공학석사학위논문

Ergonomics Issues in Improving Kiosk Accessibility for Older Adults

고령인의 키오스크 접근성 향상을 위한 인간공학 연구

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이 논문을 공학석사 학위논문으로 제출함

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Abstract

Ergonomics Issues in Improving Kiosk Accessibility for Older Adults

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In this thesis, two independent experimental studies were conducted to improve self-service kiosk (SSK) accessibility for older adults. First, in an attempt to propose an optimal on-site training tutorial design, four training methods, which were the combinations of two medium types (paper, digital) and two instruction types (goals only, goals and actions), were compared. A between-subjects experimental study was conducted to comparatively evaluate the four methods in training efficacy. In the second experimental study, the impacts of potential SSK design features, that is, side partitions, a back partition, and a chair, on perceived workloads and task performance of SSK users of different age groups were evaluated. As a result of the two studies, the dissertation research proposes design implications on training materials and public SSK design. The results from the two research studies would contribute to improving accessibility for older adults as well as enhancing the user experience (UX) of public SSK.

Keywords: Self-service kiosk, Self-service technology, Technology accessibility, Older adults, Training design, Cognitive load, Learning theory, Psychological stress, Social stress, Task performance, Workload
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Chapter 1

Introduction

1.1 Research Background

Public self-service kiosks (hereafter, simply SSK) have been increasingly adopted in various industries due to advantages including time and cost savings, greater control over service delivery, and convenience (Bitner et al., 2000; Meuter and Bitner, 1998; Salomann et al., 2006). Currently, SSK are widely available across diverse service organizations, such as fast-food restaurants, banks, hospitals, information centers, and more (Hagen and Sandnes, 2010; Lazar et al., 2019; Meuter et al., 2000; Park et al., 2021); and, a significant portion of the population has some form of SSK use experience (Wang et al., 2012). The deployment of SSK would increase further as consumers continue to embrace SSK, and businesses rush to reap the benefits (Kiosk Marketplace, 2019). The interactive kiosk market is expected to grow from USD 26.2 billion in 2020 to USD 32.8 billion by 2025, at a CAGR of 4.6% (Markets and Markets, 2020).

Despite their benefits and utilities, however, SST also came with their own problems. One such problem is the difficulties experienced by older adults during the use of SSK (e.g., Park, 2019; Miller, 2019; Poulter, 2017). Many older adult users find it difficult to read text information displayed on SSK (Hagen and Sandnes, 2010), figure out the correct user action sequence for a given SSK task (Barnard et al., 2013), and perform prolonged standing while conducting an SSK task (Park, 2019). Many describe the experience as stressful, unpleasant, and physically demanding. These difficulties can be largely attributed to the failure in considering the personal, attitudinal and situational characteristics of older users in the design of SSK. Aging is associated with significant declines in perceptual, cognitive and motor control abilities, and muscular strengths (Iancu, I. and Iancu, B., 2017; Caprani et al., 2012). The older adults are also characterized by technology anxiety and lack of confidence towards technologies that negatively affect task performance during the use of technologies (e.g., Dean, 2008; Wang et al., 2012; Gelbrich and Sattler, 2014). These attitudes are known to be invoked by situational stressors, such as time pressure and the presence of others.

The difficulties described above represent a significant problem as they can seriously compromise the functioning and well-being of the older adults in everyday life. Indeed, they should be understood as barriers that exacerbate the current generational digital divide for the aged population (Van Dijk, 2006). The digital divide, defined as inequities in terms of who accesses and benefits from the digital landscape (Fang et al., 2019), is deeply related to decreased social engagement and lower life independence (Hill et al., 2015). It is also known to produce a new form of social isolation referred to as "digital exclusion" (Seifert et al., 2018). Hill et al. (2015) described digital exclusion as a "cumulative, self-propelling spiral of isolation whereby the digitally rich continue to become included and the digitally poor continue to become isolated within a culture where more of society's business and culture is conducted through technology."

1.2 Research Objectives

In an attempt to help resolve the digital divide issue mentioned in the previous section and improve kiosk accessibility, this dissertation research conducted two empirical studies (Studies 1 & 2). Study 1 examined the effects of medium (paper, digital) and instruction type (goals-only, goals-and-actions) on the efficacy of training older adults to use a public information system. Study 2 evaluated the impacts of potential SSK design features, that is, side partitions, a back partition and a chair, on perceived workloads and task performance of SSK users. In Study 2, younger, as well as older participants, performed a food ordering task using eight design alternatives. The findings of Studies 1 and 2 would contribute to improving accessibility and the user experience (UX) of public SSK.

1.3 Structure of the Thesis

Brief descriptions of the chapters of the current MS dissertation are presented in this section. In Chapter 1, research background and objectives are described. Chapter 2 presents an experimental study (Study 1) in which different training methods were investigated to figure out the best practice in designing step-by-step instructions that maximizes training efficacy for older adults. In Chapter 3, another experimental study (Study 2) is reported in which impacts of three design variables, which are side partitions, a back partition, and a chair, on perceived workloads and task performance when using SSK were examined. In Chapter 4, a brief summary and implications of the dissertation research, and future research directions are presented.

Chapter 2

Training Design for Helping Older Adults Use Public SSK

2.1 Introduction

Designing proper instructions and training materials for older adults is important to improve technology accessibility for them and further ensure their quality of life (Czaja et al., 2019). This is especially so considering the current trend that more and more work tasks and daily activities require individual end users to directly interact with new technical systems that they may not be familiar with. Indeed, in spite of different challenges faced by older adults in learning to use new technology, they indicate that they would be more comfortable with and willing to adopt new technologies if they received some type of formal training (Rogers et al., 1996). One example is the self-service technologies (SST), including public self-service kiosks (SSK) and software programs that older adults are required to learn how to use them. Failure in learning the new systems can bring about serious consequences such as being marginalized at the technological era. On the other hand, well-designed training methods may lead to higher adoption of new technologies by older adults.

Relatedly, multiple research studies have been conducted to support the design of on-site instructions and training for the use of public self-service technologies. In the literature, different training design variables, including training schedule, media type, and guidance type, have been compared. Some previous findings are as follows: regarding the training schedules, random practice schedule, in which trial types are intermixed, is known to result in higher knowledge transfer, as compared to blocked practice schedule where trial types are grouped (Jamieson and Rogers, 2000; Battig, 1979). In terms of the media type, interactivity was found to be an important factor to enhance the objective performance as interactive media facilitates higher mental proximity (Bruder et al., 2007; Toyota et al., 2014), while non-interactive media is rather more preferred by older adults (Leung et al., 2012). As for the guidance type, in multiple research studies, concept training, where participants were given meaningful sub-goals to accomplish a system goal, was found to result in effective training than action training, in which step-by-step actions instead of sub-goals were provided to participants (Mead and Fisk, 1998; Hickman et al., 2003; Hickman et al., 2007). In addition, among different representation methods, graphical tutorials resulted in higher efficacy compared to textual tutorials (Digmayer and Jakobs, 2012).

Also, some literature provided general technology training and instruction design guidelines for older adults. Fisk et al. (2009) recommended minimizing cognitive demand and providing appropriate and immediate feedback during training so that older adults can learn by trial and error. Also, procedural skills should be delivered in a step-by-step format since older adults prefer to learn to perform task steps rather than gain a general understanding of the system (Leung et al., 2012). The step-by-step format may also be advantageous in that dividing the training into short lessons would help motivate older users through immediate successes (Fisk et al., 2009). Leung et al. (2012) also proposed similar training design guidelines which aimed at providing detailed instructional content and presentation to support cognitive capabilities. In addition, goal-oriented and self-paced training is considered effective as older adults generally prefer to learn on their own with guided training materials and sufficient time (Mitzner et al., 2008; Leung et al., 2012). In sum, the aging and training literature suggests designing goal-oriented and self-paced training with step-by-step instructions for older adults.

Despite past research, however, currently, there remain many research gaps concerning the design of on-site instructions and training for the use of public self-service technologies by older users. The design space is large; yet, many possible design alternatives have not been empirically evaluated. In order to improve the technology learning of older adults, more design research is needed.

One of the current knowledge gaps pertains to the design variable, guidance type. While Hickman et al. (2007) found that the guidance type of giving actions only for each task step (named "guided action training") was superior to that of giving the sub-goal only for each task step (named "guided attention training") for the training of older adults, another guidance type, that is, giving both the sub-goal and corresponding actions for each task has not been examined – here, we name the third one "goals and action training." In comparison with "guided attention training," "goals and action training" presents a larger amount of information to the learner (the sub-goal and additionally the related actions for each task step) loading the cognitive system more severely but it lowers the cognitive burden for having to figure out the relevant actions during learning benefiting the schema formation; also, it keeps the advantage of "guided attention training" over "guided action training," that is, informing the learner of the sub-goals in the context of accomplishing the system goal. It is not clear how "goals and action training" compares with "guided attention training" (we name it "goals only training" in this work) when considered in light of theories and principles in the field of instruction and training design, such as the cognitive load theory.

Also, it is possible that medium type, another design variable, may modify the guidance type effects. Older adults prefer a medium that they are more familiar with, for example, a non-interactive paper material (Leung et al., 2012), and, it is possible to hypothesize that the level of familiarity affects the ease of information processing and thus modifies the impacts of guidance type.

Therefore, to help address the current knowledge gap above and thereby contribute to improving technology learning of older adults, the objective of the current study was to empirically test the effects of guidance type, medium type, and their interaction on technology learning during on-site training of a public self-service kiosk system (a ticket vending machine).

2.2 Method

2.2.1 Participants

A total of 64 older adults (thirty males and thirty-four females) participated in this research study. Their ages ranged from 60 and 69 years (M = 64.5). All participants were free of obvious musculoskeletal disorders and had normal or corrected to normal vision on both eyes. Also, the prior experience using public kiosks and technology competency were carefully scrutinized in advance. In an attempt to examine the effects of training methods particularly for novice users, older adults with none or little experience using public ticket machines were recruited.

The research complied with the American Psychological Association Code of Ethics and was approved by the Institutional Review Board at Seoul National University. Informed consent was obtained from each participant.

2.2.2 Experimental Procedure

The experimental task was booking a train ticket using a public ticket machine. In each trial, the participants were given a sheet on which train information for the trial was written, and they were instructed to book a train ticket that completely matches the given information. Two kinds of booking applications of similar user interfaces (App A, App B) were utilized. The action sequences required to book a train ticket as well as the layouts of the main user interface components of the two Apps were similar. The log data, which contained information including interaction time, screen indices, and touch coordinates, were collected using a Python script.

The participants were randomly and equally assigned to one of four groups and completed a total of five task trials. Among the five task trials, the third one was a self-paced training session where the participants had to complete the ticket booking task on App B following the given training material and instructions. The first and second trials were designed to assess baseline performance for Apps A and B, respectively. The fourth and fifth trials, to assess performance for App B and App A after the training in the third trial, respectively. The post-training performance assessment without access to the instructional materials can be interpreted as transfer measures, which provide an index of learning (Schmidt and Bjork, 1992). While the training was conducted only on App B, performance measurements before and after the training were conducted both on Apps A and B. The ability assessment of untrained tasks in the same domain (App A) was conducted to evaluate how participants could generalize their trained knowledge (Hickman et al., 2007). During the four non-training sessions, the participants had to complete the ticket booking task without access to the training materials. The experimental procedure required about 60 minutes for each participant (Figure 2.1).

