공학박사학위논문

Accessible Home Appliance Design Methods for Disabled and Elderly Users: from Issue Investigation to Design Solutions

장애 및 고령 사용자를 위한 가전제품 접근성 설계 방법

– 접근성 이슈 도출에서 설계 제안까지 –

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산업공학과

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Abstract

Accessible Home Appliance Design Methods for Disabled and Elderly Users: from Issue Investigation to Design Solutions

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Modern-day technologies - including home appliances - deliver benefits to our lives yet the lack of accessibility supports from the manufacturers and designers have forsaken a considerable number of elderly and disabled people. Unlike how the development and advancement with a variety of new functions and features enriched the quality of life for non-disabled users, it only degraded the user experience for the elderlies and disabled users since such functions and features come along with the increased complexity, which hinders not only the accessible use but also the independent use of a disabled or elderly user.

Collecting user experience from the users in need of accessibility support is

much more troublesome than one might think. The users may be reluctant to provide their user experience for sensitive privacy reasons, may not be in the appropriate physical conditions for interviews or surveys, or even have communication problems. Such barriers between the stakeholder and the target users do not allow the stakeholders to fully understand and define the problems these users confront every day; simply, impossible to build empathy. The lack of empathy breeds misconceptions on the elderly and disabled users, created by misinterpretation of the users' experiences since the stakeholders have never experienced what it is like to be a disabled or elderly user. Even if manufacturers and designers who oversee developing accessible products recognize the needs and frustrations of the disabled population, it is challenging or even inaccessible for them to address these issues of their target customers.

In Chapter 3, based on the interview and observation data, this study developed eight personas for four different types of disabled users under the context of home appliance usage: visually impaired (blind and low-vision), hearing impaired (deaf and cochlear implemented), spinal cord injured (opened palm and closed fist), and elderly (grandma and grandpa). Each persona provides their accessibility issues through a persona card and scenario-like explanation. Personas created in this study will help manufacturers and designers empathize with their users although they did not meet the real users face-to-face.

Moreover, stakeholders need a tool to investigate how their users in need of accessibility support behave differently from non-disabled users, which provides a deeper understanding of the users' perspectives in terms of "interaction." In Chapter 4, this study conducted Hierarchical Task Analysis (HTA) and created general task structures of home appliances based on their product compartment and chronological usage phase. This task structure visualizes the user behavior. Combined with the task structure, therbligs expressed the user task on a micro-scale. Therbligs were redefined to fit the home appliance context and, if found problematic, there was the principle of motion economy to provide design guidance to solve the problems of corresponding therbligs. Moreover, the principle of motion economy is valuable because it reduces the burden of a researcher to convert a task-oriented problem found in terms of user behavior into a design-oriented solution.

Lastly, in Chapter 5, a design guideline is developed by collecting existing standards and guidelines. Existing standards and documents related to accessibility lack a detailed explanation of real-world application, although the documentations provide various numerical values related to designs. The numbers are not directly implementable since the context-of-use of elderly or disabled users may vary by their capability, environment, and basically by the form factor of the products they

use. Lower the expertise in ergonomics and accessibility less valuable the standards and guidelines will be to implement in a product design. With the design guideline developed and ideas collected from an ideation workshop, a total of seven prototypes were built. A total of 14 participants evaluated the prototype whether it enhanced the accessibility of target home appliances or not. As a result, most prototypes successfully improved the accessibility and approved the validity of design guidelines. This procedure as a case study will provide how to implement the principles and dimensional values found in the existing standards and guidelines when developing an accessible product.

Overall, this study applied a whole product development cycle to breakthrough the barriers of accessibility problems and proposes it as a set of novel approaches for accessibility issues resolution based on the perspectives of universal design so that a user can freely and safely use their products – especially home appliances – regardless of their disability or age.

Keywords: Accessibility, Universal Design, Home Appliances, Personas, Task Analysis, Therbligs, Accessible Design
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Contents

List of Tables

List of Figures

Chapter 1

Introduction

In the use of everyday products such as home appliances ensuring the fundamental quality of life in our lives, the disabled and elderly users have been discriminated against – although unintentional – due to the cognitive and physical conditions they have. Based on the universal design aspect, this study aims to provide methodologies and guidelines for identifying, evaluating, and improving accessibility problems so that the users can comfortably and safely use home appliances.

1.1 Accessibility Barriers

1.1.1 Barriers for Users

The advent of innovative technologies with modern features and services that make life more convenient and comfortable exists is presently taking place. The latest technologies, including home appliances, deliver benefits to our lives; however, due to the lack of accessibility support from the manufacturers and designers, a considerable number of people(Hersh, 2015) in need of accessibility support have been ignored. Such technologies may lead to more difficulties for some users when utilizing them to achieve their desired goals than outdated products would have. In particular, it is challenging for disabled users and elderlies who have diminished or impaired function in vision, hearing, or even mobility to fully appreciate the newly released top-notch technologies due to their issues with impaired modality and mobility or even lack of experience.

The World Health Organization (2011) reported that the number of people living with one or more disabilities is more than one billion—nearly 15% of the world population—and almost 200 million experience considerable difficulties in functioning. The disabled population in the United States is approximately 19%, while 12.6% are with severe disabilities (Brault, 2012). Natsun (2019) specified that the number of disabled populations in European countries is increasing. Her study summarized the data on population by sex, age, and disability status given by Eurostat and revealed that the percentage of disabled people the age of 15 and older are 18% of the population in 30 European countries on average. Moreover, the disabled population with age 60 and 74 is 27% of the population in these 30 European countries. In South Korea, registered people with disabilities were 2.4% of the total Korean population in 2001, and it increased to 4.9% by 2016. Besides, more than 40% of them are aged 65 or older (Bahk et al., 2019). Its registered population solely takes up to 5% of the whole Korean population, and their number grew twice within 15 years. The number of disabled and elderly population may grow larger in number because most disabilities are acquired during the lifetime of an individual rather than being congenital (Dziura, 2017; Ellis, 2016).

According to the survey report of the Ministry of Trade, Industry, and Energy (2014) in South Korea, accessibility issues are prevalent with home appliances, such as washing machines, microwaves, and refrigerators for people with visual impairment, hearing impairment, and upper and lower limb impairments. From the survey, the disabled population reported their frustrations and needs for temperature control, turning on and off, replacement of accessory compartments, and loading/unloading target objects. Besides the issues related to the operations, there can be issues about situation awareness, error resolution, and safety as well.

