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An Ergonomics Study on Improving Accessibility of Washing Machines for People with Disabilities

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지도교수 윤 명 환

이 논문을 공학석사 학위논문으로 제출함

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위 원 장 _____박 우 진_____(인)

부위원장 _____윤 명 환_____(인)

위 원 _____박 건 수_____(인)

Abstract

An Ergonomics Study on Improving Accessibility of Washing Machines for People with Disabilities

Yoonki Kim

Department of Industrial Engineering

The Graduate School

Seoul National University

More than 200 million people face difficulties in daily activities due to disability and aging. As the number of elderly people grows worldwide, it is becoming increasingly important for everyone to have equal opportunities in everyday and social activities. Despite the increasing statistics of the disabled and elderly population, limited research has been done to provide an accessible design by analyzing anthropometric data.

This study identifies the usage issues on preferred control types on washing machines for people with disabilities; visual impairment, hearing impairment, spinal cord injury, elderlies, and analyze the anthropometric characteristics of people with spinal cord injuries and identify optimal accessible measurements for washing machine design. The purpose of this research is to propose a design guideline on washing machines for people with disabilities. Surveys and interviews were conducted with participants with visual

impairment, hearing impairment, spinal cord injuries, and elderlies to analyze the preferred product control types and designs. From the interview of washing machine usage, participants with spinal cord injuries showed a significant difference compared to other groups as they have a limited range of movement due to the wheelchair and their physical difficulties.

Thus, anthropometric data of people on a wheelchair are used to formulate equations for washing machine measurements that are optimally accessible for people with spinal cord injuries. The formulas were used for finding the anthropometric mismatch of five existing washing machines, in order to identify how the current washing machines accommodate anthropometric characteristics of people with spinal cord injuries. From the results of preferred control types and optimal washing machine measurements, possible design considerations for accessible washing machines are proposed in this research.

Keywords: Anthropometric design, Accessibility, Universal design, Washing machine, Product Controls, Disabilities, Spinal Cord Injury
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Chapter 1

Introduction

According to the World Health Organization, about 200 million people worldwide encounter significant difficulties in functioning daily lives [1]. For the equal use of products regardless of age or disabilities, the universal design ensures the accessibility of products and environments [2]. During recent years, the attention to enhancing accessibility is increasing as the emphasis on providing equal opportunities for all people to participate in social and daily activities is growing [3] [4]. However, people with disabilities, especially those who are living with spinal cord injuries, show low independence in interacting with home appliances. Therefore, by analyzing the anthropometric characteristics of people with spinal cord injuries, optimal accessible measurements for washing machines is identified in this research. With an increasing number of elderlies worldwide, the importance of improving the quality of life and accessibility of people with disabilities has been raised since early 2000 [5]. Various studies regarding accessibility are conducted in the field of information and communication and architecture, including studies suggesting guidelines for improving web accessibility for people with disabilities [6].

Due to the improved medical care and aging in population, the number of people with disabilities is increasing considerably [7]. In addition, as people with congenital or long-term disabilities are living longer, they experience similar ways of difficulties in interacting with products or environment with the elderlies. The increase in the number of people with reduced function has a significant impact on assistive technology research.

However, the design in the assistive technology does not fully take into account of elderlies and disabled users. The elderlies face different functionality issues from the general disabled users while using assistive technologies. Instead of having a single disability such as visual, hearing, and mobility, normal elderly people have more general impairments including vision, hearing, dexterity and some disturbances in memory [8]. In addition to these minor disturbances, older people are more likely to have more severe disabilities as they are aging [9]. In recent years increasing emphasis has been placed on designing improved technical aids for physically disabled people [10].

The purpose of this research is to propose a design guideline on washing machines for people with disabilities and elderlies. Surveys and interviews were conducted with participants with visual impairment, hearing impairment, spinal cord injuries, and elderlies to analyze the preferred control types and designs. From the interview of washing machine usage, participants with spinal cord injuries showed a significant difference compared to other groups as they have a limited range of movement due to the wheelchair and their physical difficulties.

Anthropometric data of people on a wheelchair are used to formulate equations for washing machine measurements that are optimally accessible for people with spinal cord injuries. The formulas are used for finding the anthropometric mismatch of existing washing machines, to identify how the current washing machines accommodate the anthropometric characteristics of people with spinal cord injuries. From the results of preferred control types and optimal washing machine measurements, possible design considerations for accessible washing machines are proposed in this research.

1.1 Problem Description

In applying universal design in home appliances, the American Disability Act (ADA) provides guidelines in the reach range of washing machine design. However, the reach range does not fully accommodate the anthropometric characteristics still leaves washing machine inaccessible to people with spinal cord injuries. Previous research on accessibility focuses on the environment and the accessibility in web settings and not enough research has been done in identifying accessibility in home appliances.

The findings from this study are expected to be used in enhancing accessibility on washing machines for people with disabilities, especially for those with spinal cord injuries. The approach of considering anthropometric data to find the optimal measurements of accessible washing machine and identifying the mismatch with existing washing machines would further provide methods in forming accessible design guidelines and in evaluating accessibility in product designs.

1.2 Research Motivation and Contribution

The research motivations and main contributions of the thesis are as follows:

(a) Identify the usage issues on washing machines and preferred control types for people with disabilities (visual impairment, hearing impairment, spinal cord injury, elderlies).

(b) Analyze the anthropometric characteristics of people with spinal cord injuries and identify optimal accessible measurements for washing machine design.

(c) Evaluate the accommodation level of existing washing machines for people with spinal cord injuries.

(d) Propose a design guideline on washing machines that are optimally accessible for people with spinal cord injuries.

1.3 Organization of the Thesis

This thesis is composed of 5 chapters.

In Chapter 1, the purpose of the study is defined according to the problems identified in the background research.

In Chapter 2, background knowledge is introduced to convey the basic concepts and ideas of this study.

In Chapter 3. survey and interview conducted with participants with visual impairment, hearing impairment, spinal cord injury, and elderlies in order to identify the preferred control types in home appliances are illustrated. Usage Patterns in Washing Machines were also analyzed through usage testing and interview to identify the usage patterns in using washing machines.

In Chapter 4, anthropometric data of people using a wheelchair from Sizekorea is used to formulate equations that are optimally accessible to washing machines for people with spinal cord injuries. The equations are used for finding an anthropometric mismatch of existing washing machines. Five washing machines were analyzed to identify how the existing washing machines accommodate with the anthropometric characteristics of people with spinal cord injuries. Possible design considerations for accessible washing machines is proposed from the results of preferred control types and optimal washing machine measurements.

In Chapter 5, findings are summarized and the implications, limitations and future works are suggested.

Chapter 2

Literature Review

2.1 Review on Universal Design

Universal design refers to 'design for everyone' and represents a design approach that integrates buildings and functions that are available to everyone to the maximum possible extent [11]. Universal design can be defined as the design of products and environments that do not require adaptation to as many people of all ages and abilities [12]. As an example, the universal design feature should be inconspicuous, as it is fully integrated into the thoughtful design solution to be approachable by every user. Universal design includes designs that have been developed considering the need for a diverse population, for men and women, children and elders, small and large people, and those with temporary or long-term disabilities [13].

The Center of Universal Design at NC State University provides the principles of universal design. Table 2.1 shows the principle and definition of universal design [12].

Table 2.1. Principle of universal Design (The Center of Universal Design)

Principle	Definition
1. Equitable use 2. Flexibility in use	- Usable and marketable to people with diverse abilities - Accommodates a wide range of individual preference and abilities
3. Simple and intuitive use	- Easy to understand, regardless of experience, knowledge, language skills or current concentration level
4. Perceptible information	- Communicates necessary information effectively, regardless of ambient conditions or sensory abilities
5. Tolerance for error	- Minimizes hazards and adverse consequences of accidental or unintended actions
6. Low physical effort	- Can be used efficiently and comfortably, with a minimum fatigue
7. Size and space for approach and use	- Appropriate size and space for approach, reach, manipulation, and use regardless of body size, posture, or mobility

(Center for Universal Design, North Carolina State University, 2001)

2.2 Review on Accessibility

Accessible design refers to designs that meet the code requirements specified for use by people with disabilities [14]. Accessibility consists of two main categories, physical and informational accessibility. Physical accessibility refers to studies are based on physical conditions such as wheelchair users with disabilities, elderly people, while information Information accessibility: research on the environment in which users accept information, such as web and mobile

In order to acknowledge such universal design principles, the United States Government has announced the issuance of the American Disability Act (ADA) [15]. The US Department of Justice has issued the 2010 ADA Standard on Accessible Design to provide standardized guidelines for designing more accessible environments and products [16].

From a design-oriented perspective, environmental design guidelines, especially wheelchair mobility guidelines, are offered rather than product design. In terms of products, the focus is on wheelchair users such as those with spinal cord injuries, but the provided specifications are difficult to apply directly to product design. Therefore, most ADA standards provide design guidelines for physical accessibility, and do not apply to the design of accessible products for people with information accessibility. As well as looking at accessibility as a relationship between people and the environment, environmental factors are as important in determining the degree of independence of an individual and in defining the condition of people with disabilities in society [17].

2.3 People with Disabilities and Elderlies

Disability is an individual's disability that substantially limits key activities in life. Disability is defined as a physical or mental disorder experienced by an individual and substantially limits one or more major life activities [15]. Current UN Convention Definition of People with Disabilities People with disabilities have long-term physical interactions that may interact with various disabilities and prevent full and effective participation in society equally with others. Includes people with mental, intellectual or sensory disabilities. People with disabilities find it difficult to function in one or more areas of life at the body, person or social level, as individuals interacting with contextual factors and experiencing health conditions [18]

The International Classification of Functioning and Disability defined disability as a comprehensive term that describes the negative aspects of the interaction between the contextual factors and an individual, thus the word accessibility is much more complex. [19]. In this respect, an accessible environment is an environment in which an individual with certain impairments can function independently.