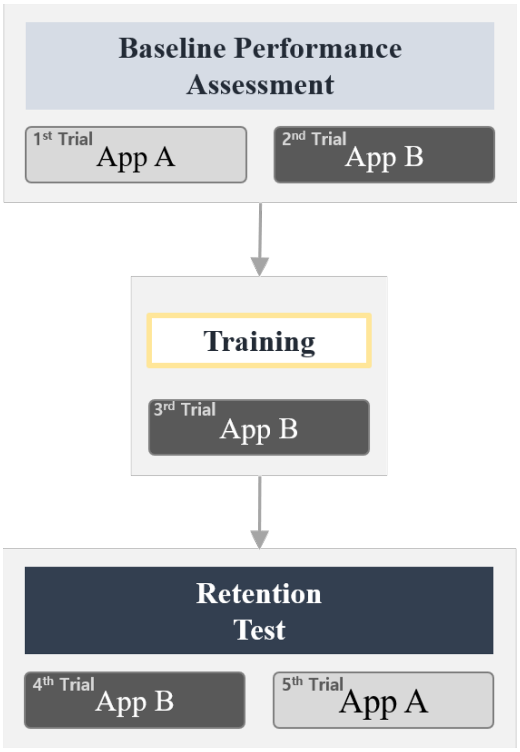


Figure 2.1: Experimental procedure

2.2.3 Training Methods Design

The current study comparatively evaluated four different training methods, which were the combinations of the levels of the two variables: 4 = two levels of medium × two levels of instruction types.

Concerning medium, the two types of medium were paper (P) and digital (D). The paper manual was non-interactive and offered a step-by-step guided tour by text instructions with screenshots of the application on a sheet of paper. During the training session, the participants had to complete the task by reading and following the instructions written on the paper manual. On the other hand, the digital manual was an interactive tutorial where instructions were provided directly on the screen. During the training session, the participants using the digital manual had to perform operations by reading and following the instructions written on the screen.

As for instruction type, one of the two levels was giving only the goals to be accomplished at different steps (goals only; what-to-do), whereas the other was providing goals and also associated actions (goals and actions; what-to-do and what-to-click). Before the onset of the training session, the participants of the goals and actions group were instructed to pay attention to additional graphical indications on the screen. Figure 2.2 illustrates the four training methods employed in the study ("P-goals only", "P-goals and actions", "D-goals only", and, "D-goals and actions").

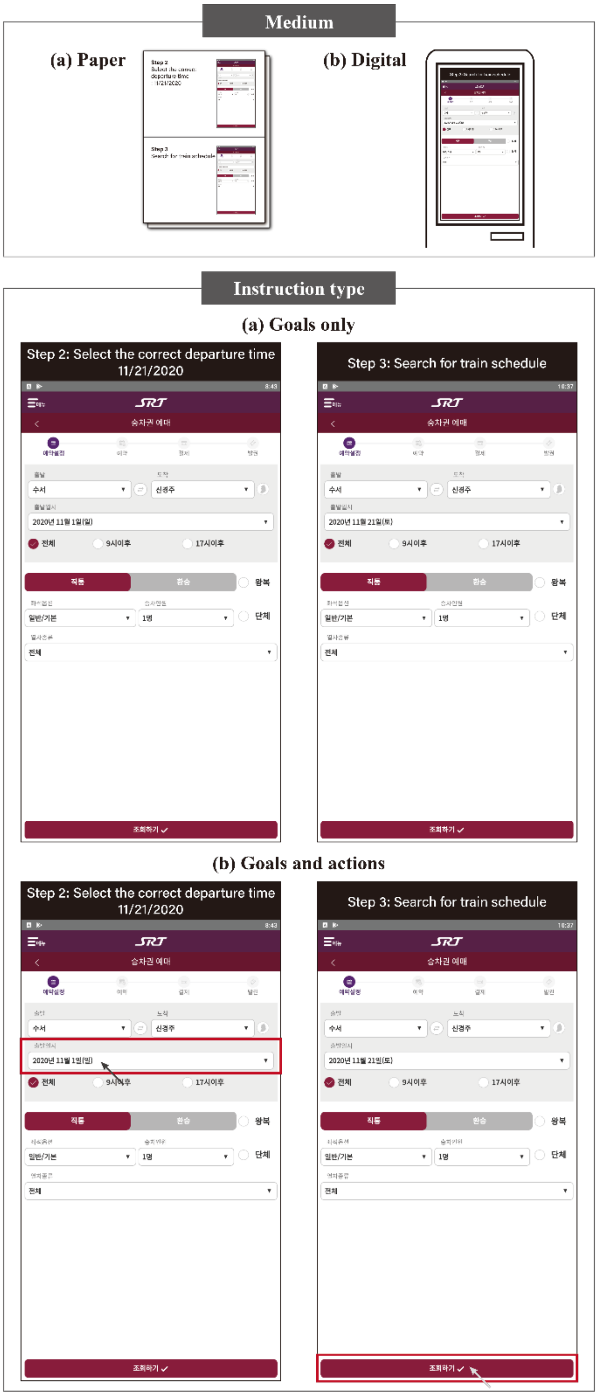


Figure 2.2: Descriptions of training methods

2.2.4 Independent and Dependent Variables

In this study, two independent variables (medium, instruction type) of two levels were considered in designing four different training methods. The current study was concerned with investigating the training effects for novice users; and, thus, the independent variables were between-subjects factors.

In each of the performance assessment trials (Trials 1, 2, 4, and 5), the participant's task performance and workload were evaluated. The task performance was measured in terms of time (task completion time) and accuracy (total number of clicks, action sequence length). In addition to the performance measures, the participant's perceived workload was evaluated using the NASA-TLX questionnaire (Hart and Staveland, 1988). Each participant rated the perceived workload for each of the six dimensions of workload (mental demand, physical demand, time pressure, effort, performance, and frustration) immediately after the completion of each trial. Table 2.1 presents a summary of the dependent variables employed in the study.

For the training session (Trial 3), training time, the total amount of time between the onset of training and completion of the last operation, was measured.

Table 2.1: Dependent variables

Dependent variables		Definition/Quantification
Time	Task completion time	The total amount of time between the onset of the trial and completion of the last operation (s)
Accuracy	Total number of clicks	Total number of clicks (touch operations) during task performance
	Action sequence length	Total number of screens participants went through during task performance (Action sequence length results in the minimum if a participant completes the task following the standard action sequence.)
Workload	Mental demand	NASA-TLX questionnaire

2.2.5 Data Analyses

Both the task performance and workload before and after the training session were statistically analyzed. First, differences between the mean values before and after training were tested to evaluate the general training effects irrespective of the training methods.

Second, for each dependent variable, a two-way ANOVA test was conducted to examine the difference between the four training methods. Group differences before the training session were tested to verify that the participants' baseline performance did not differ by groups. On the other hand, the group differences after the training session were tested to evaluate whether the training effects differed by groups. The model included two between-subjects factors of two levels (Medium: paper, digital; Instruction type: goals only, goals and actions). In cases where a two-way interaction was statistically significant, post hoc tests with Bonferroni corrections were conducted.

All statistical analyses were conducted using SPSS 25 (IBM Crop, Armonk, USA), and an alpha level of 0.05 was utilized.

2.3 Results

2.3.1 General Training Effects

Regarding all dependent variables, the mean values before and after training were significantly different. The paired t-test results indicate that the mean values of task completion time, total number of clicks, action sequence length, and average workload were significantly lower after training than before (Figure 2.3).

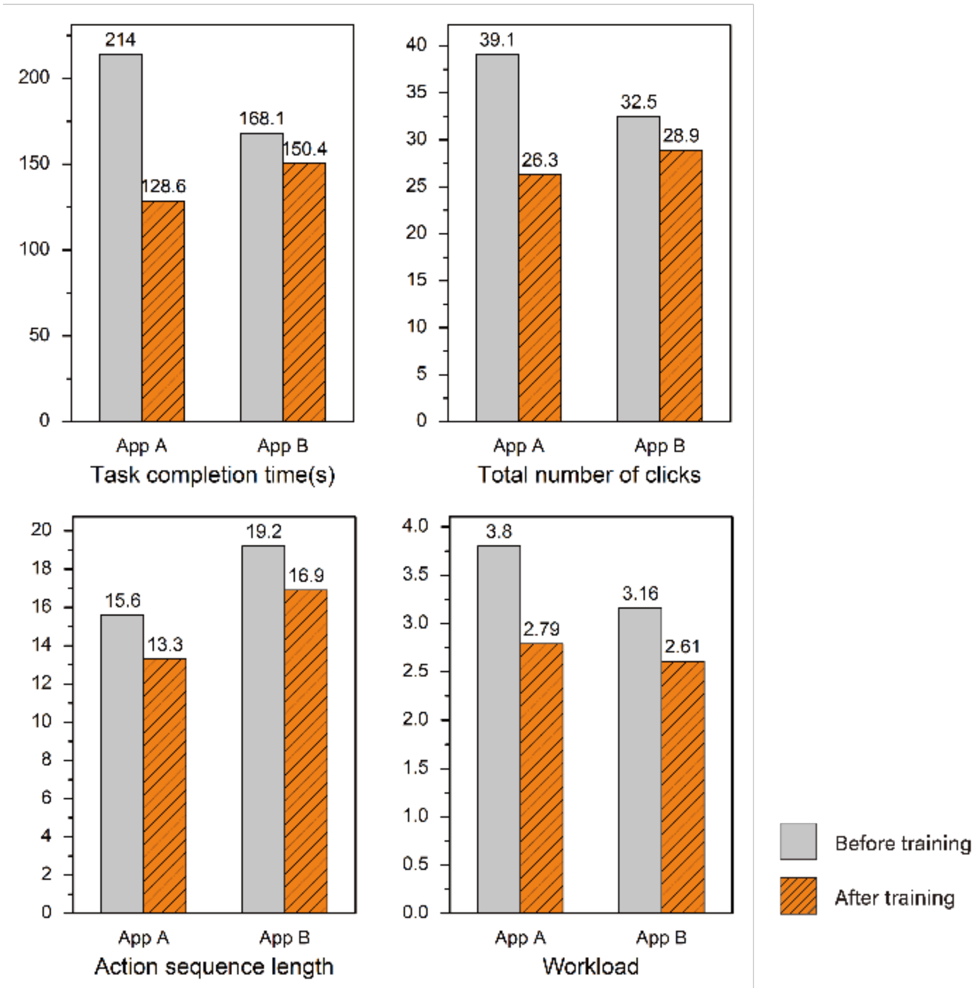
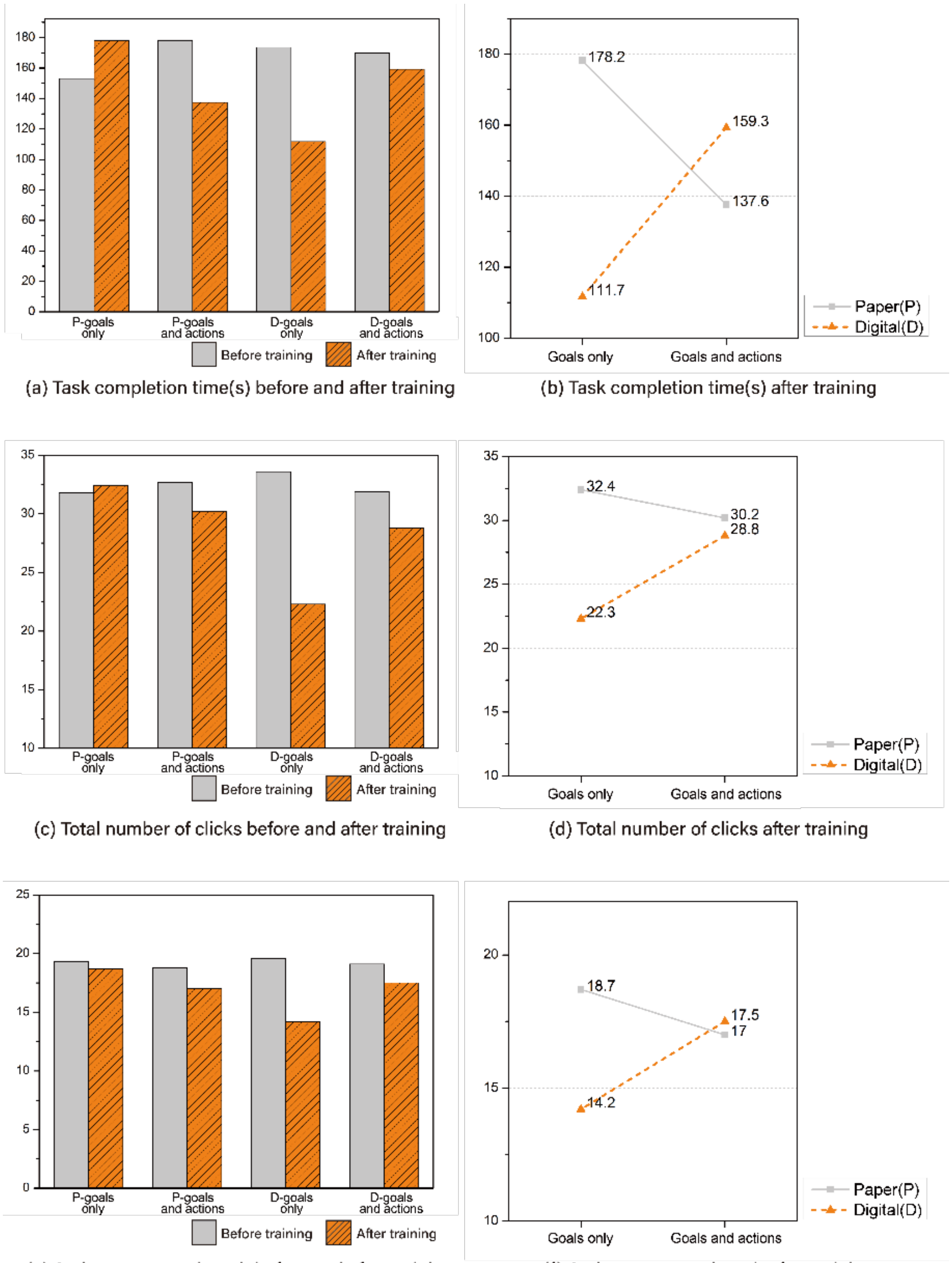