It may seem easy to resolve such accessibility issues at a glance. However, it requires the details and insightful analogy to deliver accessible solutions – especially usable by as many users as possible. It is also important to assure that such users do not feel that they are dependent or need help in their everyday life issues (Buzzi et al., 2019; Merkel et al., 2016) when using a product. The design shall compensate for the user's loss of autonomy due to disability (Plos et al., 2012). Furthermore, the solution must provide a unified approach throughout home appliances and interaction methods, relieving the burden of learning each and every feature of different appliances for the target users. It is sensible to reckon that the disabled and elderly users need accessibility support when using a daily product like home appliances, otherwise there can be not only unreasonable endeavors of both cognitive and physical manner, along with consequent safety issues.

1.1.2 Barriers for Stakeholders

Presently, stakeholders, including manufacturers, recognize that there is a significant population with accessibility issues using their products. Moreover, it is a major social responsibility of manufacturers to ensure a product is accessible to diverse users (Kim et al., 2016b), especially for the manufacturers of home appliances built to satisfy the core human needs. Nonetheless, there are various problems building barriers against the stakeholders.

1.1.2.1. Impractical reference standards and guidelines

The documents such as design guidelines and standards with inadequate explanation and their low practicality build the first barrier. There are documents established by a nation or international organizations, which provide information about disabled users and their characteristics. However, two major reasons make the documents impractical: ambiguous/biased target domain and incompatibility (incomprehensible) by stakeholders. The application domain, target users, and provision of design dimensions by each representative accessibility document are given in Table 1.1.

Table 1.1 Application domain, target users, and provision of design parameters from accessibility documents (standard/guidelines)

<table>
<tr><th>Documents</th><th>Application Domain</th><th>Target Users</th><th>Design Guideline?</th></tr>
<tr><td>ADA Standards</td><td>Mainly environmental, minimal product designs</td><td>Mainly wheelchaired users, some blind users</td><td>Yes, with dimensions, but vague</td></tr>
<tr><td>ISO 9241-20</td><td>Software</td><td rowspan="6">- people who are blind
- people with low vision
- deaf and deafblind people
- people who are hard of hearing
- people with physical disabilities, and
- people with cognitive disabilities</td><td>No</td></tr>
<tr><td>ISO 9241-171</td><td>Human-Computer Interface</td><td>Principles only</td></tr>
<tr><td>ISO 29138-1</td><td>Software</td><td>Principles (Issues) only</td></tr>
<tr><td>ISO TS 16071</td><td>Human-Computer Interface</td><td>Principles only</td></tr>
<tr><td>ISO 22411</td><td>Overall designs</td><td>Yes, with dimensions</td></tr>
<tr><td>IEC 63008</td><td>Compartment (Product) designs</td><td>Yes, with dimensions</td></tr>
<tr><td>IEC 62678</td><td>Multi-media systems and equipment</td><td>Unspecified, but borrowed from ISO 29138-1</td><td>No</td></tr>
</table>

First, the target users and the application domain are often biased and ambiguous in some documents. The United States government has published the Americans with Disabilities Act (hereafter, ADA), including ADA standards (US Department of Justice, 2010) for accessible design with recommended numbers and measures so that manufacturers and designers can utilize them as design reference.

The ADA standard provides design guidelines for various home appliances such as refrigerators, ovens, cooktops, washers, and dryers. However, the ADA's guidelines on products are obscure or rather minimal when it comes to reflecting the context of use, unlike the environmental design guidelines it provides numerous use cases of. For example, it recommends locating the bottom of the opening to the laundry compartment at 15 inches minimum and 36 inches maximum above the finished floor in case of front-loading washing machines or dryers. Even though it provides a figure showing that the minimum side reach height of a person on a wheelchair is 15 inches from the floor, it is inexplicable why the maximum height is 36 inches to be exact.

The ADA standards may be useful for manufacturers and designers looking for whole product design dimensions and such exact numbers may help designers decide their product dimensions. However, it does not help them understand and empathize with the users because it does not explain what kind of disabilities or their consequences derives such numbers. Moreover, the numbers are based on American anthropometrics only, so designers outside of the U.S. cannot directly implement them in their product design for ensured accessibility. Not to mention, most of the product guidelines aim to meet the accessibility issues of the physically disabled population disregarding the population with accessibility needs in information, such as users with visual or hearing impairments. The target users are also biased toward a certain type of disabled population.

On the other hand, ISO standards provide wide coverages on target users (ISO 9241-20, 2008; ISO 9241-171, 2008; ISO Guide 71, 2014; ISO TR 22411, 2008; ISO TR 29138-1, 2008; ISO TS 16071, 2003). Especially, ISO TR 29138-1 (2008) provides summarized user needs of different types of disabilities. It summarizes the user needs for people who are blind, people with low vision, deaf and deafblind people, people who are hard of hearing, people with physical disabilities, and people with cognitive disabilities. It summarized user needs by each disability type, and it further provided possible recommendations and alternative implementations - in terms of design principles - to fulfill the corresponding accessible needs based on ISO Guide 71 (2014) and ISO TR 22411 (2008). Although the manufacturers and designers can acknowledge various user needs by each disability type in a concise form through ISO 29138-1, the real-world context can broadly vary to rely on this one document.

Moreover, it solely focused on web accessibility. Despite the wide coverage of disability types, ISO documents such as ISO 9241-20 (2008); ISO 9241-171 (2008); ISO TR 29138-1 (2008), and ISO TS 16071 (2003) mostly focused on the context of software or web accessibility issues. It can be challenging for manufacturers of physical products to directly apply the given user needs from the standards into their product development. This is because the user behaviors for Graphical User Interfaces (GUIs), such as web or software activities, which are mostly cognitive with minimal physical tasks, can differ from the user interactions for a product with Physical User Interfaces (PUIs).

Unlike the ISO documents, IEC 63008 deals with the physical designs – for control elements, doors, lids, drawers, and handles. Despite it provides specific design parameters, it is insufficient for a designer or manufacturer who designs a whole product since it delivers the guidelines only for the operable parts whereas the ADA focuses on the home appliance as a whole product for the specific disabled population. ADA standard provides some physical design guidelines for home appliances, as mentioned before. However, the ADA standard preferably provides guidelines mostly for environmental designs rather than for product designs, since it is specifically targeted for the mobility of wheelchair users.

Going back to the user domain, the users in IEC 63008 are defined differently from that of ISO standards although it states that it borrowed the user groups from them of ISO 29138-1. It is because it named the users based on the user interaction: partial sight, blindness, deafness, hearing impairment, touch impairment, dexterity impairment, manipulation impairment, movement impairment, strength impairment, intellect/memory impairment, and language impairment. IEC 63008 certainly considered multiple user groups with various impairments and stated that such impairments become more severe as the user ages; however, elderly users are not included as target users that may encounter different contexts of use. Most ISO documents related to accessibility, other than ISO TR 22411 (2008) and ISO 9241-20 (2008), also omitted elderly users.