In this study, people with visual impairment, hearing impairment, spinal cord injury, and elderly people are identified. In Chapter 4, the anthropometric data of Korean people with spinal cord injury is used to identify the mismatch of the anthropometric data and the configuration of each part of the washing machine. ISO 9999 Identifies the disability types and definition as shown in Table 2.2 [20].

Table 2.2. Types of Impairment and definitions

Disability Types	Definition/Characteristics
Motor and Physical Disabilities	- Condition that affects a person's ability to perform motor tasks, limits the person's ability to navigate the environment - Limits or precludes mobility - Significantly impacts gross motor function such as walking, running, skipping, etc.
Vision Impairment and Visual Disabilities	- Restricted field of vision or diminished ability to see sharpness of detail, read standard-size print, determine color or depth perception, see contrasts, adjust to changes in light or glare, or locate objects.
Hearing Impairment	- Conductive, Sensorineural, and Central hearing loss - Mixed hearing loss : combination of conductive and sensorineural impairments
Communication Disabilities	- Any incapacity, condition, or disease that affects a person's ability to interact and communicate. It may result in limitation in understanding, receiving, or producing a communication.
Cognitive Disabilities	- Affects areas including orientation, insight, attention, memory, abstract thinking, calculating, problem solving, and organization

2.3.1 Visual Impairment

According to the World Health Organization (WHO), people with visual impairment include those with low vision and blindness who have low vision less than 6/18, but 3/60 or more, or a corresponding loss of vision Define as More than 20 degrees with the best possible eye [21].

2.3.2 Hearing Impairment

Hearing impairment is defined as a pure tone average> 25 dB hearing level (dB HL) of the airborne hearing threshold for four frequencies (0.5, 1, 2, and 4 kHz). Unilateral hearing loss is defined as hearing loss in one ear and no hearing loss in the other. Bilateral hearing loss is defined as hearing loss in both ears [22].

2.3.3 Spinal Cord Injury

According to the American Spinal Cord Injury Association (ASIA), spinal cord injuries is the damage in interfere with communication between the brain and the body. Sensory, motor and reflex messages are affected [23].

Tetraplegia results in impairment of function in the arms, trunk, legs and pelvic organs. Paraplegia, refers to impairment of motor or sensory function in the thoracic, lumbar or sacral segments of the spinal cord, secondary to damage of neural elements within the spinal canal. Although arm functioning is possible with paraplegia, depending on the level of injury, the trunk, legs and pelvic organs may be limited for movement [23].

2.3.4 Elderlies

Elderlies face one or more obstacles to aging similar to those of people with disabilities [20]. Their needs are similar to people with multiple disabilities, including loss of muscle, vision, hearing and cognitive skills [24].

As with the rest of the body, the eye experiences many changes for aging [25]. Most of the elderly with visual impairment are not completely blind but have partial or weak vision [20].

Hearing loss is the third most common chronic disease reported by the elderly [26]. The estimated prevalence of hearing impairment among elderly people over the age of 65 is 40 to 45 percent and among people over the age of 70 exceeds 83 percent [27].

Hearing loss affects communication, and decreased communication can result to isolation and depression [28]. Hearing loss can also affect health and safety in other ways, such as failing to hear fire alarms or not being able to clearly understand how pharmacists are taking medications.

Aging itself does not necessarily prevent the use of new technologies, but some cognitive functions decline [29] [30] and motor functions and finger dexterity [31] [32]. In addition, vision, cognitive functions, and the locomotor system, may make it more difficult to use high-tech devices [33].

2.4 Washing Machines

2.4.1 Accessibility on Washing Machines

According to a survey on the accessibility of household appliances for people with disabilities and elderlies, by the Korea Electronics and Information Promotion Agency, the accessibility of many home appliances is low [34]. This report also illustrates the need for accessibility of information in consumer products as well as physical accessibility. Therefore, to achieve universal design successfully, it is necessary to provide clearer guidelines for both physical accessibility and information accessibility.

Washing machine are the most important technical appliance in the home for functioning daily activities [33]. Accessibility of appliances is defined as the availability of appliances in spite of restrictions on their use, which may be due to disability or aging. In other words, it can be defined as indicating how much people with disabilities can use household appliances, indicating that information and control of appliances are recognized, operated, and easily understood. Thus, the accessibility design of household appliances can be defined as a method of designing household appliances considering users having some physical or cognitive ability to perform, such as persons with disabilities and the elderly.

2010 ADA Standards for Accessible Design [16] provides guidelines in designing washing machines. For example, for front loading washing machines, ADA provides maximum height for operable parts to be below 48” maximum low forward reach for 15”.

2.4.2 Parts of Washing Machines

A front loading washing machine can be divided into five parts based on the function of the washing machine; moveable, non-moveable, control, display, and separable. Moveable refers to the moving part of a washing machine such as door and detergent drawer. Non-moveable refers to the tub of the machine. Control refers to the control part of the washing machine, such as dial, buttons, and touch screens. Display refers to the screen of the washing machine showing remaining time, and selected functions. The separable refers to the parts that can be detached from the washing machine such as filter. The division of the parts of a washing machine is employed in this research to identify the usage issues regarding each parts and formulating mismatch equation in the later chapters of this study.

2.5 Anthropometric Design

Anthropometry is an important element of ergonomic research to address the problem of matching tasks and products to the characteristics of the user. However, anthropometric data and those for designing ergonomic products and environments There is a gap between applications [35]. Ergonomics studies the interaction of product, person and ergonomic factors. Thus, it is becoming more important to study the application of ergonomic principles and methods of analysis, which enhance the design or use and thus reduce the hazard or risk [36].

Designers of household goods, automotive and aircraft compartments, and many similar innovations have gained access to a variety of anthropometric data. These resources provide valuable information about the range of critical body dimensions and segment movements that are invaluable to the design process [10]. Designers of products, environments, and systems need to consider the physical size and shape of the target user.

This is also called designing for physical considerations [37]. Appropriate analysis tool, as well as anthropometry and knowledge in applying the data is required for designing products that fits users body size, thus making the product easier to use.

Use of improperly designed products and workplaces that are incompatible with users' anthropometry are known as one of the factors that can increase the risk of developing musculoskeletal pain and discomfort [38, 39]. This increased risk is due to the difference in individual characteristics of anthropometric parameters, influencing the method of task performance and consequently affecting the severity and amplitude of exposure to inappropriate working postures, movements, and the forces exerted [40].

Chapter 3

Product Control Types & Washing Machine Usage

3.1 Introduction

The importance of the market created by the elderly and other consumers with limited functional capacity has been recognized by electronic consumer goods manufacturers [41]. As the need for providing barrier free environment for people with disabilities, Koncelik stated "a consumer product designed for accessibility should not impede a disabled user while interacting or manipulating it for daily use, and should experience the same ease as a normal user would." While this concept has been advocated in various research, its adoption has been limited [42].

Rahmen and Springle provided guidelines of consumer product controls for physical accessibility on six types of controls on appliances; 1) Push-button switch (finger/ palm operated) 2) Membrane keys 3) Slide switches 4) Toggle switches 5) Rocker switches 6) Rotary selectors and three types of controls on computer hardware; 1) Touch screens, 2) Mice, 3) Track ball [43]. The product components of each of the controls included characteristics such as application, design, size, spacing, force, feedback.

Vanderheiden described the concept of accessible design as an extension of general product-design principles to discuss a wide range of user abilities. Four options to achieve accessibility were offered: a) direct product accessibility; b) accessibility via standard options or accessories; c) third party assistive devices; and d) custom modification. General

examples and guidelines addressed the accessibility of outputs/ displays, inputs/controls, manipulations, documentation, and safety [5].

In this chapter, the preference in control types and usage pattern in washing machine was identified for people with visual impairment, hearing impairment, spinal cord injury, and elderly people.

3.2 Method

3.2.1 Participants

The data was collected through survey, usage testing and interviews. Participants were grouped in their disability types and were interviewed in groups. The interview focused on the usage issues regarding using washing machines in their daily lives.

A total of 52 participants with age range of 20 to 81 years participated in the survey and interview. 14 participants with nine females and five males had visual impairment. The average age of this group was 41.6 years old. 93% of the group answered that they use their right hand, however, 46% of them use their left hand to read the braille. For 11 participants, they had visual impairment grade of 1, which was 79% of the group. One participant had the disability grade of 3 while two of the participants' disability grade is unknown. 29% of the group were born with the visual impairment while 57% acquired visual impairment. In addition to auditory and tactile senses being their primary dependent sense, about 58% of the participants answered visual senses as their primary dependent sense as people with amblyopia still rely on their visual senses.

13 participants with eight females and five males with average age of 38.1 had hearing impairment. A total of 62% answered that they mainly use the right hand. Ten

participants had the disability level of 2 which were 77%, two people with disability grade 1 and one person with disability level 3. 54% of the participants were born with the hearing impairment while 46% acquired the disability. 77% of the participants used visual sense as their primary dependent sense.

A total of nine participants, three females, six males with average age of 33.6 years had Spinal Cord Injuries. 78% of the participants are right handed. Eight participants had the disability grade of 1, which was 89% of the group. All participants used visual sense as their primary dependent sense and chose auditory and tactile senses respectively.

