger adults when performing tasks using unfamiliar technology. Furthermore, this difference does not seem to be a result of background knowledge or prior experience.

The increased number of interaction steps required by older adults can be explained by the higher rates of erroneous action and rigid exploration. The difference in the interaction step numbers between younger and older adults is related to the selection of wrong functions, rather than the omission of indispensable actions or insertion of unnecessary actions. The consequences of the errors seem to play important roles in increasing interaction steps. We found that older adults made more erroneous actions than the younger adults, especially in the domains of negative error consequences and non-effective actions, meaning that the older adults often failed to receive meaningful hints from their action results, and thus made less progress toward achieving their goals. Moreover, the higher tendency of older adults toward rigid exploration often resulted in repetition of the same erroneous actions, and this caused increases in the numbers of interaction steps.

<table>
<thead>
<tr>
<th>Workload aspects</th>
<th>Mean (and standard deviation)</th>
<th>ANCOVA</th>
<th>Effective factors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Younger adults</td>
<td>Older adults</td>
<td>Age: ( F(1,53) = 4.65, \ p = .036 )</td>
</tr>
<tr>
<td>Mental demand</td>
<td>46.7 (14.4)</td>
<td>57.0 (15.6)</td>
<td>Age: ( F(1,53) = 10.50, \ p = .002 )</td>
</tr>
<tr>
<td>Physical demand</td>
<td>34.8 (18.4)</td>
<td>43.1 (18.0)</td>
<td>Cellular phones: ( F(1,53) = 4.61, \ p = .036 )</td>
</tr>
<tr>
<td>Temporal demand</td>
<td>26.8 (17.1)</td>
<td>47.8 (17.7)</td>
<td>Age: ( F(1,53) = 5.37, \ p = .024 )</td>
</tr>
<tr>
<td>Performance</td>
<td>43.2 (15.7)</td>
<td>59.1 (11.9)</td>
<td>Cellular phones: ( F(1,53) = 4.70, \ p = .035 )</td>
</tr>
<tr>
<td>Effort</td>
<td>45.4 (15.4)</td>
<td>52.5 (15.3)</td>
<td></td>
</tr>
<tr>
<td>Frustration</td>
<td>33.6 (14.5)</td>
<td>44.4 (16.7)</td>
<td></td>
</tr>
<tr>
<td>Total workload</td>
<td>39.1 (12.2)</td>
<td>50.7 (13.6)</td>
<td></td>
</tr>
</tbody>
</table>
4.1.2. Use of input devices and motor skill

Motor skill is an important factor for using complicated electronic devices, wherein a given input device often provides more than one operation method. Thus, deteriorated motor skills can complicate the ability of older adults to use small multi-functional devices.

In this study, we found that older adults showed more motor-control problems, and had more difficulties with long operation requirements, than did younger adults. This result is similar to that of a previous study reporting that the successful completion of complex operations such as clicking or double-clicking in computer mouse tasks decreased with age (Smith, et al., 1999). Long operations are more difficult for older adults, who tend to make more unintentional motor errors than do younger adults, because of decreases in muscle control with age (Czaja et al., 1998; Walker et al., 1997). For example, 47% of older adults failed to change the device from radio mode to MP3 player mode, because although they chose the correct MODE button, they failed to complete the long-press operation. Even in tasks or devices that do not directly require physical dexterity, better motor skills can often improve task efficiency by reducing the number of interaction steps and the time required for task achievement. For example, in adjusting the radio frequency of the MP3 player, a user could reduce the number of interaction steps and time by utilizing one long push of the joystick instead of several short pushes.

When a user is comfortable with the various operation methods and input devices, he/she is also more likely to explore and learn more functions of the device. For example, adjusting the radio frequencies of the PMP could be achieved by not only short or long clicks of the adjusting icon on the touch screen, but also by short or long pushes of the joystick. Identifying various alternatives capable of operating a given function provides the user with a wider knowledge of the device. However, since older adults often could not successfully discriminate various operations, they tended to learn and use fewer diverse functions of the devices compared to the younger adults. Moreover, the preference of older adults for less physically demanding input devices may limit the general use of some input devices, and the exploration of various functions by such devices. In this study, older adults showed a greater preference for the less physically demanding input device, the touch screen, compared to a joystick or buttons. This result is similar to those of previous studies (Charness et al., 2004; Chou and Hsiao, 2007) showing a preference, by older adults, for direct devices over indirect devices.