Figure 2.3: General training effects

2.3.2 Training Method Effects

No significant group differences were found before training. On the other hand, after training, regarding App B, the two-way interaction of medium and instruction type was significant for task completion time ($F(1, 60)=9.325$, $p=0.003$), total number of clicks ($F(1,60)=4.729$, $p=0.034$), and action sequence length ($F(1,60)=5.907$, $p=0.018$). The mean values of "D-goals only" were significantly lower than those of "P-goals only" ($p<0.05$). The largest training impact was found for the "D-goals only" method (Figure 2.4). Concerning App A, a similar result was found for task completion time ($F(1,60)=10.250$, $p=0.002$). No other significant differences were found regarding the workload measures.



(a) Task completion time(s) before and after training
(b) Task completion time(s) after training
(c) Total number of clicks before and after training
(d) Total number of clicks after training
(e) Action sequence length before and after training
(f) Action sequence length after training

Figure 2.4: Training method effects on App B

2.3.3 Training Time

The average time spent for each training method was compared. No significant main effects or two-way interaction effect were found regarding training time (Figure 2.5). The overall average training time was 121.49 seconds.

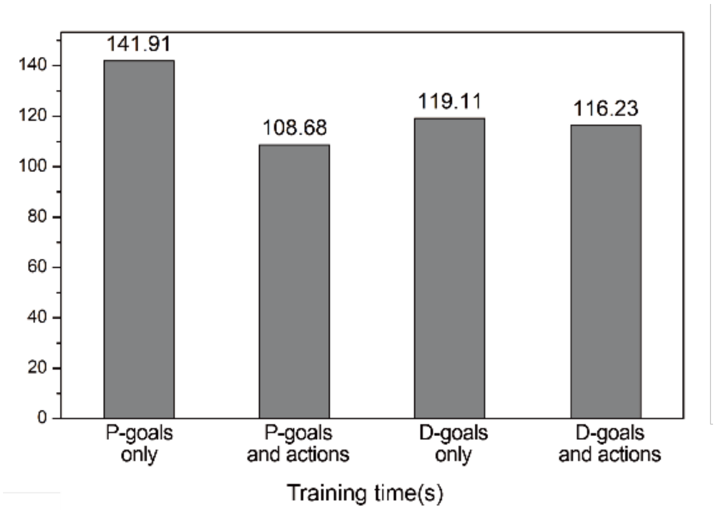


Figure 2.5: Training time

2.4 Discussion

This study comparatively evaluated four different training methods in terms of training efficacy when training older adults to use a public ticket machine. The four training methods were combinations of 2 medium types (paper, digital) and 2 instruction types (goals only, goals and actions). The participants' task performance and workload when using the public ticket machine were evaluated both before and after training. Since training should support learning the task well enough so that an individual can use the system when the instructional materials are no longer accessible (Hickman et al., 2007), except for the training session, participants had to complete the given task without access to the training materials, and the task performance under such condition was evaluated. The findings indicated that: (1) task performance generally increased while workload decreased after training, (2) the degree of improvement differed by the type of training method the participants experienced, (3) The "D-goals only" training method was the best in terms of procedural knowledge transfer, and (4) between the two training methods employing the paper medium, the "P-goals and actions" method was better than the "P-goals only" method.

2.4.1 General Training Effects

Concerning all dependent variables, the differences between the mean values before and after training were significant. The participants' performance generally increased after training, and their perceived workload scores decreased irrespective of the training methods. The findings are consistent with the previous result the older user's technology competency can be enhanced by training (Czaja and Sharit, 2012). The study results also seem to lend support to the necessity of providing proper technology training programs for older adults as one of the major challenges faced by them in learning to use new technology is their lack of relevant technology experience (Kurniawan, 2006).

2.4.2 Training Method Effects

Aside from the general training effects, the degrees of improvement by training were found to significantly differ by groups. Before training, no significant differences in task performance across the four groups were found. This indicates that the participants' baseline competency to use the application was homogeneous across the groups. On the contrary, after training, between-group mean differences in task completion time, total number of clicks, and action sequence length for App B became significant. Since the group differences were significant only after training, they would logically be attributed to the effects of the training method. In particular, the medium × instruction type interaction effect was significant for all three performance measures. In the digital manual condition, it was found that on average, only providing goals to be accomplished in each step (goals only) resulted in shorter task completion time, the smaller total number of clicks, and shorter action sequence length than providing descriptions of actions required as well (goals and actions). The results seem to suggest that when designing interactive tutorials, allowing for trial and error by not providing required actions but goals would facilitate learning. That is, interactive training materials would better be designed to require attentional processing by the individual, lest the learner become so reliant on the materials (Hickman et al., 2007). On the other hand, in the paper manual condition, the "P-goals and actions" method resulted in higher performance compared to the "P-goals only" method. This seems to suggest that when the training medium is non-interactive, detailed instructions are more helpful. In cases when it is difficult to provide real-time feedback, specific descriptions may need to be provided to train users.

The significant medium × instruction type interaction effect on task completion time for App A after receiving training on App B is also notable. Considering that training was only conducted on App B, the significant training effect differences on the untrained task seem to support the generalizability of the major finding that the "D-goals only" method is recommended.

The interaction effect between medium and instruction type can be explained by different amounts of cognitive load required to access and process information written in paper and digital manual, which consequently might have led to dissimilar efficacy of an identical instruction type when delivered through the two different types of medium. According to the Cognitive Load Theory (CLT), humans have limited working memory capacity. Thus, care must be taken to ensure that a learner's brain is not overloaded during training (Sweller et al., 1998; Merrienboer and Sweller, 2005). To be specific, training should be designed to minimize the workload that occurs due to extraneous factors such as the training interface. When a learner's working memory gets overtaxed by factors unrelated to the training content, it hinders the learner from fully concentrating its mental resources on the training material.

In terms of CLT, two main features in training design, medium and instruction type can both affect training efficacy. First, regarding the medium type, information access cost and a trainee's familiarity with the particular type would determine the amount of cognitive load it provides to the learner. Paper manual, compared to digital manual, requires many attentional resources to process instructions written on it, as participants have to consciously compare content on the manual and that on the machine. In other words, the paper manual is inferior concerning spatial contiguity. On the other hand, the digital manual has higher spatial contiguity since a learner's interaction occurs and training material appears in the same place. Henceforth, when training with the digital manual, the additional effort required in processing information written on the manual would be far less than that with the paper manual.

Such different amounts of cognitive workload required to process the information on the manual then would determine the remaining amount of resources that can be concentrated on understanding and internalizing instructional contents. The current research study findings imply that in the digital manual condition, since attentional resources can be relatively focused more on training material itself, practice problems with less specified goals might have led to more extensive exploration of the problem space, which, in turn, lead to improved learning (Burns and Vollmeyer, 2002; Sweller and Levine, 1982). On the contrary, in the paper manual condition where relatively more amount of mental resources are required to process and translate instructions written on the manual, it is likely that the efficacy of the "Goals only" instruction type is reduced. In other words, primarily due to high information excess cost in the paper manual condition, learners would have a limited amount of mental resources to actively figure out what specific actions they have to perform when they are only provided with goals. Thus, in the paper manual condition, it is likely that the "Goals and action" instruction type, which delivers more detailed instructional content, was more effective to train learners.

2.4.3 Implications

Some practical and theoretical implications of the study results are provided here: first, the study results overall recommend properly determining both the medium and instruction type in training design in order to minimize working memory demand for learners. In particular, it should be considered to first pay attention to the amount of required mental resources for processing information on the manual. Then, appropriate instruction type should be selected by taking into account how much mental workload is remaining. When relatively a lot amount of mental resources is still remaining, training with the "Goals only" instruction type would be more effective for learners to explore a solution space and learn by trial-and-error. However, when not enough mental resources are available, such instruction type would rather impose excessive loads on learners and deteriorate their training efficacy. The overall findings of the current research study provide a significant theoretical implication by confirming the Cognitive Load Theory.

In addition, it is important to note that age-related changes in cognition do not mean that older adults cannot learn to use new technology. Depending on how well a training program is designed, older adults may have fewer difficulties remembering newly learned skills. In fact, among different kinds of long-term memory, the degree of age-related declines in procedural knowledge is known to be dependent on how well-learned the procedure is (Czaja and Sharit, 2012). In other words, the procedural knowledge which has been acquired with a well-designed training program would be retained in an older adult's memory without much effort.

Moreover, as it also takes longer for older adults to unlearn procedures (Czaja and Sharit, 2012), proper design of training programs of methods is particularly significant for the older population.