Another major reason for the impracticality of the aforementioned standards and documents is that they are not written in a language easily comprehensible by designers and manufacturers. The designers and manufacturers who are new to the concept of accessibility may not fully utilize or comprehend the contents of these standards due to the lack of detailed explanation on the context of use (Lewthwaite, 2014). The ADA standard provides design guidelines with recommended numbers and measures so that manufacturers and designers can utilize them as design references. However, ADA's guidelines are obscure or rather minimal as they do not explain how they derived such numeric values. It does not help them understand and empathize with the users because it does not explain what kind of disabilities or their consequences derives such numbers. There should be descriptions of a target user's behavior or possible use case scenarios for readers to understand the context of use and implement the values in their designs.

Such documents will help manufacturers to logically understand the fact that many potential users encounter such accessibility issues in their ordinary lives; however, the specific needs and frustrations of disabled users when using inaccessible products will only remain unknown, vague, and without empathy. The lack of empathy can breed many misconceptions of disabled users, created by misinterpretation of disabled people's experiences and knowledge (Goodman et al., 2007; Segelström, 2009) since the stakeholders themselves have never experienced what it is like to be a disabled user (Kitchin, 2000). This does not mean they are not applicable at all, because these documents can be useful for the accessibility experts to undergo accessibility assessment on various products and to design their control compartments with recommended design specifications with numeric references. However, one must remember that not all readers have pre-built empathy and expertise to directly implement the given numbers. In short, such already available information is not suitably presented in terms of the stakeholders' language (Goodman et al., 2006; Goodman et al., 2007). Therefore, it is an essential prerequisite to investigate and empathize with the users by leveraging appropriate user studies to build empathy and expertise before reading the aforementioned guidelines.

1.1.2.2. Predicament of conducting user research

To empathize with the users, one can conduct user research. A suitably selected and conducted user research method can provide abundant meaningful insights depending on the focus of the study (Daae & Boks, 2015). The user-centered approach allows designers and manufacturers to successfully construct user profiles or user models, which is essential to understand the vulnerable user population like the disabled and elderly users. However, there is a barrier for stakeholders when they conduct user research for the users in need of accessibility support. This barrier of inaccessibility is not one-directional but mutual; it is also inaccessible for the stakeholders to hear from their target users about their experience; ironically, it is similar to how it was not accessible for users to appreciate the designs from the stakeholders.

There are several methods of collecting user profiling data along with important factors—inaccessibility problems—to consider in advance, especially for the vulnerable yet inaccessible population. For example, when conducting a survey, the same questionnaires must be in various formats to meet the capability of users. It must be screen-reader-compatible for visually impaired users, neither verbose nor too complex for sign language users, less burdensome to answer for physically disabled users, and given in both manual and online formats for elderly users with lower Information and Communications Technology ability (Carmichael et al., 2005; Laguna & Babcock, 1997; Virokannas et al., 2000). Other user research methods also have the same barrier issue. Interviews require a dedicated moderator to create adequate rapport to encourage participants to share their true experience with accessibility issues in detail (Kitchin, 2000). It also requires a skillful sign language translator for interviewing deaf participants in addition to an experienced moderator (Balch & Mertens, 1999; Kroll et al., 2007). Day Reconstruction Method

(DRM) reduces participants' burden of recording episodes by imposing a chronological process only in a daily manner. However, it still requires highly systematic participation and engagement of disabled users to record their specific user experiences (Kujala & Miron-Shatz, 2013; Maguire, 2001). Most critically, it is challenging to recruit disabled and elderly users and to manage an interview or observation session.

1.1.2.3. Lack of accessibility tools

Unlike web accessibility with a standard accessibility evaluation tool such as WCAG 2.0 by W3C (2008), there is no standard evaluation method for physical products. There are various methods and frameworks to evaluate the interactions of disabled and elderly users and the accessibility of products and environments. Cardoso et al. (2006) classified accessibility assessment methods: 1) Random Assessment, 2) Simulation, 3) Expert Assessment, 4) User Observation, 5) User Group Evaluation, 6) Analytical Assessment, and 7) Structured Assessment. Also, Petrie and Bevan (2009) categorized the evaluation methods into five: 1) Automated checking of conformance to guidelines and standards, 2) evaluation conducted by experts, 3) evaluations using models and simulations, 4) evaluations with users or potential users, and 5) evaluation of data collected during eSystem usage. Their categorizations are mostly similar and combinable.

The methods used in studies for Afacan and Erbug (2009) and Mosca and Capolongo (2018) utilized checklists based on universal design principles and other design guidelines. By applying the heuristic evaluation method, they assessed whether a system or product met a particular criterion. Therefore, it corresponds to the random assessment and expert assessment methods. Having a referable checklist or criteria is advantageous for the evaluator. Nevertheless, these methods are highly dependent on the evaluator's expertise, resulting in a high barrier for the novice evaluator.

On the other hand, Kaklanis et al. (2011), and Li et al. (2006) utilized digital human modeling software to simulate 3D humans and evaluate the accessibility level by manipulating the posture, range-of-motion (ROM), and environment of the simulated user. It is a versatile method to investigate the various context of use. Moreover, by linking with the existing anthropometric data, this evaluation method can calculate the population included and excluded for each specific design. However, it requires dedicated software and learning, thereby, it may not be feasible for every evaluator.

User interviews and observation methods create direct interaction for the stakeholders and the users, which create empathy and rapport. Nonetheless, they are time and effort-consuming, and costly. The disabled users and elderly users are challenging to recruit in the first place. Moreover, most of the data collected are qualitative, thus analyzing the data can require high expertise and insights. The interview or observation method leaves it entirely up to the researcher to link the user's needs and concrete problem definition to the applicable design solution outcome; such analysis tools do not provide any guidance on design or analysis. As a result, stakeholders will concentrate on a certain issue and it may not provide holistic, overall accessibility assessment results for each target product. Accordingly, tools that provide more analytical results, in this case, can be helpful.

Evaluators need an accessibility evaluation tool that can 1) be easily performable by a novice evaluator, 2) be done without dedicated software, 3) be not time and money consuming, and yet 4) deliver relatively equivalent evaluation performance, along with an analytical result.