In addition to poorer motor skills, the older adults tended to show fewer instances of applying operation methods they had previously used with other devices. For example, even though all older adults participating in PMP observation had experience with PCs and knew the double click or drag and drop methods, few of them utilized those operation methods when using PMP. This is similar to previous studies showing that the expertise of older adults declines when they are confronted with new domains of familiar tasks (Lindenberger et al., 1992; Salthouse et al., 1990; Szlyk et al., 1995). The less frequent application of known operation methods may indicate another rigid aspect of the older adults. Older adults seem to lack mental and physical flexibility; so they cannot easily apply known operation methods to the use of a new device. This implies that older adults utilize their prior experiences and background knowledge less effectively than younger adults when confronted with a new device.

4.1.3. Workload: subjective performance

The workload ratings obtained herein showed that the older adults tended to underestimate their performance levels, even though their actual task completion rates did not differ significantly from that of the younger adults. Because older adults experienced higher workloads than younger adults when performing the various tasks, due to more erroneous actions and operation failures, older adults tended to have a higher level of uncertainty about the correctness of their actions, and to feel more time pressure, leading to perceptions of lower subjective performance and less satisfaction with task achievement. A previous study showed that older adults have less confidence in computer-related knowledge than younger adults, while their confidence in common knowledge is similar to that of younger adults (Marquié et al., 2002). Thus, the older adults observed in the present study may have tended to have less confidence in using the small multi-functional devices, potentially contributing to their underestimation of task performance.

4.2. Behavior differences related to background knowledge

4.2.1. Task completion rate

In this study, older and younger adults showed similar levels of task completion rate on small multi-functional devices with the statistical power value above 0.80 (0.83 for observation I and 0.81 for observation II). This finding is inconsistent with previous studies (Marquié et al., 2002; Sit and Fisk, 1999; Ziefle and Bay, 2005) in which older adults showed poorer performance than younger adults in using computer-related appliances and cellular phones. However, some previous studies (Birdi et al., 1997; Laberge and Scialf, 2005) reported that age differences in performance on computer works and web navigation decreased when the analysis was controlled for differences in expertise. Thus, the similar levels of task completion rate between younger and older users observed in the present study may indicate that experience is a more influential factor than age difference when assessing this performance aspect. Our present findings, therefore, may indicate that experience and background knowledge are important for task completion rates not only in the domains of computers and cellular phones, but also in the domain of small multi-functional devices.

4.2.2. Trial-and-error strategy

We found that older adults adopted trial-and-error strategies more frequently than younger adults, and our
analysis revealed that this was associated with a lack of background knowledge in electronic devices, rather than an effect of age difference. Thus, trial-and-error behavior is not a characteristic of older adults, but instead appears to be a characteristic of novice users who lack domain knowledge (Hollnagel, 1993; Van Der Linden et al., 2001). In using PMP and MP3 player, background knowledge in various electronic devices seemed to aid users in selecting appropriate information items and functions on the screen, and facilitated operation of UI input devices. These results may suggest that the age difference in the adoption of trial-and-error strategies could be reduced if older adults acquire related domain knowledge and experience.

4.2.3. Workload

Except in the aspect of workload and performance and temporal demand, we found that the most influential factor for workload was background knowledge, not age. In PMP observation, the effects of background knowledge of PCs and Internet were significant, whereas in MP3 observation, only the effect of background knowledge of cellular phones was significant.

The influential background knowledge types on workload aspects seem to reflect similarities between the tested devices and the previously used devices. Since the software programs found in PMP resemble those found in PCs, background knowledge of PCs played an important role in determining workload when users interacted with PMP. Similarly, since large portions of the task execution in PMP required navigation among on-screen menu or information items, prior experiences with searching and navigating Internet websites seemed to have a significant effect on workload. In contrast, use of MP3 player mainly depended on the physical operation of buttons and the joystick, so background knowledge of PCs or Internet had less effect. Instead, experiences in operating the various types of buttons or keys on cellular phones tended to decrease the workload.