Chapter 3

An Investigation of SSK Design: A Partition and Chair Effects on Perceived Workloads and Task Performance

3.1 Introduction

In ergonomics and human-computer interaction (HCI), much research has been conducted to improve the design of SSK and thereby enhance the SSK user experience (UX). The existing research efforts may be broadly classified into two categories. The first category consists of the studies that aimed to empirically investigate the effects of design variables associated with the typical, dominant SSK designs and further develop pertinent design guidelines. The design variables considered included both the ones related to graphical user interface (GUI) elements and also the physical dimensions determining the size and shape of SSK hardware. Colle and Hiszem (2004), Jin et al. (2007), Schedlbauer (2007), Sesto et al. (2012), Chen et al. (2013), and Kang and Shin (2017) are some example studies that investigated GUI element design variables. These studies examined the effects of touchscreen key size, location and spacing on task performance and user preference. As for physical dimensions of SSK hardware, Al-Saleh and Bendak (2013) and Rana et al. (2018) compared different SSK in major physical dimensions, including the screen, card slot, and cash slot heights. Also, Gao and Sun (2015) examined the effects of the inclination angle of an SSK touchscreen panel on user interaction performance and satisfaction. Some studies, such as Maguire (1999) and Sandnes et al. (2010), provided design guidelines for SSK, which covered a wide range of human factors topics.

The second category of research studies represents attempts to develop novel, innovative SSK designs, focusing on identifying or creating new SSK features/functions rather than investigating design variables of typical designs. Some example studies are as follows: Hagen and Sandnes (2010) proposed an adaptive SSK, in which touchscreen height, text size, and target size were adjusted to fit the user's height, reading distance, and motor abilities, respectively. A digital camera installed on the top of the SSK continuously monitored the height and the reading distance of the user, and the system dynamically adjusted the touchscreen and user interface parameters. Mäkinen et al. (2002) incorporated an interactive agent into an SSK utilizing computer vision technologies. The SSK invited and greeted the user as he/she approached it, and provided appropriate help when the user was next to the SSK but no interaction occurred. Hone et al. (1998) and Chan and Khalid (2003) incorporated a speech input function into an SSK and investigated its impact on the user experience. Lamel et al. (2002), Johnston and Bangalore (2004), and Niculescu et al. (2016) developed a multimodal SSK that enabled the users to use speech input with their smartphones in addition to conventional touchscreen operations, thus encouraging them to verbally ask for help whenever troubled. The use of multi-modal interaction has been shown to increase the functionality and flexibility of SSK (Günay and Erbuğ, 2015).

Despite substantial past research, however, the design of SSK is by no means a closed chapter. There remain many unresolved issues that compromise user experience (UX) and hinder user adoption of SSK – see Andrews (2009), Lazar et al. (2019), Meuter et al. (2000), and Park et al. (2021) for different SSK UX issues and related design challenges. One such SSK UX issue is the psychological and social impacts of the unique environmental and situational characteristics of SSK.

The phrase "the unique environmental and situational characteristics of SSK" refers to the fact that SSK are installed in public open spaces and used in time-sensitive situations, where users are hurried and people are waiting in a long line (Lazar et al., 2019). These characteristics can cause an SSK user to experience psychological and social stresses, including perceived time pressure, fear of making other people wait, fear of negative social responses, and fear of public embarrassment (Andrews, 2009; Dabholkar and Bagozzi, 2002; Kelly, 2015; Kelly and Lawlor, 2019; Gelbrich and Sattler, 2014). This is especially so for many individuals who do not have the knowledge and skills required for using SSK. It should be noted that the psychological and social stresses are not groundless. Negative social responses and public embarrassments do occur in reality as the self-reported anecdote below from Forbes (2008) reveals:

> I am still mad about this! I was trying to get money out of machine in Chicago, late at night. There were many people waiting in line for me. The machine gave me an incorrect amount of money and then ate my card! I kept trying to fix the problem while everyone in line was yelling at me to hurry up. I was so angry and was very embarrassed. One guy yelled at me and said "what's the problem lady, can't you use an ATM machine" and everyone laughed.

The psychological and social stresses can also lead to performance anxiety (Andrews, 2009; Dabholkar and Bagozzi, 2002), which impairs task performance and increases workloads. Performance anxiety under pressure and associated performance decrements are referred to as "choking under pressure" (Baumeister, 1984; Beilock and Carr, 2001). Multiple research studies have shown that time pressure generally increases behavioral errors while resulting in faster response production (Freedman and Edwards, 1988; Slobounov et al., 2000). A technology acceptance model (TAM) study by Gelbrich and Sattler (2014) reported that concerning the use of SSK, technology anxiety lowers perceived ease of use, and, perceived crowding and perceived time pressure reinforce the negative effect of technology anxiety.

The excerpt from Kelly (2015) below seems to describe how the anxiety due to the environmental and situational characteristics of SSK affects task performance and eventually the intention to use SSK:

> When I am there, there is a queue behind me, people... I start stressing out, because there are people behind me. I am immediately conscious; if I mess up, somebody is gonna be getting impatient with me. And so I get really nervous. And when I get nervous around technology, I just tend to shut down. So if something goes wrong, I will just kind of walk away...

Two potential SSK design features may be useful for addressing the above-mentioned UX issue. They are: partitions and a chair. Partitions, that is, side partitions and a back partition, are typically used to protect the privacy of users (Little et al., 2005), but, they may also help mitigate the problems arising from the above-mentioned environmental and situational characteristics of SSK, by lessening their psychological and social impacts. The use of side partitions or a back partition, or both for that matter, visually blocks the presence of co-actors and/or others in the queue, and, this may effectively alleviate anxiety and fears. The reduction of psychological and social stresses may positively affect task performance (Baumeister, 1984; Beilock and Carr, 2001; Dobson, 2012; Eysenck, 2014; Yerkes and Dodson, 1908). Bandura et al. (1999) reported that a higher level of psychological comfort would activate cognitive and intellectual functioning, and, consequently, improve task performance.

Provision of a chair may also have similar positive psychological and social impacts – it is thought that a chair provided for an SSK user would implicitly signal the user and the others in the queue that the user is allowed to take sufficient time to complete the SSK task, and, the right to do so should be respected. Such implicit communication may help ease social tension and psychologically support the user. Additionally, a chair eliminates standing, which requires considerable mental/attentional resources for postural control (Horak, 1987; Lajoie et al., 1993; Shumway-Cook and Horak, 1986; Woollacott and Shumway-Cook, 2002). This may help the user better perform required SSK tasks. Roerdink et al. (2011), and Kang et al. (2021) showed that sitting, when compared with standing, requires a smaller amount of cognitive resources and thus is associated with relatively higher cognitive performance for a concurrent mental task. Chourasia et al. (2013) and Schedlbauer et al. (2006) reported that the accuracy of a touchscreen task is better for the sitting than the standing position.

Despite the possible benefits of partitions and chairs described above, however, whether or not these potential SSK design features are actually useful has not been studied. Few research studies have empirically investigated their impacts on SSK task performance, workloads, and other UX evaluation criteria in the context of SSK use – the authors are not aware of any. Also, it is not clear if the benefits of partitions and chairs (assuming they exist) would be the same across different segments of the user population. Some user segments may benefit particularly more from them while some others may not find them value-adding or may even view them as cumbersome and annoying. Addressing the research/knowledge gaps would contribute to improving the SSK design and thereby the SSK user experience.

The long-term objective of our research is to improve the SSK user experience through a novel and innovative design. In an effort towards accomplishing this objective, the goal of this research study was to empirically explore the impacts of providing SSK users with side partitions, a back partition and/or a chair, employing both subjective workload measures and objective SSK task performance measures. Eight different design alternatives, varying in terms of using or not using each of the design features (side partitions, a back partition and a chair), were evaluated. The National Aeronautics and Space Administration Task Load Index (NASA-TLX) (Hart and Staveland, 1988) was employed for subjective workload evaluation. The NASA-TLX consists of scales corresponding to various workload dimensions, including not only mental and physical demands but also time pressure, self-perception of own performance and psychological stress/anxiety. Two different user segments, that is, the younger and the older, were considered in this initial study in order to examine the homogeneity of partition and chair impacts.

3.2 Method

3.2.1 Participants

Two groups of participants, the younger and older groups, participated in this research study. This allowed testing if the use of partitions and/or chairs provides equal benefits to the corresponding segments of the user population. The younger group (20~35 years old) consisted of 22 participants (12 males and 10 females); the older group (55~70 years old), 27 participants (14 males and 13 females). Table 3.1 presents a summary of the participants' demographic data. At the time of the study, all participants were free of obvious musculoskeletal disorders and had normal or corrected-to-normal vision in both eyes.

Prior to the experimental trials, the study purpose and procedure were fully explained to the participants, and informed consent was obtained from each. The study and the research protocol were reviewed and approved by the Institutional Review Board at Seoul National University.

Table 3.1: Summary of age, technology familiarity, and frequency of SSK usage (last 1 month) for the two participant groups

Dimension		Younger	Older
Age	(years)	23.7 ± 2.1	61.9 ± 4.4
Technology familiarity	(10-point scale)	8.0 ± 0.7	2.4 ± 0.8
Number of SSK uses in the last 1 month		8.7 ± 1.7	1.3 ± 1.2

*Note: Technology familiarity was self-assessed utilizing the 10-point frequency scale from Rosen et al. (2013). The number of SSK uses in the last 1 month was also self-estimated through recall.

3.2.2 Experimental Setup

An experimental setup was created to closely approximate the real usage situation in which people stand in a queue in front of SSK and take turns to order food items using the machine. Two identical SSK were installed in a row in a laboratory. Each consisted of a 23-in touch screen monitor, which is widely used in many restaurants in South Korea, and a height-adjustable monitor stand. The laboratory was spacious enough to allow much space ahead of the SSK so that participants could line up in front of them. In addition, three design features, side partitions, a back partition, and a chair, were prepared for each SSK – they were used to construct different design alternatives. Three design variables, Side Partition, Back Partition, and Chair, were used in combination to represent different design possibilities of SSK. Each of these design variables had two levels: Yes (use of the feature) and No (no use).

3.2.3 Design Alternatives

The current study comparatively evaluated a total of eight design alternatives of SSK, which were the combinations of the levels of the three design variables: 8 = two levels of Side Partition (Yes/No) × two levels of Back Partition (Yes/No) × two levels of Chair (Yes/No). The participants performed the experimental task (a food ordering task) in each of the eight design alternatives. With Side Partition, Back Partition, and Chair represented as alphabet letters S, B, and C, the alternatives were indicated as S1B1C1, S0B0C1, etc., where the number right to each alphabet symbol indicated whether or not the corresponding design feature was used (1: Yes, 0: No). For instance, S1B1C1 indicates the design where there were side and back partitions, and, chairs (Figure 3.1a), while S0B0C1 represents the design where there were only chairs (Figure 3.1b).