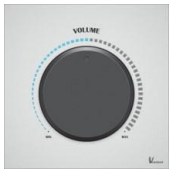
A total of 16 elderly people 11 females and five males with average age of 73.1 years old participated in this study, including housewives who mainly use household appliances. 70% were right handed and among the 16 participants, two participants acquired disability with grade 4 brain lesion and grade 5 of hearing impairment.

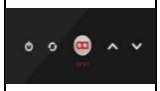
3.2.2 Control Types

Preference on 12 different types of controls in five categories were asked in the survey. The types of dials were divided into two categories depending on their discrete and continuous characteristics and the rotation limit of the dial. In Dial type I, Dial A is a dial that is round and continuous without the tactile indication of levels turned. Dial B is a round discrete dial with tactile indication of turned levels. In Dial type II, Dial C is a round continuous dial, that turns 360 degrees without endpoints, where Dial C is a round dial with both endpoints, with limited range of rotation, whereas Dial D is a round dial with both endpoints, limiting the range of rotation. For types of Switch, Switch A is a type of switch that when one side is pressed, the other side of the switch is raised. Switch B is a type to move a bar up, down, left, or right. Button A is the button that changes position after push, while Button B is a button that returns to original status, and Button C is the button that is pressed inward, that

returns to the original position. Touch control A refers to touch control with embossment surrounding the button, Touch control B is the touch control without embossment, and Touch Control C is the control that is on touch display.

Table 3.1. Product Control Types

Controls Types				
Dial Type I	 Dial A	Round Continuous dial without level indication	 Dial B	Round discrete dial with level indication
Dial Type II	 Dial C	Round continuous dial, turns 360 degrees without endpoints	 Dial D	Round dial with both endpoints, limited range of rotation
Switch		Switch when one side is pressed, the other side is raised		Toggle Switch, for moving the bar up / down / left / right

Button		Button that changes position after push		Button returning to original position		Button pressed inward, returning to original position
Touch		Touch control with embossment surrounding the button		Touch control without embossment		Touch control on touch display

3.2.3 Survey on preferred control types in Home Appliances

Survey questionnaire form were distributed to evaluate user preferences to the five categories of types. Participants were asked to choose preferred control types within each categories and were also asked to choose the most and least favored control types. By the results of Survey questionnaires and user evaluation form, the preferences of control types and opinion on the preferred control types were determined. Table 3.2 shows the survey questions.

Table 3.2. Survey Questions

Survey Questions
1. How would you rate your Participation in Household Chores (Cleaning, Laundry, Cooking, etc)? (7 point Likert Scale)
2. How would you rate your Independence in conducting Household Chores? (7 point Likert Scale)
3. What is your preference between Dial A/B and why?
4. Preference between Dial C/D &why
5. Preference between Switches &why
6. Preference among Buttons &why
7. Preference among Touch Controls &why
8. Most preferred control types &why
9. Least preferred control types &why

3.2.4 Identifying Usage Issues in Washing Machine through Usage testing and Interview

Prior to the interview, participants were asked to explore the functions and identify the usage issues regarding washing machine using Samsung WV9900 washing machine. The first step was to explore the exterior and interior of the washing machine in order for the participants to recognize functions and features of the washing machine. This step included opening and closing the door of the washing machine, pulling out the detergent drawer, and reaching inside the tub. The second step was to turn on the washing machine to further investigate the functions of the washing machine. The third step was to explore the functions by switching to different washing modes trying out the standard mode and other washing modes, such as Delicate, Perm Press, and Eco Cold. The final step was answering the interview questions shown in table 3.3. The usage testing procedure is illustrated in figure 3.1.

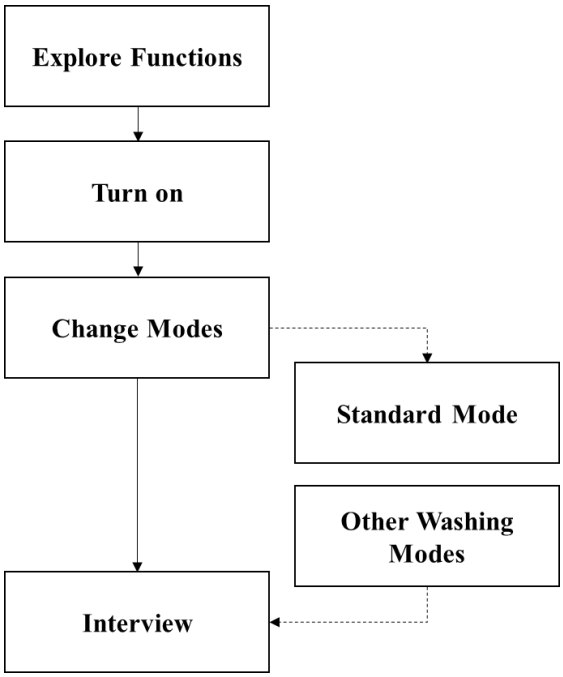


Figure 3.1. Usage Testing Procedure

Table 3.3. Interview Questions

Interview Questions
1. Do you face any difficulties in preparing for using Washing Machine?
2. Difficulties in using Washing Machines?
3. Difficulties in learning about the use of Washing Machines?
4. Difficulties after using Washing Machines?
5. Difficulties in maintaining/cleaning Washing Machines?
6. Other Issues regarding Washing Machines?

The interview was carried out in a form of focused group interview, allowing participants to freely exchange their thoughts and develop their answers by adding on to each other's responses. The overall discussion focused on the usage issues regarding using washing machines in their daily lives. For people with hearing impairment, participants were enabled to respond with sign language as sign language was interpreted through an interpreter or to write down their answers.

Figure 3.2. Scene of participants with spinal cord injury exploring washing machines during usage testing procedure

3.3 Results

3.3.1 Survey Results

3.3.1.1. Participation and Independence in Household chores

The descriptive statistics of the level of the participation in household chores and the level of Independence in household chores are shown in table 3. Participation in household activities ranged from participants actively engaging in house chores to those not participating housework at all, but mostly participation level was above 4 points on 7 point Likert Scale. Participants who have visual impairment, hearing impairment, and elderlies showed active participation in housework, whereas participants with Spinal Cord Injuries were less active due to their physical limitations. Most participants have high self-sufficiency in daily life. In spinal cord injured people, the degree of self-reliance in daily life is similar to that of other groups.

Table 3.4. Descriptive Statistics of Level of Participation and Independence in House chores among participant groups

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval		Min	Max
						Lower	Upper		
Level of Participation	Elderlies	16	5.50	1.414	0.354	4.75	6.25	3	7
	Visually Impaired	14	5.00	2.112	0.565	3.78	6.22	1	7
	Spinal Cord Injured	9	3.33	1.414	0.471	2.25	4.42	2	5
	Hearing Impaired	13	5.62	1.387	0.385	4.78	6.45	3	7
	Total	52	5.02	1.777	0.246	4.52	5.51	1	7
Level of Independence	Elderlies	16	5.63	1.784	0.446	4.67	6.58	1	7
	Visually Impaired	14	6.50	0.760	0.203	6.06	6.94	5	7
	Spinal Cord Injured	9	5.00	1.118	0.373	4.14	5.86	3	6
	Hearing Impaired	13	5.85	1.144	0.317	5.16	6.54	4	7
	Total	52	5.81	1.358	0.188	5.43	6.19	1	7

3.3.1.2. Statistical Analysis on Preference in Control Types

In analyzing the difference in preference for each control types on disability., Kruskal-Wallis Test was conducted using SPSS Statistics 24. For preferred Button and Touch control, the preferred types were different among disability type.

Table 3.5. Result of Kruskall-Wallis Rank regarding preference of control types between disability types

Rank			
Disability Type		N	Average Rank
A. Preferred Dial I	1	15	25.60
	2	14	29.00
	3	9	23.33
	4	13	25.08
	Total	51	
B. Preferred Dial II	1	15	21.83
	2	14	28.50
	3	8	25.38
	4	13	26.58
	Total	50	
C. Preferred Button	1	16	25.88
	2	13	17.31
	3	9	25.17
	4	13	35.42
	Total	51	
D. Preferred	1	15	23.30
	2	11	27.23

Switch	3	9	29.17
	4	13	20.35
	Total	48	
E. Preferred Touch	1	15	30.80
	2	14	16.50
	3	9	28.50
	4	13	28.96
	Total	51	

Table 3.6. Kruskall-Wallis Test Statistics regarding preference of control types between disability types

Test Statistics					
	A. Dial I	B. Dial II	C. Button	D. Switch	E. Touch
Chi-Square	2.955	5.091	11.584	4.748	11.149
Df	3	3	3	3	3
Asymp. Sig.	0.399	0.165	0.009	0.191	0.011

From the result of Kruskall-Wallis Test, when statistical significance is shown in $\alpha = 0.05$, the preference in Button types and Touch Control types showed significant difference between disability types as $p = 0.009$ for preference in button types and $p=0.011$ in preference of touch types.

As the preferred control types and disability types are both categorical data, in order to identify the correlation between the most preferred control type and types of disability, Cross Tabulation Analysis and Chi-Square Test was conducted to identify the difference in most preferred control types among disability types.

Table 3.7. Cross Tabulation Analysis on preferred control types and disability types

Cross Tabulation Analysis							
			Most Preferred control type A. Dial B. Button C. Switch D. Touch				Total
			A	B	C	D	
1Elderly 2Visual 3Spinal 4Hearing	1	F	0	1	0	6	7
		%	0.0%	14.3%	0.0%	85.7%	100.0%
	2	F	6	0	3	1	10
		%	60.0%	0.0%	30.0%	10.0%	100.0%
	3	F	1	1	0	7	9
		%	11.1%	11.1%	0.0%	77.8%	100.0%
	4	F	5	0	0	7	12
		%	41.7%	0.0%	0.0%	58.3%	100.0%
Total		F	12	2	3	21	38
		%	31.6%	5.3%	7.9%	55.3%	100.0%

Table 3.8. Chi-Square Test on preferred control types and disability types

Chi-Square Tests			
	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	23.302[a]	9	0.006
Likelihood Ratio	27.276	9	0.001
N of Valid Cases	38		

From the cross tabulation analysis and chi-square test, significant difference was found in the most preferred control types within disability types as p=0.006. In order to identify the difference in preferred control types, quantitative analysis was conducted with the opinions on preferred control types.