1.2 Research Objectives and Study Outline

Everyone will agree that it is important to grant the equitable use of home appliances for the disabled and elderly users, however, it is ambiguous who the target users are, how to evaluate accessibility, what principles to follow, how practical and valid the principles are, and how to build accessible design.

In the study of Law et al. (2007), they identified five unresolved problems in current practices of accessibility and universal design guideline production. The first problem is that the identification of the target user is unclear. Under the perspectives of universal design or the largest accommodation of users, sometimes it can be unclear whom the design principle targets, and users with different characteristics and behaviors are categorized under one user group. This happens mostly due to a lack of understanding of target users. Empathy for users and detailed classification of users is necessary. Therefore, in Chapter 3, personas of four different user groups (visually impaired, hearing impaired, spinal cord impaired, and elderly users) with two detailed subgroups of each group are developed to empathize with users and understand their user behaviors.

The second problem is that the term accessible and universal design is not clearly defined. There is indeed no consensus on what accessibility is (Persson et al., 2015) by the fields it is applied, even in ISO standards. In Chapter 2, this study set the boundaries of study scope by defining accessibility in this study.

The third problem is the lack of existing protocols and lack of expertise in testing procedures to conform with standards. There are not many protocols to follow through, even if a protocol is there, the use of protocol requires a certain level of expertise to successfully understand and utilize the protocol. Therefore, in Chapter 4, an accessibility evaluation tool based on therblig and task analysis is developed.

Finally, the fourth and fifth problems are the lack of enforcement of standards and the usability of guidance. In many cases, the existing accessibility standards are often ignored when developing a product because of financial issues, short of expertise, lack of acknowledgment, or lack of enforcement. There are indeed many standards and they are sometimes difficult to comprehend or envision oneself how to apply it in their product. Therefore, in Chapter 5, we collected and combined existing standards and developed a design guideline. Also, prototypes were built based on the design guideline and evaluated so that they can not only enhance the accessibility but also the results can validate the design guideline. One may take an insight on how to utilize the existing standards in their design application through this chapter

In short, the study process is as shown in Figure 1.1. In this study, 1) Chapter 2 defined target users, target appliances, and accessibility to set the study scope, 2) Chapter 3 created personas of target users to understand and empathize with the users, 3) Chapter 4 developed an accessibility evaluation tool based on therbligs and principles of motion economy, and 4) Chapter 5 developed design guideline and prototypes, and evaluated the improvement of accessibility by the prototypes. In Chapter 6, the conclusion and future studies are stated.

This study aims to provide a holistic approach to breakdown the accessibility barriers of home appliances for visually impaired, hearing impaired, spinal cord impaired, and elderly users. This study procedure is a full-product development cycle dedicated to resolving accessibility problems, named accessibility-breakthrough.

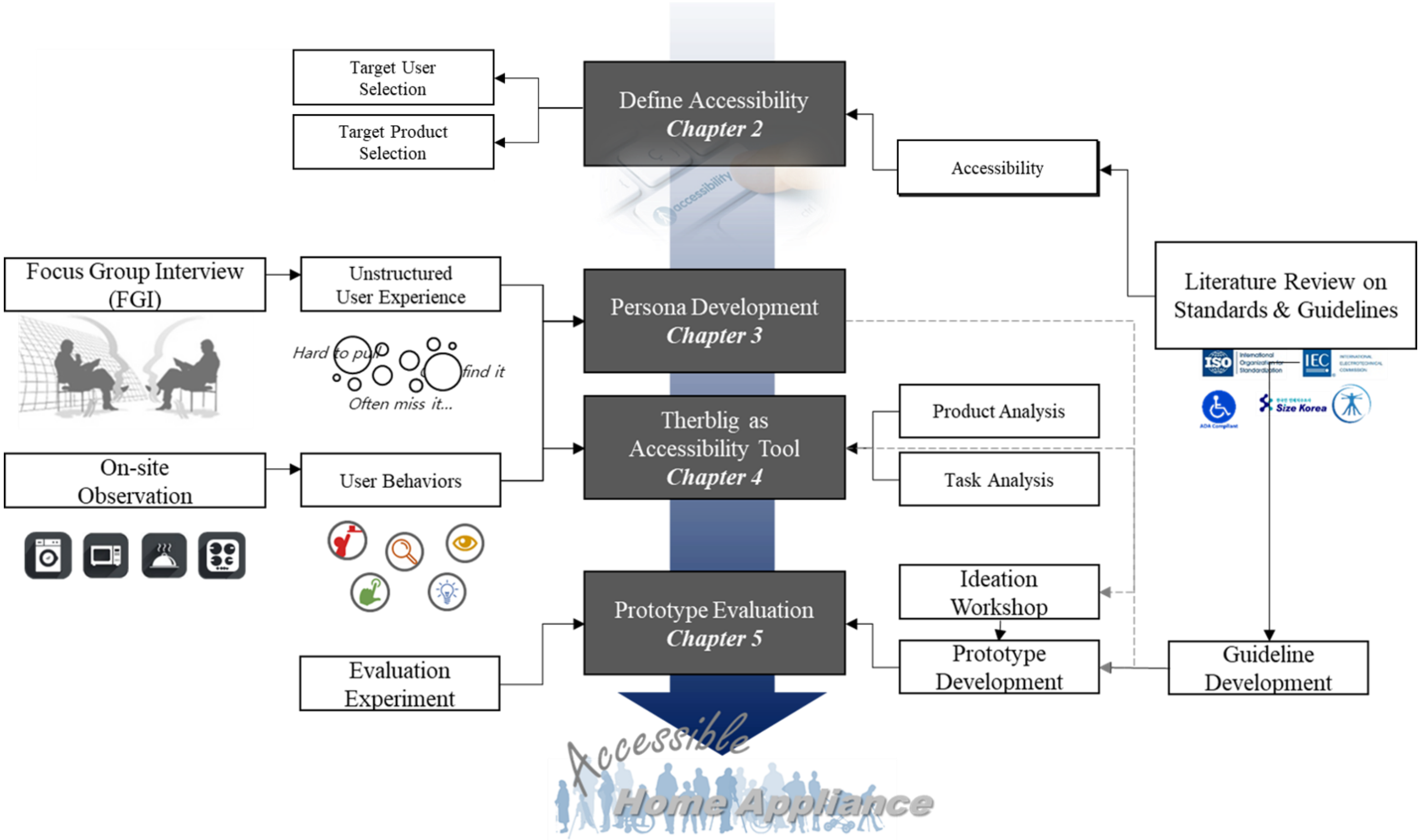


Figure 1.1 Study process overview

Chapter 2

Background

2.1 Target Users and Products

2.1.1 Target Users

The international classification of functioning, disability, and health (ICF) by the World Health Organization (2001) conceptualized and classified the world standard for functioning and disability. According to the document, "Disability" is an umbrella term for impairments, activity limitations, and participation restrictions. Also, "Impairments" represent problems in body functions and structure such as significant deviation or loss. "Activity limitations" are difficulties in executing activities. Disability is rather a vague term than impairment, however, it is con concerned with compound or integrated activities expected of the person or of the body as a whole, such as are represented by tasks, skills, and behaviors (World Health Organization, 1993). In this study, the terms disability and impairments may be interchangeably used sometimes. However, specifically, it will use the term disability to denote the health condition and inability of the users, comprehensively. On the other hand, the term impairment will be used to represent user's physiological damages or loss in their body.