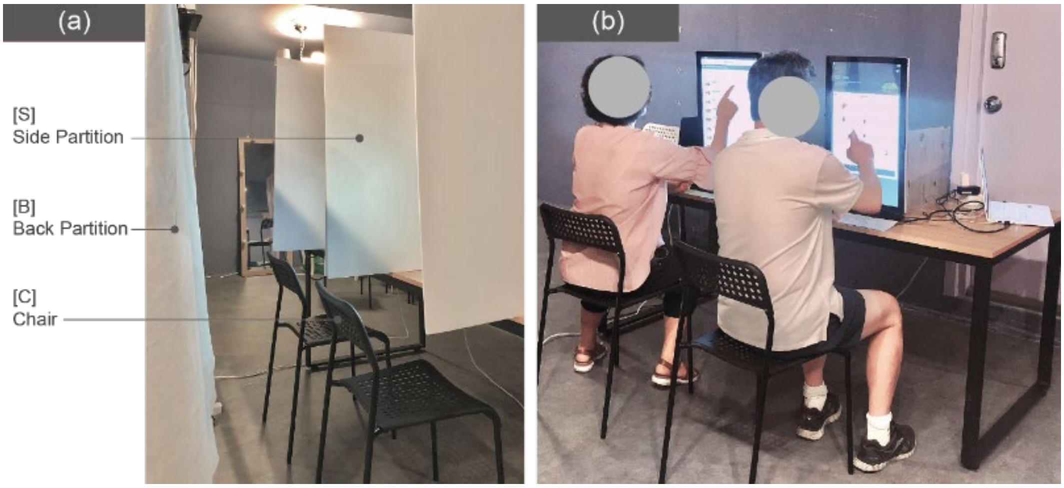


Figure 3.1: Experimental setup: (a) Three design features present in S1B1C1, (b) Participants performing the experimental task in S0B0C1

3.2.4 Experimental Task

The experimental task was a food ordering task. Each participant ordered a food item on the menu using the SSK in each of the eight design alternatives. Each participant performed a single trial for each design alternative, and, thus, conducted a total of eight experimental trials. In order to motivate the participants to quickly complete the food ordering task as they usually do in fast-food restaurants, they were informed that the entire round of the experiment would finish as soon as everyone in the group completes the task. In each trial, each participant was given an instruction sheet on which a food item for the trial was written. The food items of the eight trials were all different for each participant.

The food ordering task consisted of five sub-tasks: selecting the burger, meal size, toppings, side dish, and beverage. For each sub-task, task accuracy was measured in terms of correct (Success) or incorrect (Failure) selection.

The BURGER KING®KOREA software application available from Google Play was used for the task. The Bandicam screen recorder and the open-source multimedia manipulation tool, FFmpeg, were used along with the Python script for data collection.

3.2.5 Experimental Procedure

The participants were assigned to one of eight groups and participated in the experiment following the schedule of the group. The eight groups had similar age and gender distributions. The order of the eight experiment trials in each group was designed according to the Latin square design to ensure a counterbalanced experiment. Seven of the eight groups consisted of six participants; the other group, seven.

All participants participated in the research study for two days. On the first day, they were surveyed on their past SSK use experience and were given explanations about the experimental task. The task was fully explained to and practiced by the participants before the beginning of the first trial. In each trial, the participants were instructed to line up in front of the SSK in a single queue and use either of the two SSK which was available on their turns. At the beginning of each trial, the instructor handed over the instruction sheet on which the burger, meal size, toppings, side dish, and beverage to be selected were written. The participants returned to the end of the line when they completed the food ordering task. Immediately after the completion of the task trials by all participants in the group, the participants completed the NASA-TLX questionnaire and took a rest for 15-20 minutes. The process, which required about 30 minutes, was repeated four times a day, a total of eight times in two days. When the participants completed all trials, they were thanked and debriefed (Figure 3.2). In order to control order and sequence effects, the positions of the participants in each queue were also determined according to the Latin square design.

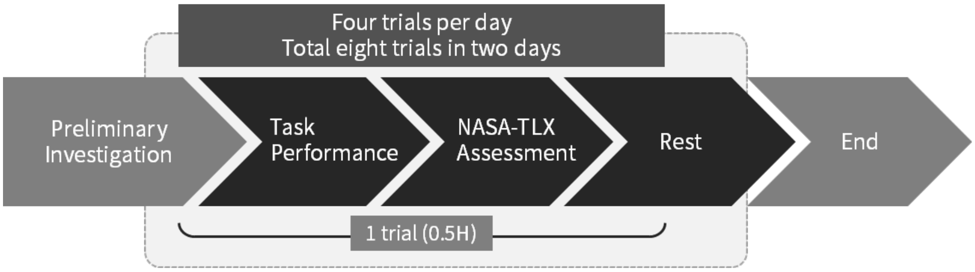


Figure 3.2: Experimental procedure

3.2.6 Independent and Dependent Variables

In this study, three independent variables (Side Partition, Back Partition and Chair) and a stratification variable (Age) were considered. The three independent variables (SSK design variables) were within-subjects factors, and, the stratification variable (Age), a between-subjects factor.

The workload of each participant was evaluated utilizing the NASA-TLX (Hart and Staveland, 1988). Each participant rated the perceived workload for each of the six workload dimensions (mental demand, physical demand, temporal demand, effort, performance, and frustration), which correspond to different aspects of the SSK user experience. The mental demand, physical demand, and effort dimensions corresponded to the mental, physical, and combined workload of the SSK task, respectively; the temporal demand, performance, and frustration dimensions corresponded to the time pressure, self-perception of task performance, and task stress/anxiety during the SSK task. The weighted average workload reflecting each participant's view on the relative contributions of the six dimensions was also calculated. In addition to the workload measures, each participant’s task performance was evaluated in terms of task completion time and accuracy. Three task performance measures, that is, task completion time, average reaction time, and the number of sub-tasks completed successfully, were employed as dependent variables (Table 3.2). Figure 3.3 presents a graphical summary of the independent/stratification and dependent variables.

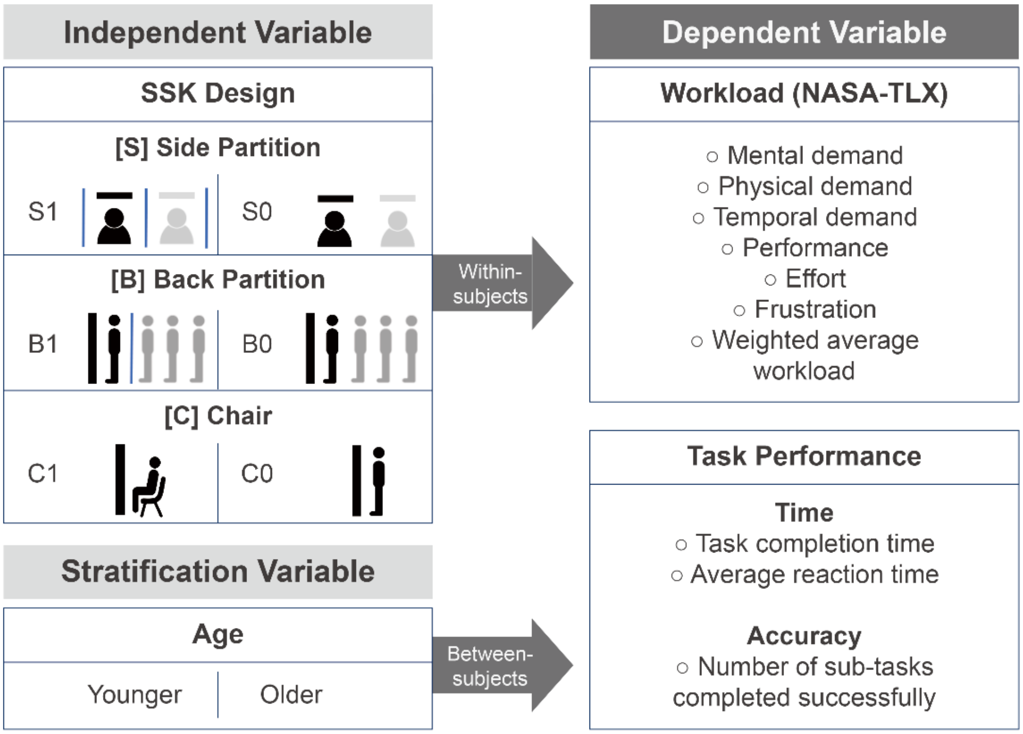


Figure 3.3: Summary of independent/stratification and dependent variables

Table 3.2: Task performance measures

Task Performance Measure		Definition/Quantification
Time	Task completion time	The total amount of time between the onset of the trial and the completion of the last operation (s)
	Average reaction time	Task completion time/(Total number of touch operations -1) (s)
Accuracy	Number of sub-tasks completed successfully	Full marks: 5 The score was computed as the number of correctly performed sub-tasks. The five sub-tasks consisted of selecting: (a) burger, (b) meal size (regular or large), (c) toppings, (d) side dish and (e) beverage.

3.2.7 Data Analyses

The task performance data were examined for outliers prior to statistical analyses. Among the participants with task performance measures greater than 3 SD above or below the mean (Pukelsheim, 1994), two participants were removed from data analyses as their time and accuracy measures were both below the mean by more than 3 SD. Their exceptionally short task completion time with very low task accuracy strongly suggested careless participation. Following outlier removal, for each dependent variable except the number of sub-tasks completed successfully, the study employed a general linear model of repeated measures to test the statistical significance of the independent/stratification variables and their interactions; a "generalized" linear model was employed for the number of sub-tasks completed successfully as the dependent variable was not continuous but a count measure. The model included one between-subjects factor of 2 levels (Age: younger, older) and three within-subjects factors (Side Partition, Back Partition, Chair) of 2 levels (Yes, No). In cases where a higher-order interaction was statistically significant, post hoc tests with Bonferroni corrections were conducted. In addition, for each age group, the eight SSK design alternatives were compared with one another in terms of the mean values of the workload and task performance measures.

Also, Pearson correlation analyses were conducted for each pair of a workload and a task performance measure in each between-group (younger, older). The purpose of the analyses was to investigate whether or not there is a linear relationship between subjective, psychological experience and objectively measured task performance, and to further examine if such relationship differs between the two participant groups. All statistical analyses were conducted using SPSS 25 (IBM

Corp., Armonk, USA), and an alpha level of 0.05 was utilized.

3.3 Results

3.3.1 General and Generalized Linear Model Analyses

Table 3.3 summarizes the statistical analysis results. The asterisks indicate statistically significant effects/differences. It is noted upfront that the younger and older groups differed significantly in all the workload and task performance measures. The between-group differences are further depicted in Figure 3.4.