3.3.1.3. Analyzing user comments on preference

From the Survey questionnaire, user preference on the five control categories were identified. The preferences of people with disability and elderly people in control types and opinion on the each of the control types were collected. The comments were analyzed for each disability types for each of the control categories according to the performance usability dimensions to analyze the comments into usability performance.

To identify user performance of a product, the following performance dimension was used in this study. The performance dimensions are classified into three categories. Perception/Cognition refers to the usability dimension adaptable to evaluate how users interpret and perceive the product. Learning/Memorization dimension represents to how users get used to the product in a timely manner and how well they memorize the functions. The Control/Action category explains that shows control activity of users and its results. [44]. The comments regarding the preference of each control types are classified into

usability performance dimension in order to discern the usability factor regarding the preference of each control types.

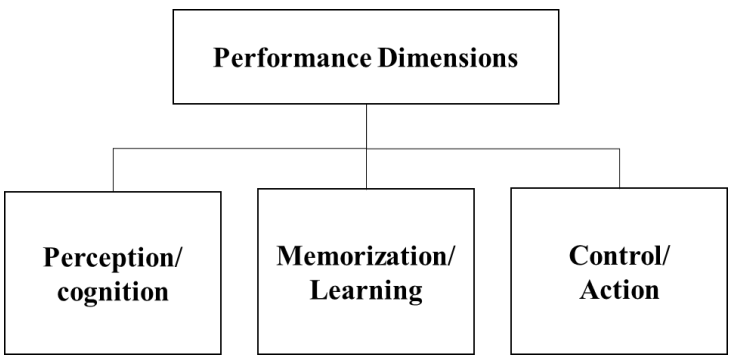


Figure 3.3. Usability Performance Dimensions (Han, 2000)

Visual Impairment

By analyzing the comments on preferred control types, it was shown that the people with visual Impairment prefers controls that can be distinguished by tactile senses as they rely on memorizing ways to use a control, thus preferring controls that are familiar to each of the users. As a way to overcome the visual impairment, the main senses used by people with visual impairment are tactile and auditory senses [45]. Comments regarding Perception/Cognition focuses on the ability to distinguish levels on dials through tactile senses. Understanding and confirming the state after operation and familiarity of control types were important in Memorization/Learning dimension. For Control/Action dimension, people with visual impairment preferred control types that are easy to control.

The most preferred type of controls among people with visual impairment are the controls that gives clear feedback after the operation and those that are easy to operate. The

least preferred types of controls were control types that does not provide indication or controls that does not offer other types of feedbacks such as auditory and tactile feedbacks.

Table 3.9. Comments on preferred control types of people with visual impairment

	Comments	Performance Dimension
Dial A/B	Able to sense stepwise level Easy to know level of adjustment	Perception/Cognition
Dial C/D	Can distinguish steps Easy to identification of control points	Perception/Cognition
Button	It is easy to understand the state. Familiar with the feeling	Memorization/Learning
Switch	Easy to understand Familiar with the control	Memorization/Learning
Touch Control	Can be distinguished by tactile sense	Perception/Cognition

Most Preferred	Able to confirm the operation	Memorization/Learning
	Easy to control	Control/ Action
Least Preferred	Dial that turns without indication is unstable to use Doesn't provide auditory feedback	Perception/Cognition

Hearing Impairment

From the comments on preferred control types, people with Hearing Impairment prefers controls that provides visual feedback through limit range or displays. Comments regarding Perception/Cognition included being able to visually confirm the state of the control, showing accurate visual range or display. Comments on Memorization/Learning includes points on familiarity and ease of understanding the usage. For Control/Action dimension, comments included Safeness and ease of control.

The most preferred type of controls among people with hearing impairment are the controls that that are easy to find and controls having familiar method of use, thus having fewer malfunction concerns. The least preferred types of controls are those that are inconvenient to check the adjustment indication and having unintuitive method of use and layout making it hard to operate the control. Moreover, they answered they face difficulties with controls that lacks feedback.

Table 3.10. Comments on preferred control types of people with hearing impairment

	Comment	Performance Dimension
Dial A/B	Able to see the control clearly	Perception/Cognition
	Comfortable because it can be adjusted sequentially	Memorization/Learning
	Easy to control	Control/ Action
Dial C/D	Visually accurate range display because you can not hear sound	Perception/Cognition
Button	Can be verified from original location	Perception/Cognition
	Familiar and Clear on whether it is visually ON form or OFF form.	Memorization/Learning Perception/Cognition
Switch	Marking is easy to understand	Memorization/Learning
	Safer	Control/ Action

Touch Control	Touch button is easy to distinguish	Perception/Cognition
Most Preferred	Easy to find	Perception/Cognition
	Usage method is the same familiar thus having fewer malfunction concerns	Memorization/Learning
Least Preferred	It is inconvenient to check whether the level adjustment indication is correct or not. Unintuitive ambiguous positioning	Perception/Cognition
	No feedback	Memorization/Learning
	Difficult to operate	Control/ Action

Spinal Cord Injury

According to the comments regarding preferred control types, it was shown that people with Spinal Cord Injury prefers controls that requires less finger use, thus preferring controls that can be pressed without force due to limited use of their hands. Comments on Perception/Cognition dimension included ease of recognition of control. Regarding

Memorization/Learning dimension, they preferred controls that are familiar and provides clear feedback. For Control/Action dimension, controls that provides less concern on making error, and controls that does not require micro-manipulation were preferred.

The most preferred control types for people with Spinal Cord Injury were the controls that can be pressed without force. The least preferred control types were controls that are difficult to distinguish the method of use or status of the control, and controls that requires use of finger.

Table 3.11. Comments on preferred control types of people with spinal cord injury

	Comment	Performance Dimension
Dial A/B	Easy to recognize can not move my fingers, so I can tell how exactly it is turning by fist	Perception/Cognition
	Provides numerical value	Memorization/Learning
Dial C/D	Familiar	Memorization/Learning
	Range is fixed	Control/ Action
Button	Able to confirm control	Memorization/Learning
	Less concern for making an error	Control/ Action
Switch	Easy to recognize on / off	Perception/Cognition

	Easy to use due to difficulty in using fingers	Control/ Action
Touch Control	Easy to recognize	Perception/Cognition
	Convenient as it doesn't require micro-manipulation	Control/ Action
Most Preferred	Controls that can be pressed without force	Control/ Action
Least Preferred	Hard to distinguish	Perception/Cognition
	Difficult to touch, requires finger use	Control/ Action

Elderly People

From the comments on preferred control types for Elderly People, this group prefers controls that are simple, that does not require memorizing in utilizing the controls. They prefer controls that are easy to recognize due to their degeneration of senses caused by aging. Specifically, as the age increases, the physical senses such as accuracy, tuning ability, and posture maintenance are reduced and it becomes difficult to operate controls that requires micro-manipulation such as the remote controller [33]. Comments on Perception/Cognition dimension includes easily visible state of controls and comments on Memorization/Learning includes familiarity and helpful feedback. Finally, controls that are easy to operate were preferred and classified as comments on Control/Action dimension.

The most preferred control types for people Elderly People were the controls that shows clear indication that are easily recognizable and controls that are familiar. The least preferred control types were controls that are complicated and hard to use for older people when the indications such as letters are too small. Moreover, Elderly People showed least preference in controls required memorization for usage.

Table 3.12. Comments on preferred control types of Elderly People

	Comment	Performance Dimension
Dial A/B	Able to feel the gradual change in dial	Perception/Cognition
	Easy to operate in order	Control/ Action
Dial C/D	Easily visible	Perception/Cognition
	Indication on both ends are helpful	Memorization/Learning
Button	clearly see the pressed state at a glance	Perception/Cognition
	Easy to operate	Control/ Action
Switch	Clearly see the state	Perception/Cognition
Touch Control	Used in daily lives (ATM, Smart phones)	Memorization/Learning
	Operates with one touch	Control/ Action
Most Preferred	As it is written, it is	Perception/Cognition

	accurate by pressing, it is seen by eyes	
	Familiar	Memorization/Learning
Least Preferred	Buttons are complicated hard to use for older people since the letters are too small.	Perception/Cognition
	Hard to memorize	Memorization/Learning

3.3.1.4. Analyzing user comments on preference

Interview on washing machine usage was analyzed regarding the feature of the five parts of the washing machine in order to identify the usage issues related to each parts.

Visual Impairment

For people with visual impairment, information accessibility was found to be weaker than physical accessibility. They had difficulties in understanding feedbacks after manipulation, understanding the state of current progress while using washing machines. Moreover, people with visual impairment found it difficult to use washing machines independently, due to the high cognitive demands such as learning and memory. As they rely heavily on tactile senses and auditory feedback, current washing machines in market do not accommodate to people with visual impairment. Furthermore, due to the difficulties in learning various functions of washing machines, people with visual impairment tend to only use basic features while showing high concern in error or malfunction while using washing machines.