IEC 63008 (2016) considered eleven different types of user impairments. They are partial sight, blindness, deafness, hearing impairment, touch impairment, dexterity impairment, manipulation impairment, movement impairment, strength impairment, intellect/memory impairment, and language impairment. They are very specific and can describe the disabilities of users in detail, however, multiple impairments can be assigned to a user with one disability type. This study selected four user types by concerning the definition of disability, impairments and activity limitation from ICF of WHO, and detailed impairments from IEC 63008.

Visually Impaired Users. First, it considered the user types with the impairments interacting with information. Partial sight and blindness are the characteristics of people with disabilities in the perception of visual information. The loss of vision or diminished vision of these types of users makes it difficult or even impossible to perceive information given only in a visual channel. They alternatively utilize an auditory and tactile source of information, instead. Therefore, in this study, "visually impaired users" or "users with visual impairment" are defined as people whose vision is lost or diminished thus the dependence on visual interaction is restricted while the dependence on auditory and tactile interaction is significant.

Hearing Impaired Users. Likewise, deafness, hearing impairment, and language impairment belong to the people with disabilities in the perception of auditory information. Hearing impairment can be re-written as hearing loss or people with hard of hearing (ISO TR 22411, 2008; ISO TR 29138-1, 2008). Language impairment can also be expressed as language disability since it describes the inability of a person. People with deafness utilize sign language to communicate with each other instead of the spoken and written language used in their country, therefore many of them can suffer from language impairment. The loss of hearing or diminished hearing of these people makes it difficult or even impossible to perceive information given only in an auditory channel. They alternatively utilize a visual and tactile source of information. Therefore, "hearing impaired users" or "users with hearing impairment" are defined as people whose hearing is lost or diminished thus the dependence on auditory interaction is restricted while the dependence on visual and tactile interaction is significant.

As the previous two impairments interacted informationally, the impairment with physical interaction shall be considered too. Touch, dexterity, manipulation, movement, and strength impairments all belong to people with disabilities in the spinal cord. The level of hand dexterity and manipulation all differ by the damaged areas in the spine. Depending on the damaged spine, whether cervical or thoracic, they can be categorized as tetraplegia or paraplegia (Association, 1984; Maynard et al., 1997). Accordingly, their grasping strength is also restricted. The impairment in the spinal cord will also restrict the user's movement with the lower limb, therefore they are in wheelchairs. Therefore, "spinal cord impaired users" or "users with spinal cord impairment" are defined as people whose manual operations (strength utilization, touch, dexterity, grasping, and manipulation) and mobility are restricted due to the impairments in the cervical or thoracic area of the spine.

Lastly, the intellect/memory impairment is left among the eleven user impairments from IEC 63008. Elderly people fall into this category because many elderly people suffer from dementia (Felzmann et al., 2015; Gregor et al., 2002) by considering the memory issue only. The definition of elderly may be controversial, however, recent studies define the elderly, or young-old adults, as over 60 or 65 and under 80 years of age (van Riet et al., 2016; Zinke et al., 2014). As they age, elderly people can suffer from dexterity, manipulation, movement, and strength impairments just like the spinal cord impaired users. Besides, they also suffer from the diminished capability to perceive visual and auditory information like the visually impaired users and hearing impaired users. For example, elderly people with visual problems and hand tremors encounter difficulties in physical product operation (Yankelovich et al., 1995). The elderly users may not appear to have "impairments" though they may behave similarly and experience similar problems with the users with impairments; they have 'disability'. Therefore, "elderly users" are defined as people whose age is over 65 and under 80, and who experience various impairments and activity limitations.

Overall, this study targets the following four user types: visually impaired users, hearing impaired users, spinal cord impaired users, and elderly users.

2.1.2 Target Home Appliances and Compartments

It is undeniable that home appliances are everyday products in general since we use home appliances on a daily basis: to cook, to keep our food being stored, to wash our clothes, and so on. However, are home appliances really the "everyday product" for the disabled and elderly population as well? According to ISO 20282-1 (2006), the definition of an everyday product is a consumer product or walk-up-and-use product designed for use by members of the general public. Unless the term "general public" is to discriminate against the disabled or elderly population, a simple statement like "home appliances are everyday products" must remain true for disabled users as well; however, this is not presently the case. To design a home appliance that is truly an everyday product, manufacturers and designers are responsible for considering the disabled population in their minds throughout product development; this needs more attention from manufacturers.

In this study, we chose the washing machines, microwaves, ovens, and cooktops as target appliances. These all require a user to perform a similar task sequence to operate; a user loads an object in or on the appliance, delivers control commands, monitors the operational status, fixes an error at its occurrence, and unloads the object from the appliance. Moreover, the structures or mechanisms of the major home appliances do not differ significantly by country, and the users with the same type of disability around the world will experience similar problems, accordingly.

2.1.2.1 Product Compartment Classification

Prior to the deeper study analyses, this study classified the components of target home appliances, that interact with users, into five categories according to the characteristics and methods of the interaction: 1) moveables, 2) non-moveables, 3) controls, 4) displays, and 5) separables. In previous studies on home appliances, product parts were classified into physical UI (PUI), graphical UI (GUI), and logical UI (LUI) (Jin & Ji, 2010; Lee et al., 2011; Mendez & Mendoza, 2013). The proposed guidelines for washing machines for elderlies from the study of Huang et al. (2018) classified the products as functions, operation and feedback, displays, doors, comfort, and guide. Finally, in the Web Content Accessibility Guidelines (WCAG) 2.0 by World Wide Web Consortium (W3C)(2008), the web content UI principles consist of the following four components: perceivable, operable, understandable, and robust. Among the four, the perceivable, operable, and understandable are both the principle but also the design components with which a user can interact.