Table 3.3: Summary of the significant main effects and interactions

(*: p<0.05, **: p<0.01, ***: p<0.001)

Dependent variable		Main effect				Interaction effect			
		Side	Back	Chair	Age	Side×Back	Side×Chair	Age×Chair	Age×Side×Back
Workload	Mental demand				***	*			
	Physical demand				***		*		
	Temporal demand		*	*	**				
	Performance	*			***				
	Effort				**	*			*
	Frustration			*	***		*	*	
	Weighted average workload			*	***				
Task performance	Task completion time				***			*	
	Average reaction time			*	***			*	
	Number of sub-tasks completed successfully				***				

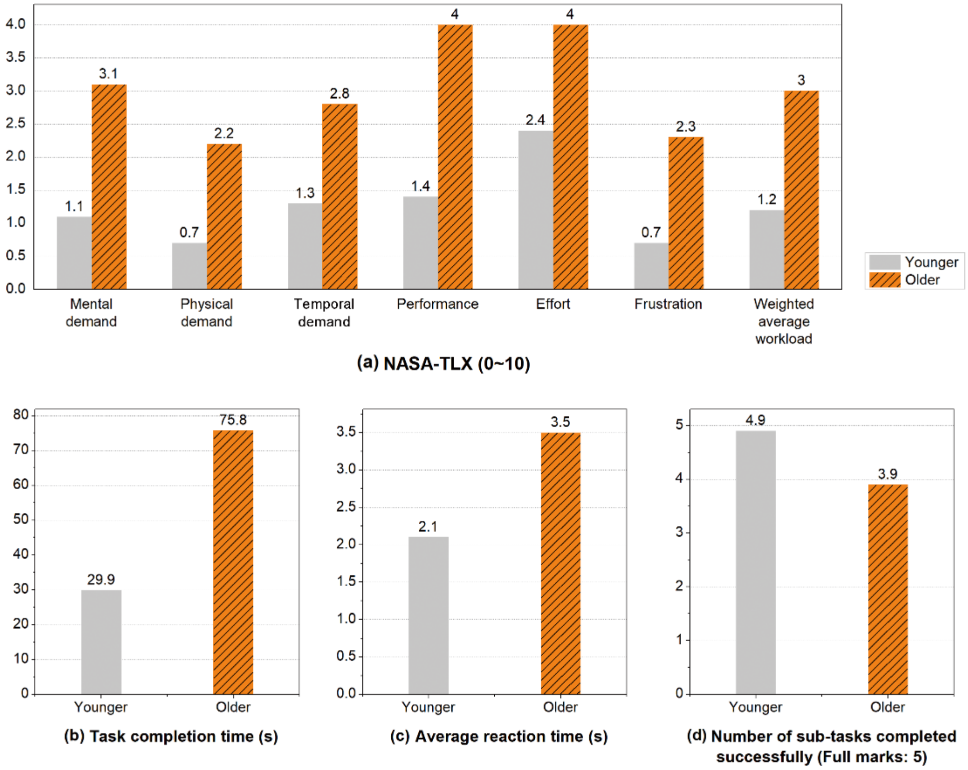


Figure 3.4: Descriptions of between-group differences:

(a) NASA-TLX workload scores, (b) task completion time,

(c) average reaction time, (d) number of sub-tasks completed successfully

3.3.1.1 Design Effects: Main and Interaction Effects of Design Variables

As shown in Table 3.3, many significant design effects were found: the Side Partition × Back Partition interaction effect on *mental demand* ($F(1,45)=5.089$, $p<0.05$), the Side Partition × Chair interaction effect on *physical demand* ($F(1,45)=5.582$, $p<0.05$), the Back Partition and Chair main effects on *temporal demand* ($F(1,45)=4.511$, $p<0.05$), the Side Partition main effect on *performance* ($F(1,45)=6.179$, $p<0.05$), the Side Partition × Back Partition interaction effect on *effort* ($F(1,45)=6.612$, $p<0.05$), the Chair main effect ($F(1,45)=6.864$, $p<0.05$) and the Side Partition × Chair interaction effect on *frustration* ($F(1,45)=4.453$, $p<0.05$), and the Chair main effect on *weighted average workload* ($F(1,45)=6.980$, $p<0.05$). The design effects are visually described in Figure 3.5.

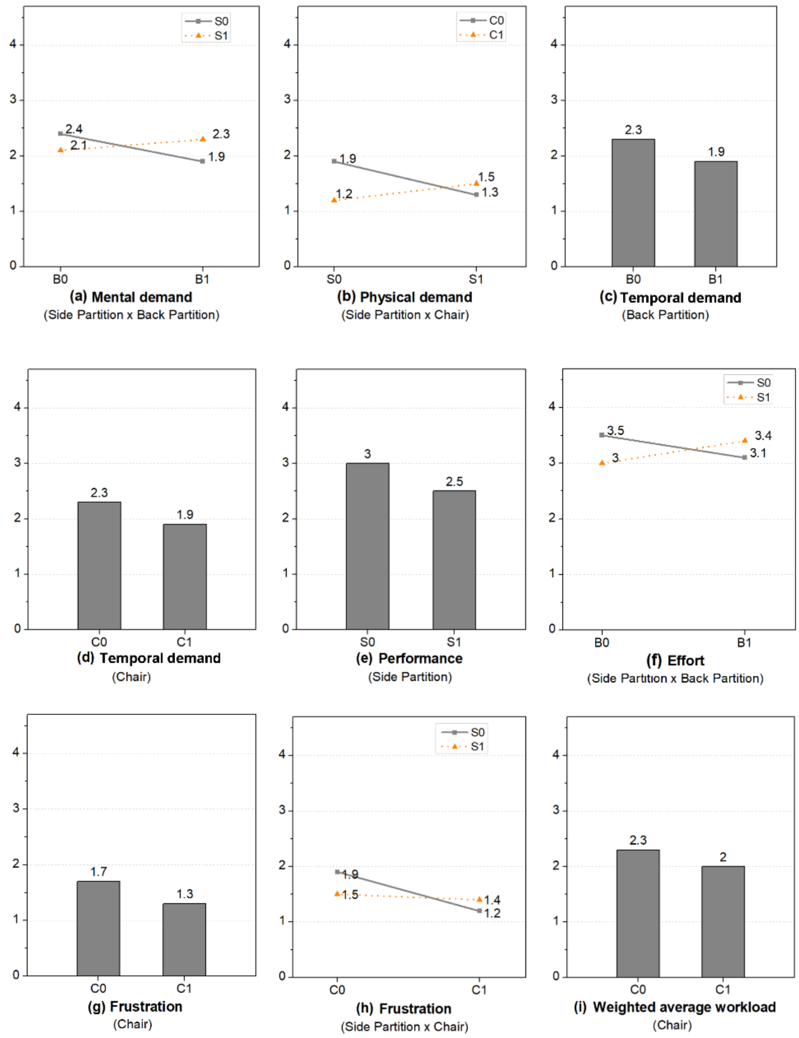


Figure 3.5: Descriptions of significant design effects: (a) Side Partition × Back Partition interaction effect on *mental demand*, (b) Side Partition × Chair interaction effect on *physical demand*, (c) Back Partition main effect on *temporal demand*, (d) Chair main effect on *temporal demand*, (e) Side Partition main effect on *performance*, (f) Side Partition × Back Partition interaction effect on *effort*, (g) Chair main effect on *frustration*, (h) Side Partition × Chair interaction effect on *frustration*, (i) Chair main effect on *weighted average workload*

Regarding the Side Partition × Back Partition interaction effect on *mental demand*, the post hoc analyses indicated that mental demand was higher in S0B0 than S0B1 ($p<0.05$; Figure 3.5a). For the Side Partition × Chair interaction effect on *physical demand*, the mean physical demand rating was significantly greater for S0C0 than for S0C1 ($p<0.01$; Figure 3.5b). As to the Back Partition and Chair main effects on *temporal demand*, the mean rating was significantly greater for B0 than B1 ($p<0.05$; Figure 3.5c) and also for C0 than C1 ($p<0.05$; Figure 3.5d). Concerning the Side Partition main effect on *performance*, the mean rating was significantly greater for S0 than S1 ($p<0.05$; Figure 3.5e). For the Side Partition × Back Partition interaction effect on *effort*, the mean score was significantly greater for S0B0 than S0B1 ($p<0.05$; Figure 3.5f). As for the Chair main effect and the Side Partition × Chair interaction effect on *frustration*, the mean rating was significantly greater for C0 than C1 ($p<0.05$; Figure 3.5g) and also for S0C0 than S0C1 ($p<0.001$; Figure 3.5h). With regard to the Chair main effect on *weighted average workload*, the mean score was significantly greater for C0 than C1 ($p<0.05$; Figure 3.5i).

3.3.1.2 Age group differences in design effects

Significant age × design interaction effects were also found (Table 3.3): the Age × Side Partition × Back Partition interaction effect on *effort* ($F(1,45)=4.776$, $p<0.05$), the Age × Chair interaction effect on *frustration* ($F(1,45)=4.643$, $p<0.05$), and the Age × Chair interaction effects on *task completion time* ($F(1,45)=4.239$, $p<0.05$) and *average reaction time* ($F(1,45)=4.328$, $p<0.05$). The significant age × design interaction effects are visually depicted in Figure 3.6.

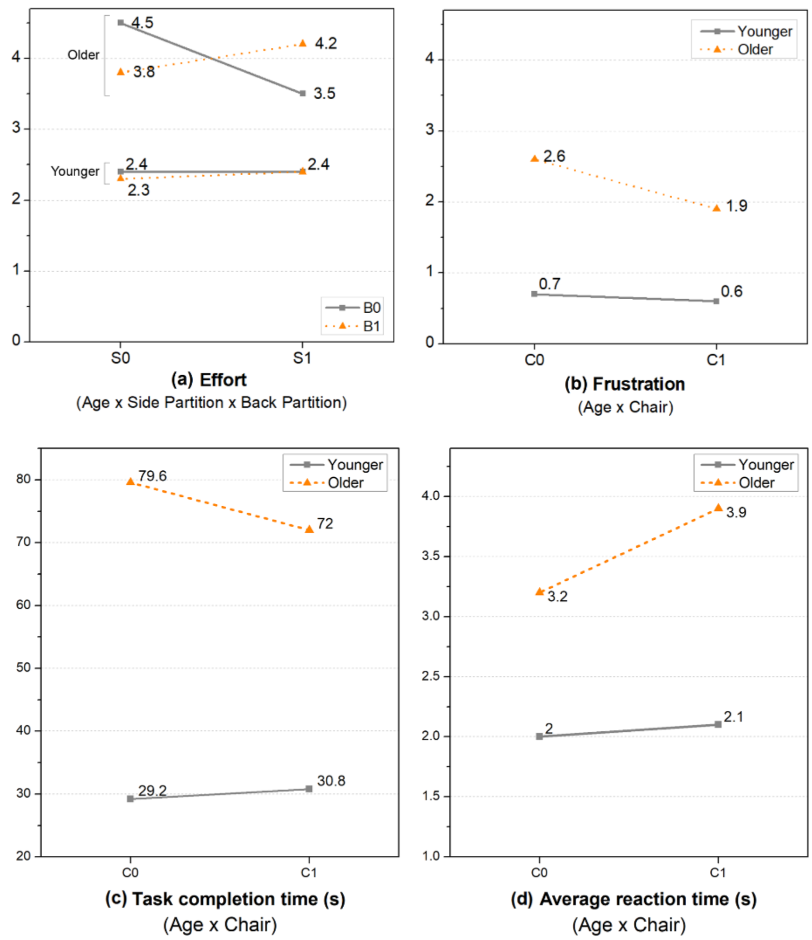


Figure 3.6: Descriptions of significant age × design interaction effects: (a) Age × Side Partition × Back Partition interaction effect on *effort*, (b) Age × Chair interaction effect on *frustration*, (c) Age × Chair interaction effect on *task completion time*, (d) Age × Chair interaction effect on *average reaction time*

In regard to the Age × Side Partition × Back Partition interaction effect on *effort*, the post hoc analyses indicated found significant differences between S0B0 and S1B0, between S1B1 and S1B0, and between S0B0 and S0B1 in the older group ($p<0.05$; Figure 3.6a). In the case of the younger group, no significant pairwise differences were found. As for the Age × Chair interaction effect on *frustration*, the mean frustration rating was significantly greater for C0 than C1 in the older group ($p<0.001$; Figure 3.6b). Regarding the Age × Chair interaction effect on task completion time, the mean task completion time was significantly longer for C0 than C1 in the older group ($p<0.05$; Figure 3.6c). As to the Age × Chair interaction effect on *average reaction time*, the mean average reaction time was significantly longer for C1 than C0 in the older group ($p<0.001$; Figure 3.6d).

3.3.2 Comparison of Design Alternatives

For each age group, the eight design alternatives were compared with one another in three evaluation criteria – the mean weighted average workload score, mean task completion time, and mean number of tasks completed successfully. Figure 3.7 presents a graphical summary of the comparisons.