Table 3.13. Usage Issues on functional Parts of Washing Machine for People with Visual Impairment

	Comments
Moveable	"I want the detergent, and softener drawer to be separated. I have a cell in the same container." "I think the detergent draw particularly uncomfortable for someone who can't see. It is too small, so I can't tell if I had put the reasonable amount to it."
Non - Moveable	"My Body becomes unstable after taking out laundry. If the tub is wide and rather shallow in depth, it would be easier to take out the remaining laundries"
Control	"Operation function, operation status, current washing step, etc. are all visual information only." "It is impossible to visualize and depend on memory, and the more functions and steps are difficult."
Display	"I wish there were features such as voice recognition / voice guidance."
Separable	"It's hard to pull it out, it's a little hard to separate it."

Hearing Impairment

For people with hearing impairment, similar to the people with visual impairment, the need for improvement in information accessibility was found. As people with hearing impairment use sign language as a way of communication, they show limited understanding in language. Thus, comprehending the functions and reading the manuals was a challenge.

Table 3.14. Usage Issues on functional Parts of Washing Machine for People with Hearing Impairment

	Comments
Moveable	"When the house is narrow, it closes the door and gets caught by other objects or children. If the door slides up, it seems to save space Front loading washing machine takes up space when you open the door."
Non - Moveable	"I often miss out on one or two small pieces of laundry."
Control	"The washing machine dial indicator is too small." "I would like to put the control part of the washing machine to the front. People with short arms are uncomfortable."
Display	"Since I can't hear the sound, so I want to see it as a phrase, a picture or a video." "Smart check function, water-repellent care, etc. I do not know the exact meaning of the vocabulary function."
Separable	"I would like to be informed about the degree of contamination inside the washing machine and the time of filter replacement by an alarm or guidance."

Spinal Cord Injury

For people with spinal cord injury, unlike people with visual and hearing impairment where they lacked one of their senses, the need for improvement in physical accessibility was pivotal as their body is limited in a wheelchair. Depending on the severity of their injuries, some had a condition of paralysis including their waist. Thus, approaching washing machine in parallel approach in order to avoid the blocking of the washing machine door without having to bend their waist. Furthermore, some participants had restricted use of hand due to the condition of their injury, thus controls requiring finger use were not accessible for such participants.

Table 3.15. Usage Issues on functional Parts of Washing Machine for People with Spinal Cord Injury

	Comments
Moveable	"Enough force to pull the handle, but it is difficult to hold." "The force required to open the door is difficult to open. Wheelchair access difficult." "Full automatic door is difficult to open and close because of its high position." "Washer door blocked wheelchair access. I do not know that I can change the direction of the washing machine door." "Washer doors should not obstruct wheelchair access and provide adequate circulation." "Detergent Drawer is too high."
Non - Moveable	"The washed laundry is heavy and difficult to pull out." "It is likely to be easier if you do not need to bend because the height is not low."

	"Uncomfortable to use front loading since it requires me to bend my waist." "Can't bend waist, only side access to the washing machine is possible." "The inside of the washing machine can't be visually confirmed."
Control	"Easy to use if the resistance to dialing is appropriate." "Access is not possible if the control panel is in the rear position."
Display	"Side access restricts view." "Need products to reduce cognitive and physical effort."
Separable	"The filter is too low to reach."

Elderly People

Table 3.16. Usage Issues on functional Parts of Washing Machine for Elderly People

	Comments
Moveable	"As we get older, we lose strength and it's hard to get heavy things." "Need to perform tasks that require strength and a lot of action when bending." "Decreased muscle strength due to aging makes it harder to open a tight door." "Does not provide guideline for appropriate detergent use."
Non - Moveable	"Difficult access to the deep position of fingers." "Didn't know tub wash function."

	"The remaining laundry is stuck in the washing machine and the remaining laundry is difficult to remove." "It takes a lot of power to wipe off dirt, and there is a lack of perception of the flushing function and filter cleaning."
Control	"Option names are not intuitive and difficult to understand if you do not speak English." "The interface is complex." "Menu is complex and there are too many options."
Display	
Separable	"I didn't know I had to clean the filter."

3.4 Discussion and Conclusion

3.4.1 Summary of findings

In this chapter, the preference in control types and usage pattern in washing machine was identified for people with visual impairment, hearing impairment, spinal cord injury, and elderly people. The opinions on preference in control types, and interview results were also examined. As a result, we were able to identify that the improvement in information accessibility is needed for people with visual impairment, hearing impairment, and elderlies. For visually impaired people, providing auditory and tactile feedback necessary in order to ensure accessibility. For people with hearing impairment, requiring visual feedback is necessary and elderly people faced difficulties in cognition, and degeneration of their senses.

However, for the people with spinal cord injury, enhancing physical accessibility was necessary as their body is limited in wheelchair. Furthermore, depending on the level of the condition, people with spinal cord injury have limited movement range of waist and hands. Thus accessing washing machine with parallel approach and prefers controls that requires less finger use due to limited use of hands.

3.4.2 Possible Design Considerations

This study proposes the following considerations on controls to enhance accessibility and better accommodate people with disabilities.

- For people with visual impairment and hearing impairment, the status of the control panel, current status or location must be easily perceived, by proper use of visual, auditory, and tactile senses.
- For people with hearing impairment, and spinal cord injury, feedback on malfunctions should be clear.
- Easy to operate and to avoid malfunction (spinal cord injury, elderly person)
- Adapting voice recognition in home appliances. However, along with the voice recognition, tactile alternatives are also needed.

Chapter 4

Anthropometric mismatch of Washing Machines for people with spinal cord injuries

4.1 Introduction

Improvement in healthcare services leads to elderly people living active and independent lives [15]. Various studies have been conducted to analyze the anthropometric characteristics of people with disabilities and elderlies.

4.1.1 Research related to designing for the elderly and people with disabilities.

For a universally convenient environment and product design, accurate structural anthropometric measurements for both healthy and disabled people are needed [46].

Numerous studies have been conducted to examination the anthropometric characteristics of elderly or people with disability and evaluate the anthropometric suitability for various products and designs. Kenwaed used the anthropometric measures of young wheelchair users to design wheelchair [47]. Moreover, anthropometric measures of elderly population was used to design Domestic furniture and appliances [48], and anthropometric measures of elderly and people with disabilities were used to design praying facilities [49]. Goswami studied Tricycle Design with anthropometric data of Men with disabilities [50]. Anthropometric measures of people with disabilities were used for workspace Design [51] [52] and for designing seating of mobility devices [10].

There is a growing need for universal design that emphasizes the importance of integrating the elderly people and the people with disabilities [53]. Following this approach, including elderly people and people with disabilities in the design expands the market for product or system [54]. This result is particularly important from a design point of view, as researchers point out the differences in structural and functional anthropometric dimensions between healthy and disabled people [55]. However, anthropometric data derived from the adult population may also not be applicable to the elderly, as the aging process involves significant changes in anthropometric variables [56].

As a result, the lack of anthropometric data from the elderly and disabled limits the ability of designers to create safe and effective products and environments for a wide range of users [10]. It is clear that with rapidly aging population, further research is needed to design products and environments specific to this population [35]. In this study, mismatch analysis was conducted for the washing machine based on Anthropometric data of Korean people using a wheelchair.

4.2 Method

4.2.1 Washing Machine

In this study, mismatch analysis was conducted for the Washing Machine based on Anthropometric data of Korean people using wheelchair.

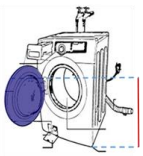
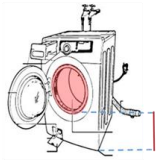
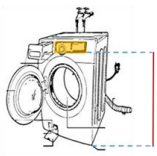
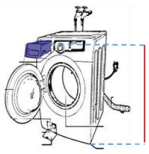
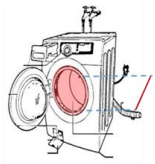
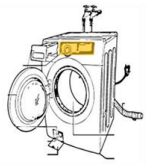
Moveable		Non - moveable		Display & Control	
Door Handle Height **(DHH)**		Tub Height **(TH)**		Display & Control Height **(DCH)**	
Detergent Drawer Height **(DDH)**		Tub Depth **(TD)**		Control Layout **(CL)**	

Figure 4.1. Illustration of Washing Machine dimensions considered in this study. Door Handle Height (DHH): Vertical length to upper door handle height from the floor; Tub Height (TH): Vertical length to the lowest point of tub from the floor; Display & Control Height (DCH): Vertical length to the display &Control Height from the floor; Detergent Drawer Height (DDH): Vertical length too detergent drawer height from the floor; Tub Depth (TD): Horizontal length of the tub; Control Layout (CL): Size and distance of controls

4.2.2 Anthropometric data

This study employed anthropometric data measured by the National Anthrompometric survey. Anthropometric data of 565 Korean wheel chair users were used, aged from 11 to 62 years old with 339 females and 226 males. Among the anthropometric measures for Koreans, the data of the following six anthropometric measures were selected: Minimum side reaching height with obstacle 250mm (Min SRH); Maximum side reaching height with obstacle 250mm (Max SRH); Knee Height (KH); Fist length from the wall (FLFW); Shoulder Height (SH); and eye level. The descriptive statistics of the six anthropometric measures are shown in Table 4.1. As from the findings of previous chapter, approaching washing machine in parallel approach in order to avoid the blocking of the washing machine door without having to bend their waist. Moreover, in order to give allowance due to the size of the wheelchair, anthropometric data of side reach with side reach height with obstacle 250mm is used in this study.