Related to lack of background knowledge, older adults experienced a higher workload, often leading to frustration and negative emotions. Because negative emotions such as “insecurity, discouragement, irritation and stress” (Byers et al., 1989) are rooted in background knowledge rather than age, it should be possible to give older adults more experience and background knowledge, thus alleviating their negative emotions when using a new device.

4.3. Design implication

Proper system designs and training programs based on age-related ability declines could enhance the performance of older adults and reduce the gap between younger and older adults in using technologies. For example, Jones and Bayen (1998) reported that older adults need special instructional designs based on age-related ability declines, and Mayhorn et al. (2004) suggested the need for a systematic training approach based on older adults’ abilities and experiences. Van Gerven et al. (2006) suggested instructional designs intended to make use of the cognitive resources of older adults, and Van Merriëndoeker et al. (2002) showed that training designed to reduce cognitive load could improve task performance in computer-based work.

Moreover, even well-designed devices require that users be trained for efficient use of functionalities (Rogers et al., 2004), and the combination of well-designed devices with appropriate training can yield remarkable improvements in usage accuracy (Sharit et al., 2003). Therefore, based on our results, we can make some suggestions about the future rational design of complicated electronic devices, and we can offer general training guidelines for older adults.

First, the devices should seek to reduce the tendency of older adults to experience rigid exploration, negative error consequences, and non-effective actions. To prevent the selection of inactive or disabled functions, available and unavailable menus and icons should be clearly distinguished from one another. Because older adults may lack perception ability, clear visual, or auditory feedback could help reduce the repetition of incorrect operations, helping to guide the user to more correct and efficient operations. Training to prevent repeats of prior unproductive actions would also reduce the tendency shown by older adults to engage in rigid exploration.

Second, when designing input devices for older users, the goal of decreased physical burden should take priority over efficiency. Direct devices (e.g., touch screens) will offer more benefits to task performance compared to indirect devices (e.g., a joystick or buttons). In addition, the use of input devices similar to those with which older adults are already familiar will encourage the older adults to use the new devices. If the proffered input devices are unfamiliar, older adults should be given practice time or training that allows them to become accustomed to the devices.

Third, long and short control activations on the same input device should be avoided. It would seem best to provide one operation method for each input device, because older adults often have difficulties distinguishing between short and long operations. At the very least, the short- and long-duration operations of input devices should be made more distinctive than is the current practice. Since the inclusion of familiar operation methods used in other devices may not guarantee that older adults will easily translate the operations to a new device, simple operation methods should be used in devices aimed at older adults. Furthermore, our findings suggest that combined operation methods should be avoided as much as possible in all electronic devices, since very few users were able to successfully complete those operations regardless of age.

Final considerations are social and marketing issues. It is important to encourage older adults to learn to use new technologies in their everyday lives, and companies should consider the needs of older adults during device design. Because background knowledge is a more influential factor
than age in the case of frustration, experience can reduce the fear shown by older adults when confronted with new technologies. Furthermore, the increasing interest and active attitude in learning new technologies shown by some older adults (Chou and Hsiao, 2007; Czaja and Sharit, 1998; Rossman, 2002) will act as a positive factor.

5. Conclusion

We have compared the characteristics shown by older adults and younger adults when interacting with small multi-functional devices, and we found that both age and background knowledge are important factors explaining interaction behavior differences between these groups. Different factors affected various aspects of interaction behaviors.

The results of this study have important implications for the future design of devices intended for older adults, which should consider not only the effects of age but also the characteristics of novice users who lack background knowledge. By distinguishing the interaction behavior characteristics that are strictly due to age from those affected by background knowledge, existing design guidelines for older adults can be improved to include various user groups having different ages and backgrounds. Since older adults generally tend to have less technological background knowledge than younger adults, the design guidelines for average older adults should likely include many characteristics of novice users. However, devices intended for older adults with more background knowledge should be designed with their experiences and expertise in mind.

Overall, this study provides important new insights into age- and background knowledge-related problems in using new technologies and designing complicated electronic items such as multi-functional devices. However, since we focused on more educated people, additional studies including various types of devices and broad range of user groups will be warranted to obtain more general results. In addition, further study, including physiological data such as attention spans, cognitive skills, and perception abilities, will yield a more objective basis for the findings of this study.

References