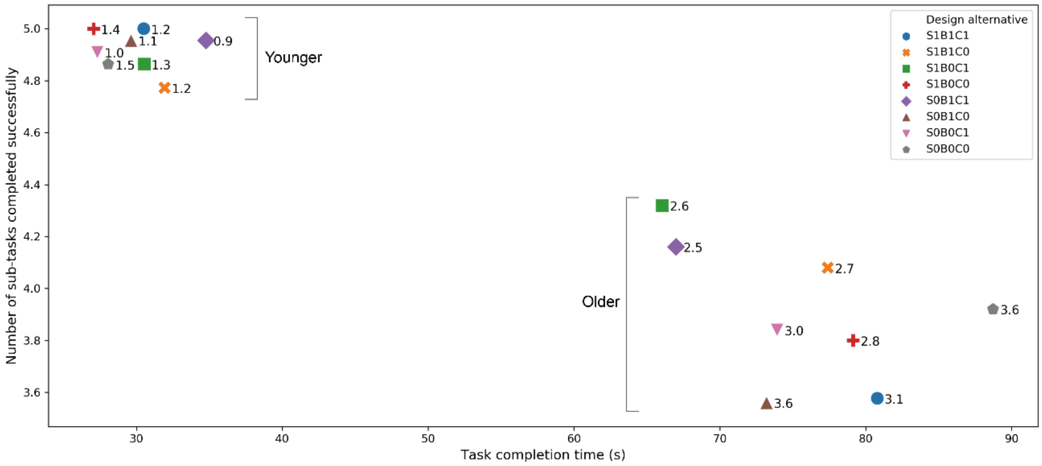


Figure 3.7: Comparisons of the eight design alternatives. For each symbol representing a design alternative, the number next to it denotes the corresponding mean weighted average workload score

3.3.3 Correlation Analyses

Table 3.4 presents the Pearson correlation coefficients for all the task performance-workload variable pairs for each age group. Overall, linear correlations between the task performance and the workload variables were more pronounced for the older group (Table 3.4b) than for the younger group (Table 3.4a).

Table 3.4: Correlations between task performance and workload variables

(*: p<0.05, **: p<0.01; Correlation coefficients larger than 0.3 were highlighted):

(a) Correlations of the younger group

Dependent variable (Task performance)	Workload						
	Mental demand	Physical demand	Temporal demand	Performance	Effort	Frustration	Weighted average workload
Task completion time	0.29**		0.29**	0.31**	0.34**	0.38**	0.39**
Average reaction time		0.18*					
Number of sub-tasks completed successfully					-0.22**		

(b) Correlations of the older group

Dependent variable (Task performance)	Workload						
	Mental demand	Physical demand	Temporal demand	Performance	Effort	Frustration	Weighted average workload
Task completion time	0.42**	0.34**	0.44**	0.25**	0.44**	0.43**	0.48**
Average reaction time							
Number of sub-tasks completed successfully	-0.40**	-0.29**	-0.26**	-0.30**	-0.25**	-0.40**	-0.39**

3.4 Discussion

The goal of this study was to empirically explore the effects of three public SSK design features, that is, side partitions, a back partition and a chair, on the workloads and task performance of SSK users. Eight different design alternatives, varying in terms of using or not using each design feature, were evaluated. Subjective NASA-TLX workload measures (Hart and Staveland, 1988) and objective SSK task performance measures were employed. The NASA-TLX workload measures consist of various dimensions, including not only mental and physical demands but also temporal demand, self-perception of own performance, and psychological stress/anxiety. Two groups of participants, the younger and older groups, participated in this research study. This was to test the homogeneity of partitions and chair impacts, that is, if the use of partitions and/or chairs provides equal benefits to the two corresponding segments of the user population.

The significant differences between the younger and the older group in all the dependent variables (Figure 3.4) indicate that the two groups recruited in this study well represented two distinct user segments. On average, the older group perceived higher workload in every workload dimension, their task completion time and the average reaction time were longer, and the number of sub-tasks completed successfully was smaller. The observed between-group differences can be attributed largely to the characteristics of older adults. The age-associated reductions in different mental and physical resources (Bonder and Dal Bello-Haas, 2017; Czaja et al., 2019; Rabbitt, 2019; Deary et al., 2009) and in the ability to cope with different stressors (Craik et al., 2010; Rabbitt, 2019) would naturally lead to increases in workload in different dimensions and decreases in task performance, as observed in this study. Additionally, the observed between-group differences may also be related to the differences in the SSK technology familiarity and skill/knowledge level, as revealed in Table 3.1. Besides, the differences also lend support to previous research that points to the need to consider user age in usability research (Sonderegger et al., 2016).

3.4.1 Design Effects: Main and Interaction Effects of Design Variables

In this sub-section, only the main and interaction effects of design variables (Side Partition, Back Partition, and Chair) are discussed. Interaction effects involving Age are discussed in the next sub-section.

Concerning the effects of design variables and their interactions, the significant findings were as follows: Side Partition × Back Partition interaction effect on *mental demand*, Side Partition × Chair interaction effect on *physical demand*, Back Partition and Chair main effects on *temporal demand*, Side Partition main effect on *performance*, the Side Partition × Back Partition interaction effect on *effort*, Chair main effect and Side Partition × Chair interaction effect on *frustration*, and Chair main effect on the *weighted average workload* (Table 3.3, Figure 3.5).

Regarding the Side Partition × Back Partition interaction effect on *mental demand* (Figure 3.5a), adding a back partition decreased perceived mental demand only when there were no side partitions. The observed benefit of a back partition, in the absence of side partitions, was consistent with our initial expectation that a back partition lessens social pressure imposed on SSK users by blocking others waiting behind in the queue, and, thereby, helps them deal with the "choking under pressure" problem (Baumeister, 1984; Beilock and Carr, 2001) and better focus their attentional/mental resources on the SSK task at hand. On the other hand, not expected was the finding that the back partition benefit was conditional, present only when there were no side partitions. In the presence of side partitions, adding a back partition showed a tendency to increase perceived mental demand (Figure 3.5a).

While it is not entirely clear what gave rise to the observed interaction pattern, we propose an explanation based on existing social psychology theories: with side partitions installed, adding a back partition would completely block the presence of others (both the co-actor at the adjacent SSK and those waiting behind in the queue). This, as mentioned earlier, would help reduce social pressure; however, it may also bring about additional psychological effects. One possible consequence of complete blocking is the hindrance of social facilitation; another, the prevention of social inhibition.

According to the drive theory of social facilitation by Zajonc (1965), when an individual performs a task, the presence of an audience or co-actors increases the individual's general arousal level (Colman, 2015; Myers, 2012; Geen and Gange, 1977; Zajonc, 1965). Increased social arousal is known to boost performance on easy and well-learned tasks (social facilitation) and hurt performance on difficult tasks (social inhibition) (Myers, 2012; Zajonc and Sales, 1966; Lin and Yu, 2018). Hence, complete blocking of the presence of others, through a design like S1B1, can hinder social facilitation for the users familiar with SSK tasks while preventing social inhibition for the users who find SSK tasks difficult. The hindrance of social facilitation would adversely affect an SSK task whereas the prevention of social inhibition, along with reducing social pressure, would have a positive impact. Thus, complete blocking (the design S1B1) would have both positive and negative sides; and, this may be the reason it did not emerge as the optimal design. The interaction pattern shown in Fig. 5a indeed suggests that the optimal design may be what adopts partial blocking, like S0B1.

Another possible consequence of complete blocking (S1B1) may be the feeling of isolation. Note that S1B1 effectively isolates the user within a visually closed space. Such isolation may induce anxiety for some individuals as it would suggest to them that it is impossible to receive help from others, that is, co-actors or audience, directly or indirectly (for example, seeing what the co-actor at the adjacent SSK is doing). The anxiety would negatively impact an SSK task.

The above explanations see the observed interaction pattern (Figure 3.5a) as the result of multiple psychological phenomena (social pressure, social facilitation, social inhibition, and feeling of isolation) regulated by the design of blocking structure using partitions. Of course, the explanations are conjectural at this time and further research is needed to confirm them.

As for the Side Partition × Chair interaction effect on *physical demand* (Figure 3.5b), it was found that adding a chair decreased perceived physical demand only when there were no side partitions. Put differently, standing (C0) increased physical demand compared with sitting, only in the absence of side partitions – no standing-associated increase in physical demand was observed in the presence of side partitions (Figure 3.5b). This suggests that the presence of side partitions somehow helped mitigate the physical demand of standing during the SSK task.

Although the role of side partitions during standing cannot be elucidated within the current study, a conjecture from a "postural control" perspective is provided for further consideration: when performing an SSK task in the standing position, the user must achieve postural equilibrium (maintaining the upright standing posture) and at the same time perform visuomanual touchscreen interactions. Achieving postural equilibrium requires feedback control – detecting body sway motion by visual, vestibular, and proprioceptive sensory systems and generating an appropriate corrective torque (Horak, 2006; Johansson and Magnusson, 1991; Peterka, 2002). The sensorimotor integration requires substantial efforts and is what makes standing more challenging than sitting – note that sitting also requires postural control but it is much less demanding than what is involved in standing. The NASA-TLX physical demand score would reflect the physical and mental (motor control) efforts for the sensorimotor integration.

Regarding the role of side partitions during standing SSK use, they may have played the role of visual references facilitating the sensorimotor integration and thus postural control - when perceived by the peripheral vision, the side partitions as visual references would help the SSK user detect his/her body sway motions and thus support the sensorimotor integration. Related to this, the effectiveness of utilizing visual references for improving postural control during standing has been demonstrated in multiple previous studies (Simeonov and Hsiao, 2001; Simeonov et al., 2003; Simeonov et al., 2009). It is perhaps worth noting that the side partitions would likely facilitate postural control without degrading the performance of the primary SSK task as they are perceived through peripheral vision. The multiple resource theory (Wickens, 2008) distinguishes between focal and ambient vision.

Focal vision, primarily foveal, supports object recognition and, in particular, high acuity perception such as that involved in reading text and recognizing symbols (Wickens, 2008). Ambient vision, distributed across the entire visual field and preserving its competency in peripheral vision, is responsible for the perception of orientation and movement (Wickens, 2008). Again, the above idea concerning the possible role of side partitions is a conjecture; and, further postural sway studies would help test it.

As to the Back Partition main effect and the Chair main effect on *temporal demand* (Figures 3.5c and 3.5d), the mean rating was significantly greater for B0 than B1, and for C0 than C1. The Back Partition main effect agrees with our initial expectation that blocking the presence of others waiting behind would reduce social pressure. The Chair main effect is also in line with our initial expectation that a chair provided for an SSK user would help ease social tension and psychologically support the user as it would implicitly signal the user and others in the queue that the user is allowed to take sufficient time to complete the SSK task, and, the right to do so should be respected. The implicit message communicated to both the user and others may be understood as an affordance (perceivable action possibility) (Norman, 1988) of a chair provided to an SSK user.

Concerning the Side Partition main effect on perceived *performance* (Figure 3.5e), the mean rating was significantly greater for S0 than S1 (Figure 3.5e) indicating that adding side partitions improved the perception of one's own performance. It is thought that the presence of side partitions helped the participants reduce performance anxiety (fear about one's ability to perform a specific task) as it precluded comparing one's own performance with that of the co-actor at the adjacent SSK. According to Seta (1982), when there are co-actors and the tasks are identical, individuals tend to attribute any differences in performance levels to differences in abilities. Such a tendency could increase the level of anxiety and decrease the confidence level of a performer (Seta, 1982).