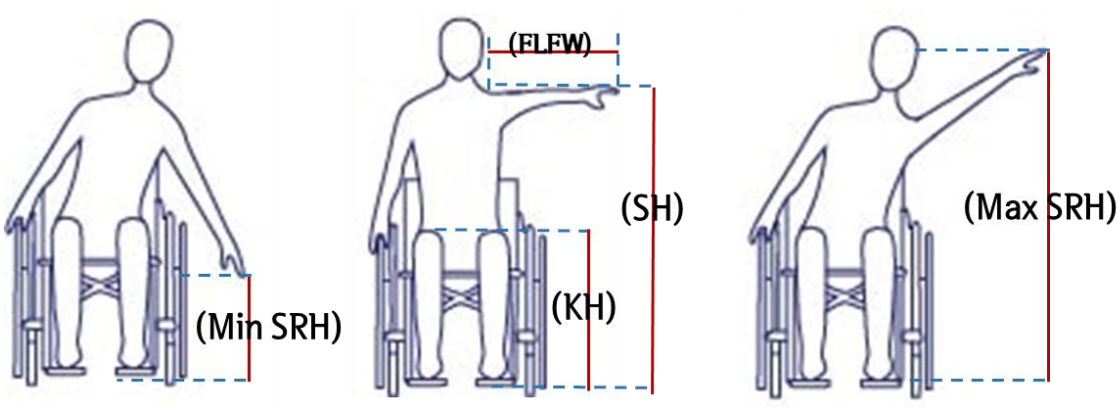


Figure 4.2. Anthropometric measures used in this study. Minimum side reaching height with obstacle 250mm (Min SRH); Maximum side reaching height with obstacle 250mm (Max SRH); Knee Height (KH): Vertical distance measured from the bottom surface to the base of the tibia in wheelchair; Fist length from the wall

(FLFW); Shoulder Height (SH): Height from floor to shoulder in sitting posture in wheelchair; Eye Level: Height from floor to eyeball in a wheelchair

Table 4.1. Anthropometric Measures of Korean people using wheelchair

Descriptive Statistics	Max SRH (mm)	Min SRH (mm)	EL (mm)	KH (mm)	FLFW (mm)	SH (mm)
5th	1032.2	57.2	927.2	488.6	525.2	877
50th	1418	242	1079.5	579	619	1013.5
95th	1666.9	513.8	1237.7	675.9	703.9	1174.7
Mean	1392.6	255.5	1079.7	581.4	615.9	1019
Median	1417	239.5	1084	579.5	617.5	1015.5
SD	186.1	148.9	94.3	56.7	53.8	110.1

4.2.3 Mismatch equations of Washing Machine Parts

The Mismatch equations of Washing Machines define the minimum and maximum limit of the furniture dimensions by using anthropometric measures. In this study, mismatch equations for DHH, DHH, TH, and DCH are proposed, while providing design guideline on TD and CL.

4.2.3.1 Mismatch Equation for Moveable Parts: Door Handle Height & Detergent Drawer Height

Locating objects to be handled below waist height increases injury risk, Where loads are manually handled, they should be stored at waist height rather than on the floor or above shoulder height [57]. Therefore, the DHH and DDH must be located over minimum reach and waist height, thus requiring loads to pull the moveable parts, while located lower than the maximum reach but should not be higher than the shoulder height, as the comfortable

reach zone when seated on a wheelchair is between 900 mm and 1200 mm [58]. The following equation is proposed for DHH and DDH.

$$\mathbf{KH \leq DHH \leq SH}$$

$$\mathbf{Minimum\ reach \leq DHH \leq Maximum\ reach}$$

$$\mathbf{KH \leq DDH \leq SH}$$

$$\mathbf{Minimum\ reach \leq DDH \leq Maximum\ reach}$$

4.2.3.2 *Mismatch Equation for Non-Moveable Part: Tub Height*

ADA provides guideline on front loading machines suggesting that the bottom of the opening to the laundry compartment located 380 mm minimum 915 mm maximum above the finish floor [16] However, as the 5th percentile of Minimum side reach range of Koreans using wheelchair is 57.5mm and the 95th percentile of maximum side reach range is 1666.9mm, the guideline is not directly applicable. As the maximum comfortable reach zone seated on wheelchair is SH, TH must be located between minimum side reach range in order to grab the laundry inside the tub. Therefore, the following equation is proposed for TH.

$$\mathbf{Minimum\ reach \leq TH \leq SH}$$

4.2.3.3 *Non-Moveable Part: Tub Depth*

The maximum parallel reach range of people with wheelchair is 500 mm when bending waist [58]. Due to the physical limitations for people with Spinal Cord Injuries, depending

on the level of injury, the bending posture may not be possible for some. In order to fully accommodate people with Spinal Cord injury with limited movement of their waist, for users to reach the further end of the tub of the washing machine, using the FLFW of 5th percentile 525.2 mm, considering the allowance of 250mm the TD is proposed as followed.

$$\text{TD} \leq \mathbf{275mm}$$

However, the dimensions of existing TD of washing machines have significant difference compared to following equation, thus it may not be applicable to generate the volume of the washing machine, therefore, the above equation is not used for evaluating mismatch of anthropometric data of wheelchair users and existing washing machines.

4.2.3.4 *Mismatch Equation for Control Part: Display & Control Height*

The mismatch equation of DCH was formulated using the lower eye sight and maximum reach height. Lower eye sight was calculated through Eye Level by setting the distance from user to object as 550mm, by adding obstruction of 250mm to 300mm, half the width of average wheelchair. The angle of comfortable sight range without neck movement range from 25 degrees above normal line of sight to 35 degrees under normal line of sight [59]. Thus, using the distance measure of 550mm and sight range, lower eye sight can be obtained.

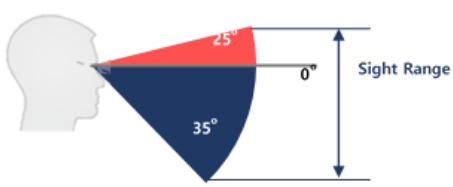


Figure 4.3. Comfortable sight range without neck movement

Lower eye sight ≤ Touch DCH ≤ Max SRH

4.2.3.5 *Display & Control Layout*

Due to the limited use of hand for people with Spinal Cord Injuries, controls must be accessible with hands other than fingers. As people with spinal cord injuries commonly use their metacarpal when operating product controls, by using the dimension of metacarpal, the minimum size of the control can be proposed. As controls and displays operate with slight pressure or touch, based on the hand thickness of 30.83mm with 95th percentile of men the following constraint is proposed.

Table 4.2. Hand thickness (metacarpal) of Korean Male and Females

(mm)

Hand Thickness (Metacarpal)	Male	Female
5 %tile	24.63	21.98
95%	**30.83**	28.02

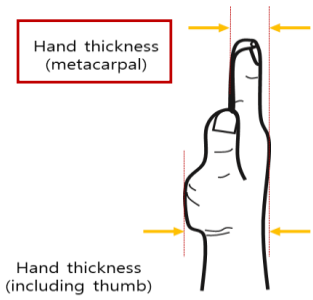


Figure 4.4. Hand thickness (metacarpal)

$$30.83 \leq \text{Control Diameter}$$

Using the above proposed equations, in order to find the mismatch between anthropometric measures and existing washing machines, five household washing machines were analyzed. Table 4. 3. Shows the dimension of washing machines used for evaluation.

Table 4.3. Dimension of Washing Machines used for evaluation

Model	DHH (mm)	DDH (mm)	TH (mm)	DCH (mm)
SEW-HQW111T	540	700	250	720
WD19H9400KW	690	840	360	965
FR1017WC	520	790	200	850
WKG120	520	655	230	750
WMY91283LB3	610	760	250	760

4.3 Results

4.3.1 Mismatch of Door Handle Height

In order to calculate the minimum DHH, comparing the values of Knee Height and Minimum reach, lower value of each of the wheelchair users was used to analyze the mismatch condition. Likewise, the maximum DHH was retrieved by comparing the values of Should Height and Maximum reach for each of the wheelchair users.

Figure 4. 5 and Table 4.4 shows the percentage of the mismatched anthropometric measures of wheelchair users in Korea, for each of the washing machine on DHH. SEW-HQW11T matched 23.11% while there were 76.89% mismatch as a result of the door handle height positioned too low for the wheelchair users. WD19H9400KW matched with 95.90% of the wheelchair users, whereas 3.46% of the users found the door handle height too low, and 0.65% of the users found the height too high. As FR1017WC and WKG120 had the same measurement of DHH, for both washing machine, 15.15% of the users matched, while

84.85% mismatched due to the height being too low. WMY91283LB3 matched with 33.05% of wheelchair users, while 66.74% of the users found the height too low, and 0.22% of the users found the height too high.