These classifications are well-organized and conceptually distinct but are so classified as upper-level concepts that their scope is too broad to comprehend or scrutinize how users interact with their products. There is a point where users' tasks may vary significantly within the same category. Such broad terms are not so intuitive to comprehend the context and purpose of each use, or what task is performed within the component.

The components were classified in accordance with the user interaction they can offer. As proposed by Lee et al. (2018), the product was divided into five distinctive parts: moveables, non-moveables, controls, displays, and separables. These five components can be grouped into operables and non-operables, as shown in Figure 2.1. Operables are the parts where interaction with the user involves physical movements and is associated with the operation of the product, such as moveables, controls, and separables. In contrast, the non-operables are the parts where interactions with users are cognitive and indirectly or even not associated with the operation of the product. They are non-moveables and displays. Table 2.1

provides a detailed definition of each component and example.

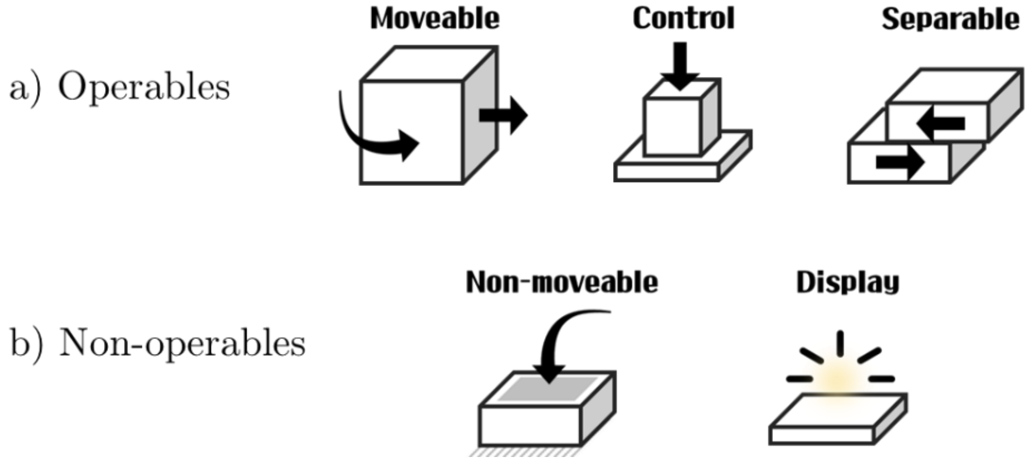


Figure 2.1. Simplified graphical representation of the product components

Moveables. Moveables, as the name suggests, refer to the component where a user can move its orientation. Also, it is essential to note that the moveables move in accordance with the direction in which the user moves their hands and that this moving part moves without separating itself from the product body. The representative examples of this component are the door of the product or the tray inside. Users reach for a moveable, grasp it, and push or pull to move it. The user can allocate or fix its position for the next task. The moveables are the preemptive and essential parts of product usage (task goal), but on the other hand, it does not directly operate the product to run. It is mostly used for preparation purposes, especially for creating access openings.

Non-moveables. In contrast to the moveables, non-moveables are the parts where the user's interaction does not alter the position of the parts. Due to the characteristics of home appliances, users can lay, place, or store their intended items inside home appliances. Therefore, the non-moveables are mostly internals of a product. For example, a tub of washing machines or the inner area of microwaves is the non-moveables. In the case of cooktops, which have no determined inner side, it corresponds to the grill or top part where a user can place the cooking wares.

Controls. Controls are the actuators receiving the input command from a user. The operational direction of the device may not correspond to that of the user's movement direction. Users perform various hand motions to use a control such as grasping, rotating, pushing, or pulling. Examples are physical buttons, touch buttons, knobs, etc.

Displays. Displays are the parts where a product displays intended or desired information to its users. It can be as simple as the texts written around a control, or as complex as the information cluster given on a digital screen. Besides, a product can deliver information to users through not only the vision but also through other sensations such as auditory signals and vibrations. Users need to perceive, recognize, or monitor this dedicated component.

Separable. Finally, separable are the moving parts that can be detached from the body of a device for maintenance. Separable move along with the user's motion just like moveables, however, the separables will be detached or disassembled from their product body. Examples are accessories and replacement components like filters and grills. Drawers and trays, which are examples of moveables, can also be separable if they are detached from their product. Such a case is the context in which the user intends to proceed with maintenance work. Users perform similar tasks as required by the moveables, but will perform additional assembling and disassembling tasks.

Table 2.1. Product Compartments Classification

Categories	Definitions	Related product compartments
Operables	Products parts where user's interaction is associated with the product's operation	Moveables, Controls, Separables
Non-Operables	Products parts where user's interaction is not associated with the product's operation	Non-moveables, Displays

Sub-categories	Definitions	Related Therbligs	Examples Compartments
Moveables	Moving parts moving in a direction in accordance with the movement of a user's action. Mostly used for preparation rather than actual usage	Reach, Grasp, Use (Push) Move (Pulling)	Doors, Drawers, Handles
Non-Moveables	Parts without movement nor interactions with users, but where an essential object of task purpose is placed on. Used for preparation just like moveables	Search, Position, Inspect Release	Product body, Washer's tubs, Shelves, Trays, etc.
Controls	Actuator receiving input command from a user. The operational direction of the device may not correspond to that of a user's movement or action	Select, Grasp, Position, Use	Buttons, Knobs, Touch buttons, Slide bars, etc.
Displays	Parts displaying explanation on control parts or delivering information to users directly or indirectly through a user's sensation	Inspect (feedback), Search, Find, Plan	Screens, Texts, Operational sound, Speakers, Haptic motors, etc.
Separable	Moving parts that can be detached from the body of a device for maintenance. Replaceable parts, which only has "assemble and disassemble: as corresponding therbligs	Reach, Grasp, Use, Move, Hold, Disassemble, Assemble	Drawers, Trays, Grills, Filters, Accessories, etc.

2.1.2.2 Product Compartment Classification by Target Appliances

This study concentrated on the use of home appliances by disabled and elderly users. The target home appliances are washing machines (washers), dryers, microwaves, ovens, and cooktops (gas stove and electric stove). In order to investigate issues with respect to user interactions, all the target appliances were classified according to the product component classification in the following categories: moveable, non-moveable, control, display, and separable. Their movement directions are presented in linear (x, y, z) and rotational (roll, pitch, yaw) directions as shown in Figure 2.2, so that an evaluator may comprehend how each therblig performs when applied.