The Side Partition × Back Partition interaction effect on *effort* is not discussed here. Instead, the three-way Age × Side Partition × Back Partition interaction effect is discussed in the next subsection.

As for *frustration*, which represents psychological and social stresses, the Chair main effect (Figure 3.5g) and the two-way interaction of Side Partition × Chair (Figure 3.5h) were significant. The Chair main effect seems to indicate that adding a chair reduced different types of psychological and social stresses combined during the SSK task. This is consistent with the notion mentioned earlier that a chair would ease psychological and social stresses through implicit communication. The Side Partition × Chair interaction effect further reveals that the psychological benefits of a chair were conditional, present only in the absence of side partitions. It is not clear why a chair provided no psychological benefits in the presence of side partitions. One possibility however is that the "frustration level" dimension might be somehow related to that of physical demand. Note that the interaction plot for the frustration level (Fig. 5h) is similar to that for physical demand (Figure 3.5b).

With regard to the Chair main effect on *weighted average workload* (Figure 3.5i), the mean score was significantly greater for C0 than C1, which indicates that adding a chair decreased the overall workload of the SSK task. This lends support to the utility of a chair as an SSK design feature.

3.4.2 Age Group Differences in Design Effects

This sub-section presents a discussion of the interaction effects involving Age, which indicate the design effect differences between the two age groups. The significant interaction effects involving Age were as follows: Age × Side Partition × Back Partition interaction effect on *effort*, Age × Chair interaction effect on *frustration*, *task completion time*, and *average reaction time* (Table 3.3, Figure 3.6).

The three-way Age × Side Partition × Back Partition interaction effect on *effort* (Figure 3.6a) indicates that the design of blocking structure specified by the design variables Side Partition and Back Partition affected the overall perceived task demand/difficulty of the SSK task differently for the two age groups. For the younger group, the design of blocking structure had no effect. On the other hand, for the older group, the two-way interaction pattern (Side Partition × Back Partition) was observed - the designs representing partial blocking of the presence of others, that is, S0B1 and S1B0, were lower in effort than the design with no blocking (S0B0) and that with complete blocking (S1B1) (Figure 3.6a). The pairwise differences between S0B0 and S1B0, S0B0 and S0B1, and S1B1 and S1B0 were significant.

The result for the older group may be explained, again, utilizing social psychological constructs, such as social pressure, social facilitation (for those who are familiar with SSK tasks), social inhibition (for those who are not familiar with SSK tasks), and fear of isolation. Increasing the degree of blocking is thought to reduce social pressure and social inhibition to help the user's information processing, but it may hinder social facilitation and increase the feeling of isolation to have the opposite effect. This trade-off may be the reason the designs with partial blocking (S0B1 and S1B0) were lower in effort than the design with no blocking (S0B0) and that with complete blocking (S1B1). On a separate note, among the four psychological constructs, social facilitation was likely to be less important than the other three for the older group as the older user group on average was low in the SSK technology familiarity (Table 3.1).

The lack of design variable effects for the younger group (Figure 3.6a) is thought to be mainly because the younger participants were familiar with SSK tasks (Table 3.1), and, therefore, the difficulty of the SSK task was very low relative to their cognitive resources. Additionally, compared with older adults, younger adults are known to be better at tasks requiring executive functions and focused attention (Craik and McDowd, 1987; Deary et al., 2009; Rabbitt, 2019). Thus, it is possible that the younger group was able to effectively suppress the perceptual and cognitive distractions resulting from the exposure to the presence of others and the spatial isolation. In such circumstances, the design of blocking structure would not affect the information processing.

As for the Age × Chair interaction effect on *frustration* (Figure 3.6b), the use of a chair was found to reduce the NASA-TLX frustration score only for the older group. The benefit of using a chair for the older group is again consistent with the idea that a chair provided to an SSK user would send a signal to the user and others that the user is allowed to take sufficient time. The chair benefit may also be related to the physical demand reduction - as noted earlier, postural control for sitting is much less demanding than that for standing. Overall, the use of a chair could help an SSK user perform SSK tasks better and more easily, and, this in turn would lead to reduced psychological stresses. The lack of chair-associated reduction in frustration for the younger participants is thought to be because the SSK task employed in this study was not mentally/physically demanding for them, and, therefore, they did not need the chair benefits.

The Age × Chair interaction effect on *task completion time* (Figure 3.6c) indicates that the use of a chair was found to reduce task completion time only for the older group. The observed improvement in task performance for the older group again can be attributed to the benefits of a chair mentioned earlier.

The Age × Chair interaction effect on *average reaction time* (Figure 3.6d) shows that the use of a chair increased average reaction time (the average amount of time used for a single touch operation) for the older participant group, while no such chair effect was found for the younger group. The chair effect for the older group supports the notion that a chair can ease social tension in the public SSK setting through implicit communication – the older participants were indeed less hurried and took more time to perform each operation during the interaction. What is important is that the calmer, more relaxed behavior of the older participants in the C1 condition did not worsen but improved task performance in task completion time (Figure 3.6c). When considered together, the chair effects on decreased task completion time and increased average reaction time for the older group imply that the use of a chair reduced the number of touch operations for them. This was found to be the case – the number of touch operations was 38.5 and 29.5 for the C0 and C1 conditions, respectively.

In sum, the significant interaction effects involving Age indicate that design variables differently affected the two user segments. The graphical comparisons of the eight design alternatives in Fig. 7 confirm the result.

3.4.3 Correlation Analyses

The correlation analyses results shown in Table 3.4 overall indicate that subjective, psychological experience is more tightly coupled with objectively measured task performance for the older than the younger group. They seem to lend support to the view that psychological stress may affect actual SSK task performance more for older than younger SSK users, although the direction of causality cannot be confirmed from the correlation analyses. All in all, it is thought that the proper design of SSK is more important for older users as it would likely provide a two-fold benefit (enhancing task performance and also subjective experiences) to older users.

3.4.4 Implications

Some practical and theoretical implications of the study results are provided here: first, the study results overall recommend the designs S1B0C1 or S0B1C1 for public SSK. These designs would provide benefits in terms of improved task performance and psychological experience for older users without negatively impacting younger users. Also, these designs are expected to benefit businesses as well as users, as they would help increase profits by improving turnover and also customer satisfaction in general.

It is acknowledged however that some additional investigations may be needed to further confirm the practicality of the recommended designs, including a study on the impacts of the designs on the experience of the customers waiting in the queue. Second, more generally, the study results seem to suggest that adding simple design features, for example, side partitions, a back partition, and a chair, as demonstrated in this study, can improve the task performance and subjective experience of SSK users. While previous studies on the innovative design of SSK were mostly focused on the application of technological elements, such as adaptive systems, interactive agents, computer vision, and natural language processing (Chan and Khalid, 2003; Hagen and Sandnes, 2010; Hone et al., 1998; Johnston and Bangalore, 2004; Lamel et al., 2002; Mäkinen et al., 2002; Niculescu et al., 2016), relatively little research has been conducted concerning the utilization of simple design features devised on the basis of psychological and ergonomics considerations. Further research is needed to explore different design possibilities in this area. Third, the current study showed that two distinct user segments, that is, the younger and the older, differed substantially in terms of the design variable effects. This implies that it is necessary to study the cognitive and physical characteristics of different user segments and utilize the knowledge for the universal/inclusive design of SSK. Some examples of major user segments include various disability groups and cultural groups. Finally, the current study results suggest that the research on the design of SSK and similar systems can draw upon related disciplines, in particular, social psychology and motor control.

Chapter 4

Conclusion

4.1 Summary and Implications

Study 1 (Chapter 2) investigated the medium and instruction type effects on the efficacy of training older adults to use a public information system (a public ticket machine), in an attempt to improve and develop technology training design for older users. Four training methods, combinations of 2 medium types (paper, digital) and 2 instruction types (goals-only, goals-and-actions), were evaluated in a lab experiment. While the older participants' task performance generally increased after training, the degree of improvement differed significantly between the training methods. The combination of the digital medium and the use of goals-only instructions showed the highest performance improvement resulting from training.

In Study 2, through a lab experiment, the impacts of potential SSK design features (side partitions, a back partition, and a chair) on perceived workloads and task performance were elucidated. Two participant groups, the younger and the older group, were recruited to test the homogeneity of design feature effects between the corresponding user segments. The study results overall recommend the use of either side partitions or a back partition, and, that of a chair for public SSK. A medium degree of social exposure created by the use of either side or back partitions was found to reduce mental demand and effort for the older group without negatively impacting the younger. Also, providing a chair was found to lower temporal demand, frustration, and weighted average workload of both older and younger groups, and, improve task performance for the older group, again without negative impacts on the younger. The proposed design recommendations would help address the psychological and social stresses due to the unique environmental and situational characteristics of SSK, and, thereby improve the user experience of SSK for many members of our society.

4.2 Future Research Directions

Some limitations of Studies 1-2 are acknowledged here, along with future research directions.

In Study 1, the experimental procedure consisted of five trials of task completion including a training session, and all trials were completed within a day. The training efficacies of different training methods need to be evaluated more thoroughly to further strengthen the current results. For instance, the evaluation of retention several days after training may be considered in future studies. Also, future studies that compare the four training methods in different task contexts are needed to confirm the generalizability of the current study findings.

Concerning Study 2, first, this study was a lab experiment. The actual effects of the design variables and interactions in real-world environments might not be the same as those reported in this study. We expect that the effects would be more pronounced in the actual environments where there are more disturbances and distractions, such as visual signs and noises, and time pressure and social tension would be higher. Currently, a new study in a real-world setting is underway to confirm this prediction. Second, this study did not consider the effects of audience size (the number of people waiting in the queue) although it may affect the social and psychological experiences of SSK users in a profound manner. An experimental study is needed to address the research need. Third, in this study, we provided possible explanations for the research findings, and, some of them were conjectures constructed utilizing concepts from the fields of social psychology and motor control. Further studies employing the research methods from the disciplines are warranted to test the conjectures.

Lastly, an integrated study investigating the mixed effects of training and SSK design could further elaborate the current research findings. It would be highly meaningful to examine whether training efficacy can be further maximized under public SSK design where psychological stress is reduced through the use of side partitions and a chair.

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국문초록

본 논문에서는 고령인의 키오스크 접근성 향상을 위한 두 가지 방안을 고려한다. 첫째, 고령인의 키오스크 사용 방법 학습 효과를 극대화하는 방안을 모색하고자 각 두 종류의 정보 전달 매체와 설명 방식의 조합인 4개의 서로 다른 트레이닝 설계의 학습 효과를 비교한다. 피험자 간 설계 실험으로 4개의 트레이닝 설계의 효과를 비교 분석한다. 둘째, 키오스크에 설치 가능한 물리적 설계 요소(좌우 칸막이, 뒤 칸막이, 의자)가 키오스크 사용자의 작업 수행도와 작업부하에 미치는 영향을 평가한다. 그 결과 본 논문에서는 고령인의 키오스크 접근성 향상을 위한 효과적인 트레이닝을 설계하기 위해서는 어떤 정보 전달 매체와 설명 방식을 선택해야 하는지, 공공 키오스크의 전반적인 사용자 경험을 개선하기 위해서는 어떤 물리적 설계 요소를 설치해야 하는지에 대한 가이드라인을 제공한다.

주요어: **키오스크**, **셀프서비스기술**, **기술 접근성**, **고령인**, **트레이닝 설계**, **인지부하**, **학습 이론**, **심리적 긴장**, **사회적 스트레스**, **작업 수행도**, **작업부하**

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