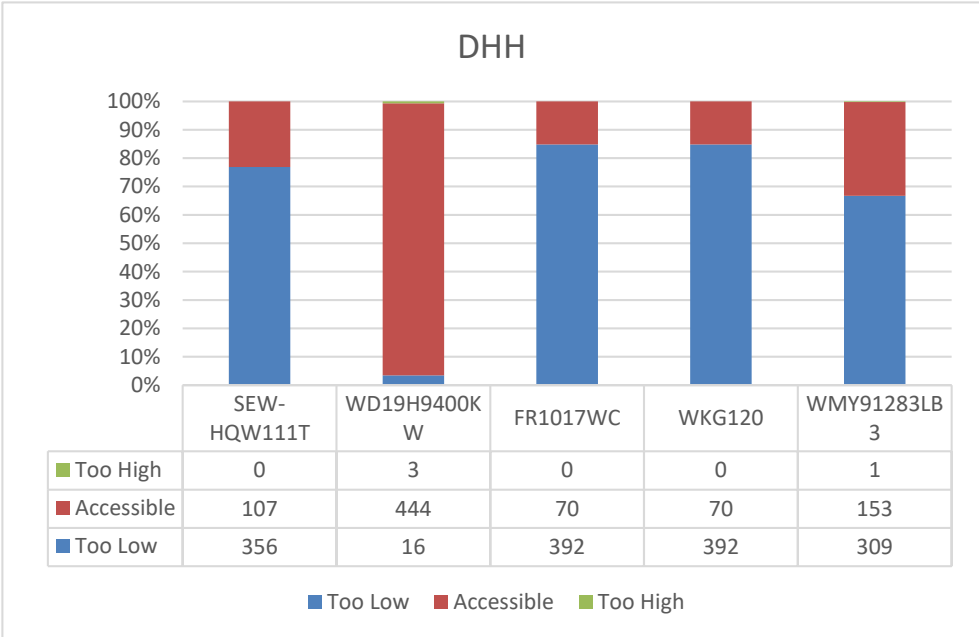


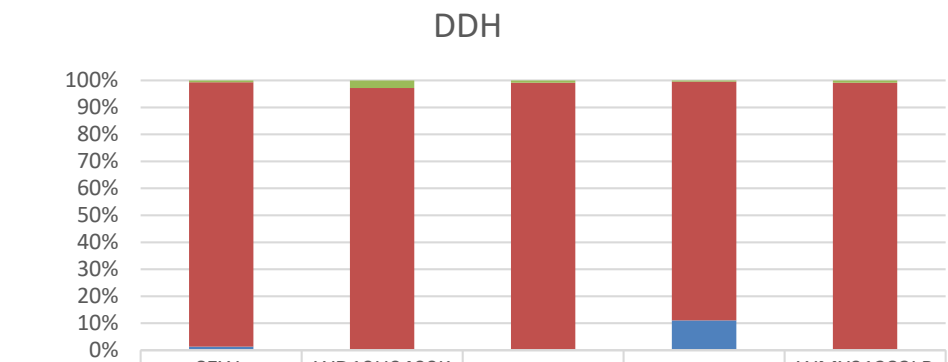
Figure 4.5. Percentage and number of mismatch anthropometric measures of wheelchair users for each of the Washing Machine on DHH.

Table 4.4. Percentage of mismatch anthropometric measures of wheelchair users for each of the Washing Machine on DHH

	SEW-HQW111T	WD19H9400KW	FR1017WC	WKG120	WMY91283LB3
Too Low	76.89	3.46	84.85	84.85	66.74
Accessible	23.11	95.90	15.15	15.15	33.05
Too High	0.00	0.65	0.00	0.00	0.22

4.3.2 Mismatch of Detergent Drawer Height

Figure 4.6 and Table 4.5 shows the percentage of mismatched anthropometric measures of wheelchair users for each of the Washing Machine on DDH. SEW-HQW11T matched 98.06% while there were 1.30% mismatch as a result of the height positioned too low for the wheelchair users. 0.65% mismatch was due to the height positioned too high for users. WD19H9400KW matched with 97.19% of the wheelchair users, whereas 2.81% of the users found the door handle height too high. FR1017WC matched 99.13% of the users, while 0.87% of the users were mismatched due to the height being too high. WKG120 matched 88.53% of the users while 11.04% of the users found the height too low and 0.43% of the users found the height too high. WMY91283LB3 matched with 99.13% of wheelchair users, while 0.87% of the users found the height too high.



	SEW-HQW111T	WD19H9400KW	FR1017WC	WKG120	WMY91283LB3
Too High	3	13	4	2	4
Accessible	454	450	458	409	458
Too Low	6	0	0	51	0

Figure 4.6. Percentage and number of mismatch anthropometric measures of wheelchair users for each of the Washing Machine on DDH.

Table 4.5. Percentage of mismatch anthropometric measures of wheelchair users for each of the Washing Machine on DDH

	SEW-HQW111T	WD19H9400KW	FR1017WC	WKG120	WMY91283LB3
Too Low	1.30	0.00	0.00	11.04	0.00
Accessible	98.06	97.19	99.13	88.53	99.13
Too High	0.65	2.81	0.87	0.43	0.87

4.3.3 Mismatch of Tub Height

Figure 4. 7 and Table 4.6 shows the percentage of mismatched anthropometric measures of wheelchair users for each of the Washing Machine on TH. SEW-HQW11T matched 52.48% while there were 47.52% mismatch as a result of the height positioned too low for the wheelchair users. WD19H9400KW matched with 77.97% of the wheelchair users, whereas 22.03% of the users found the door handle height too low. FR1017WC matched 40.48% of the users, while 59.52% of the users were mismatched due to the height being too low. WKG120 matched 47.84% of the users while 52.16% of the users found the height too low. WMY91283LB3 matched with 52.48% of wheelchair users, while 47.52% of the users found the height too low.

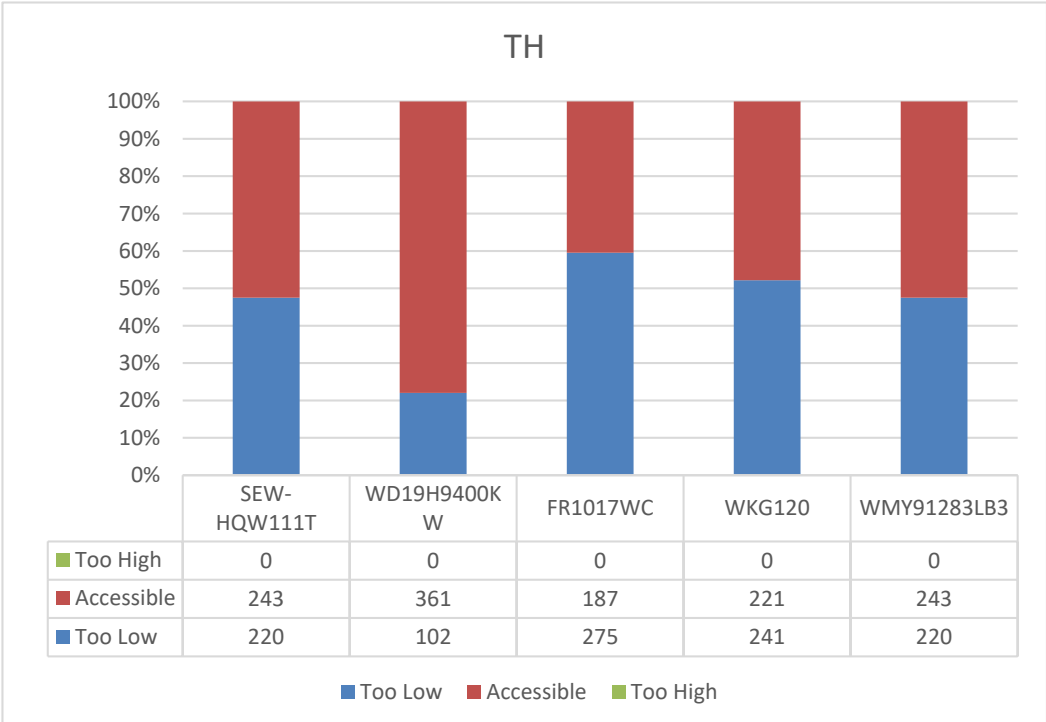


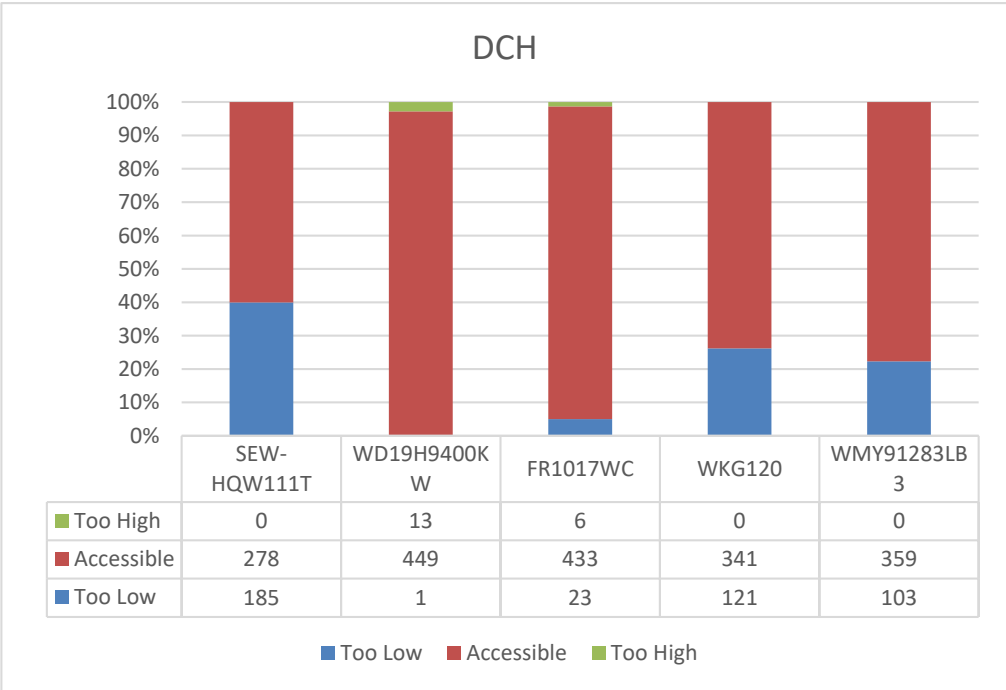
Figure 4.7. Percentage and number of mismatch anthropometric measures of wheelchair users for each of the Washing Machine on TH

Table 4.6. Percentage of mismatch anthropometric measures of wheelchair users for each of the Washing Machine on TH

	SEW-HQW111T	WD19H9400KW	FR1017WC	WKG120	WMY91283LB3
Too Low	220	102	275	241	220
Accessible	243	361	187	221	243
Too High	0	0	0	0	0

4.3.4 Mismatch of Display and Touch Control Height

Figure 4. 8 and Table 4.7 shows the percentage of mismatched anthropometric measures of wheelchair users for each of the Washing Machine on DCH. SEW-HQW11T matched 60.04% while there were 39.96% mismatch as a result of the door handle height positioned too low for the wheelchair users. WD19H9400KW matched with 96.98% of the wheelchair users, whereas 0.22% of the users found the too low and 2.81% of the users found the DCH too high. FR1017WC matched 93.72% of the users, while 4.98% of the users were mismatched due to the height being too low and 1.30% of the users were mismatched due to the height being too high. WKG120 matched 47.84% of the users while 52.16% of the users found the height too low. WMY91283LB3 matched with 77.71% of wheelchair users, while 22.29% of the users found the height too low.