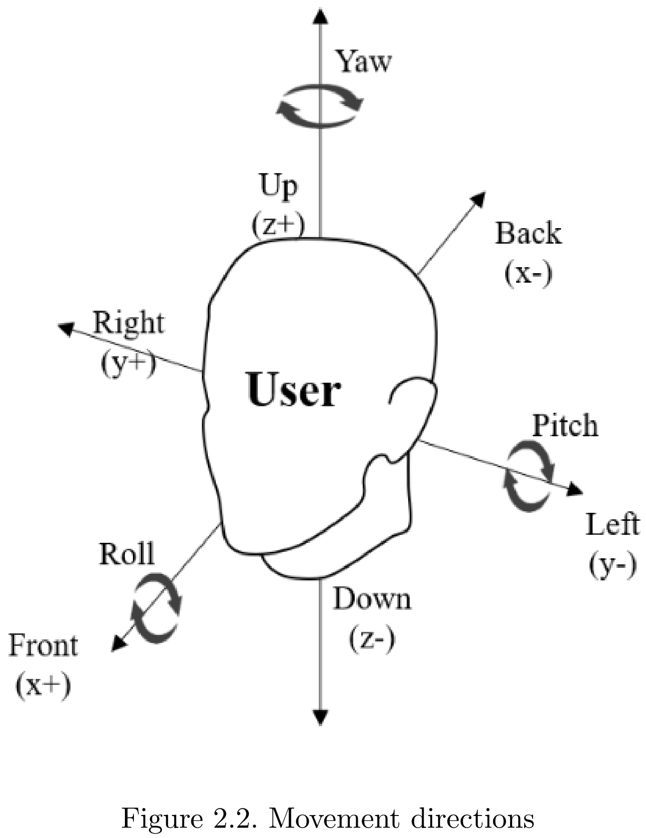


Figure 2.2. Movement directions

Washing machines & Dryers. Washing machines can be segregated into two types: top-loading and front-loading. Same for the dryers, however, only the front-loading type is considered for dryers, considering its market share. The moveables of washing machines are the doors and detergent drawers. The top-loading door opens upward (pitch), while the front-loading door does sideways towards the user (yaw). The detergent drawer moves along the x-axis (front-back). The non-moveable of washing machines is the tub, where laundries go in. The controls are the control panels which consist of buttons and a knob. Displays are visual displays, auditory alarms, and feedbacks. Finally, the separables are the filters located either in the tub (top-loading) or the bottom of the body (front-loading). For dryers, there can be a water drain container that a user has to empty occasionally.

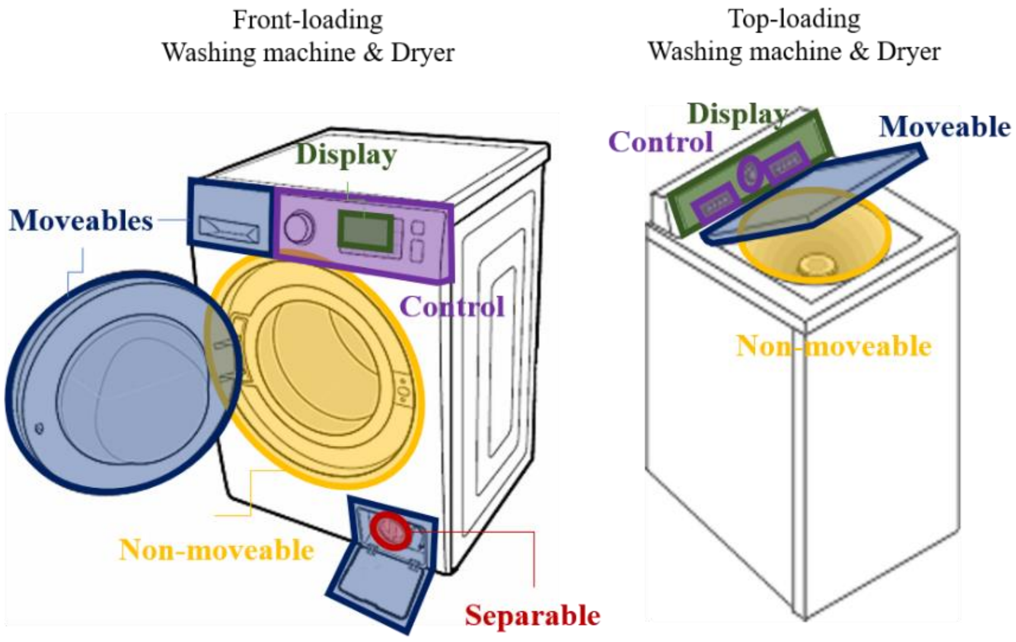


Figure 2.3. Compartments of front-loading(left) and top-loading(right) washers

Cooktops. Cooktops are unique in the sense that they do not have moveables. So, the preparation and wrap-up work during the pre-usage and post-usage context may be shorter, comparably. The non-moveables are the fire-eye of the cooktop, where a user allocates their cooking wares. Controls are the knobs, buttons, or touch buttons (electric stoves, especially). Displays are not only the screens built into the electric stoves but the fire or red eyes of stoves. This is where a user directly monitors the heat level, therefore, it is a display. A separable part is a grill for gas stoves, and it is barely found within the electric stoves.

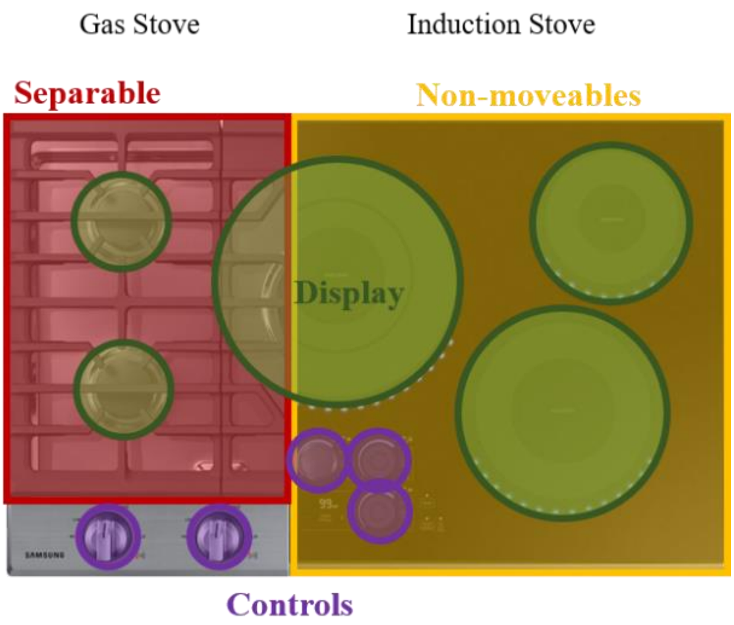


Figure 2.4. Compartments of gas stove(left) and induction stove(right)

Microwaves. The door(handle) is the only moveable part of the microwave and it moves in the yaw direction. The spinning plate inside is considered to be non-moveable since a user place food on top of it during the pre-usage and post-usage contexts. The inner walls may also be considered non-moveables if a user cleans the inner side during the maintenance context. Controls are straightforward. The control panels and may include the door opening button if exists. Displays are the digital display, the texts written to describe controls, and the transparent screen to watch the food being cooked. Finally, separable is the spinning plate inside during the maintenance context.