	SEW-HQW111T	WD19H9400KW	FR1017WC	WKG120	WMY91283LB3
Too High	0	13	6	0	0
Accessible	278	449	433	341	359
Too Low	185	1	23	121	103

Figure 4.8. Percentage and number of mismatch anthropometric measures of wheelchair users for each of the Washing Machine on DCH

Table 4.7. Percentage of mismatch anthropometric measures of wheelchair users for each of the Washing Machine on DCH

	SEW-HQW111T	WD19H9400KW	FR1017WC	WKG120	WMY91283LB3
Too Low	185	1	23	121	103
Accessible	278	449	433	341	359
Too High	0	13	6	0	0

4.4 Analysis of anthropometric mismatch

Figure 4.9 shows the percentage of mismatched wheelchair users for DHH, DDH, TH, and DCH with each of the washing machine. As shown in figure 4.8, WD19H9400KW showed the lowest mismatched percentage, having the highest match rate, as the dimensions for DHH, DDH, TH, DCH were all bigger than other types of washing machine.

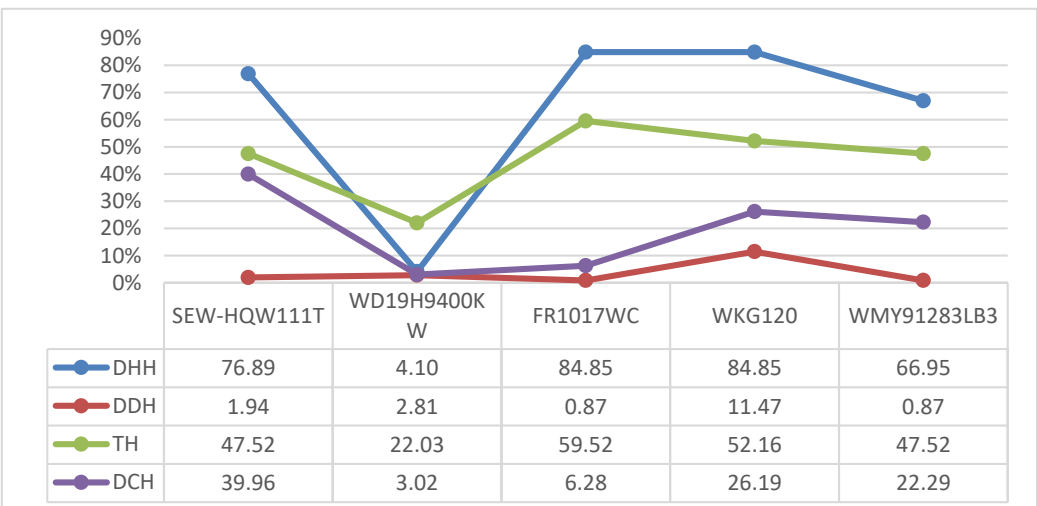


Figure 4.9. Percentage of mismatched wheelchair users for DHH, DDH, TH, and DCH with each of the washing machine

4.5 Discussion and Conclusion

This study analyzed the anthropometric mismatch of the five existing washing machines and anthropometric data of Korean wheelchair users were analyzed. From the results it may be concluded that none of these five commonly available models of washing machines are suitable for comfortable and efficient use by wheelchair users, though a few of the dimensions of the washing machines were found compatible with the users' anthropometric measurements. However, WD19H9400KW showed the lowest mismatched percentage, having the highest match rate, as the dimensions for DHH, DDH, TH, DCH were all bigger than other types of washing machine. Thus, washing machines for general home use (9kg) does not successfully accommodate for wheelchair users, resulting in high mismatch for DHH and TH.

Optimal accessible measurements for each part of the washing machine design is proposed in this research which allows making modifications on mismatched parts and allows the washing machine to be accessible by making modifications in mismatched parts.

Chapter 5

Discussion and Conclusion

5.1 Summary of findings

In chapter 3, Surveys and interviews were conducted with participants with visual impairment, hearing impairment, spinal cord injuries, and elderlies to analyze the preferred control types and designs. From the interview of washing machine usage, participants with spinal cord injuries showed significant difference compared to other groups as they have limited range of movement due to the wheelchair and their physical difficulties.

In chapter 4, anthropometric data of people on wheelchair was used to formulate equations for washing machine measurements that are optimally accessible for people with spinal cord injuries. The formulas are used for finding the anthropometric mismatch of existing washing machines, in order to identify how the current washing machines accommodate with anthropometric characteristics of people with spinal cord injuries. From the results of preferred control types and optimal washing machine measurements, possible design consideration for accessible washing machines are proposed in this research. five existing washing machines and anthropometric data of Korean wheelchair users were analyzed using the mismatch equations. From the results, none of these five commonly available models of washing machines are suitable for comfortable and efficient use by wheelchair users, though a few of the dimensions of the washing machines were found compatible with the users' anthropometric measurements.

5.2 Possible Design Considerations

From Chapter 3, the following considerations on controls to enhance accessibility and better accommodate people with disabilities.

- For people with visual impairment and hearing impairment, the status of the control panel, current status or location must be easily perceived, by proper use of visual, auditory, and tactile senses.
- For people with hearing impairment, and spinal cord injury, feedback on malfunctions should be clear.
- Easy to operate and to avoid malfunction (spinal cord injury, elderly person)
- Adapting voice recognition in home appliances. However, along with the voice recognition, tactile alternatives are also needed.

In chapter 4, mismatch equations for DHH, DHH, TH, and DCH are proposed, while providing design guideline on TD and CL. DHH and DDH must be located over minimum reach and waist height, thus requiring loads to pull the moveable parts, while located lower than the maximum reach but should not be higher than the shoulder height. As the maximum comfortable reach zone seated on wheelchair is SH, TH must be located between minimum side reach range in order to grab the laundry inside the tub.

5.3 Limitations and Future Research

This study has limitations in the survey as it was conducted only for the control part of the washing machines. Moreover, due to the limited number of participants during the interview and survey, the results shows limited range of usage issues found for using washing machines.

For future research, the parts of the washing machine can be subdivided into various parts, and posture of washing machine usage can also be analyzed to create more accurate mismatch equations. The specified washing machine parts and employing anthropometric measures accordingly would allow to formulate precise mismatch equations, making washing machine more accessible to people with spinal cord injuries. Moreover, along with the findings of Chapter 3, using the tactile markings guideline [60], it is possible to conduct in depth research to enhance accessibility in control types for people with disability.

5.4 Contribution of this study

The findings from this study are expected to help people with disabilities by addressing the issues and providing guidelines to improve accessibility on washing machine usage.

It is also possible to evaluate the accommodation level of existing washing machines for people with spinal cord injuries to enhance accessibility on washing machines for people with disabilities, especially for those with spinal cord injuries. This approach of considering anthropometric data to find the optimal measurements of accessible washing machine and identifying the mismatch with existing washing machines would further provide methods in forming accessible design guidelines and in evaluating accessibility in product designs. Therefore, the findings from this research provide a novel method in increasing the accessibility of washing machines for people with spinal cord injuries.

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국문초록

고령자 및 장애인의 인구가 세계적으로 증가함에 따라 모든 사람들의 일상 및 사회 활동에 동등한 기회를 제공하는 것이 중요해지고 있다. 그에 따라 연령이나 장애 여부에 관계 없이 제품을 동일하게 사용하기 위해 제품과 환경의 접근성을 향상하는 연구가 활발하게 이루어지고 있다. 그러나 고령자와 장애인 인구가 증가함에도 불구하고 인체 측정 데이터를 분석하여 접근 가능한 가전 제품의 설계를 제공하는 연구는 제한적이다. 특히 척수장애인들은 가전 제품과의 상호 작용에서 낮은 독립성을 보인다. 따라서, 본 연구에서는 고령자와 시각, 청각, 척수 장애인을 대상으로 세탁기 사용의 접근성 향상을 위한 가이드라인을 제안하였다. 연구 1 에서는 설문 조사 및 인터뷰를 통해 시각장애, 청각장애, 척수장애인과 고령자를 대상으로 선호하는 제품 컨트롤 유형 및 디자인을 분석하였으며, 세탁기 사용시의 주요 이슈에 대해 분석하였다. 연구 2 에서는 척수 장애인을 대상으로 인체 측정 데이터를 분석하여 척수장애인의 세탁기 사용의 접근성 향상을 위한 최적의 세탁기 규격을 파악하였다. 또한, 기존의 세탁기가 척수 장애인의 인체 특성을 수용하는지 식별하기 위하여 기존 세탁기와 규격과 제시된 식을 분석하여 미스매치를 파악하였다.

주요어: 접근성, 유니버설 디자인, 인체측정학, 세탁기, 척수장애인

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