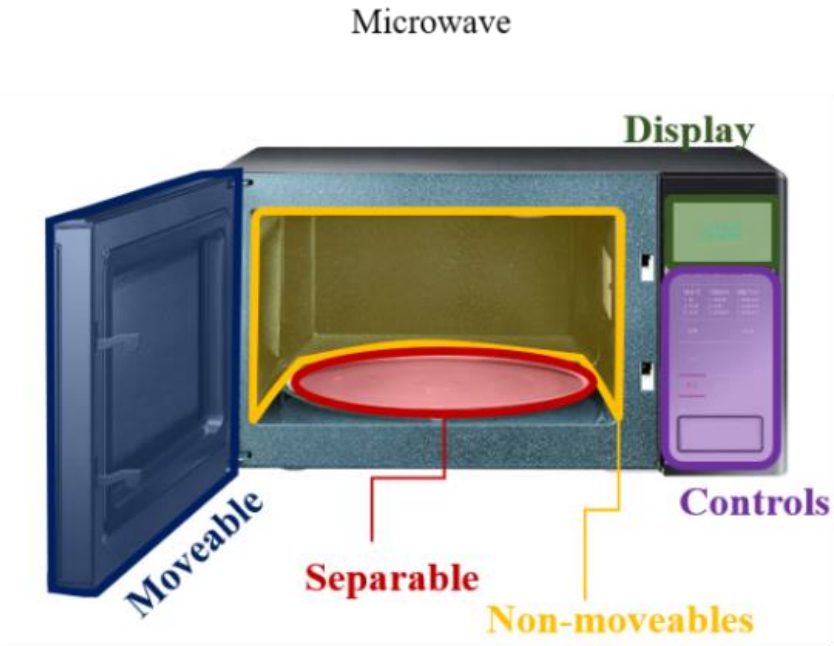


Figure 2.5. Compartments of microwave

Ovens. Ovens are quite similar to microwaves, yet larger. Doors and trays are moveables of ovens. Each of them moves along the yaw, and x-axis accordingly. Trays of ovens are versatile; they can be moveable, non-moveable, and separable. Controls and displays are also straightforward. Just like microwaves, transparent glass takes a role as a visual display to watch the food being cooked.

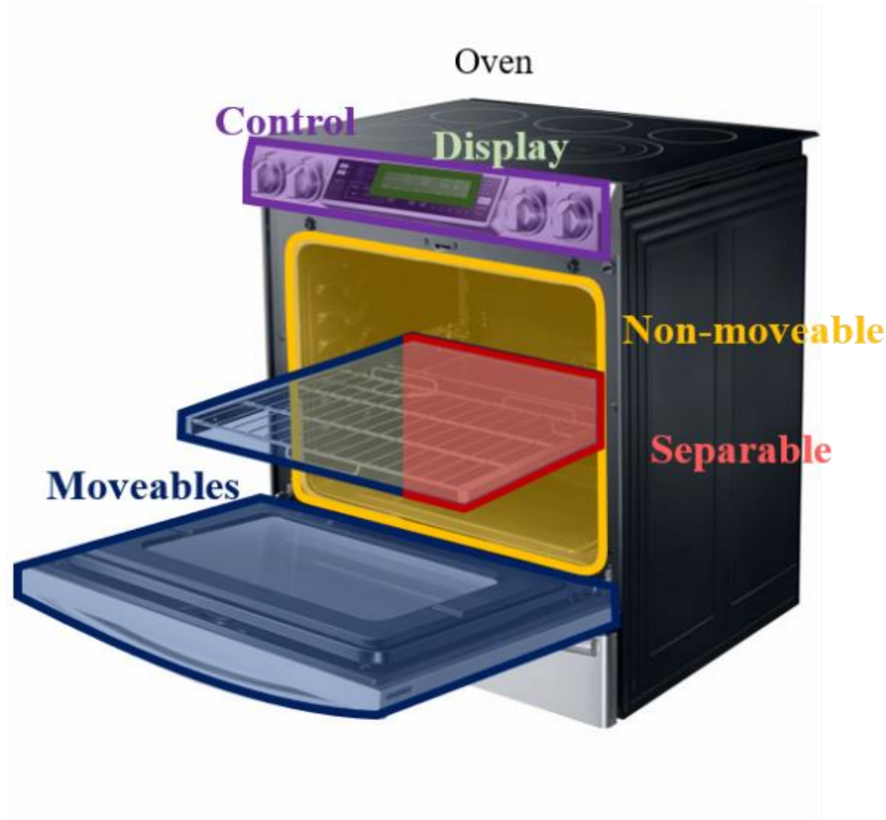


Figure 2.6. Compartments of ovens

2.2 Definition of Accessibility

"Usability" is no longer an obscure term. Nowadays, even the common people who are not experts in the fields of product development, human factors and ergonomics, and Human-Computer Interface (HCI) are well-acknowledged of the term. However, the main focus of this study – accessibility – is yet remained obscure even by the developers and designers.

What is accessibility? Usability and accessibility are often interchangeably used. However, such use breeds ambiguity. Accessibility is interpreted in various meanings depending on the fields of study (Persson et al., 2015). ISO 9241-171 (2008) defines accessibility as, "usability of a product, service, environment or facility by people with the widest range of capabilities." This definition expressed usability as a subset of accessibility. This definition expressed that usability will turn into accessibility when the target user is fully extended to its possible range.

On the other hand, Web Content Accessibility Guidelines 2.0 (World Wide Web Consortium, 2008) defined accessibility as "(web) accessibility means that people with disability can perceive, understand, navigate, and interact with the Web." In this case, accessibility is the subset of usability because accessibility is considered only for a subset of users (Petrie & Bevan, 2009). After all, it expressed that the target of usability evaluation is a non-disabled unspecified user group whereas accessibility targets only specified disabled user groups. The relationship between usability and accessibility by each definition is shown in Figure 2.7.

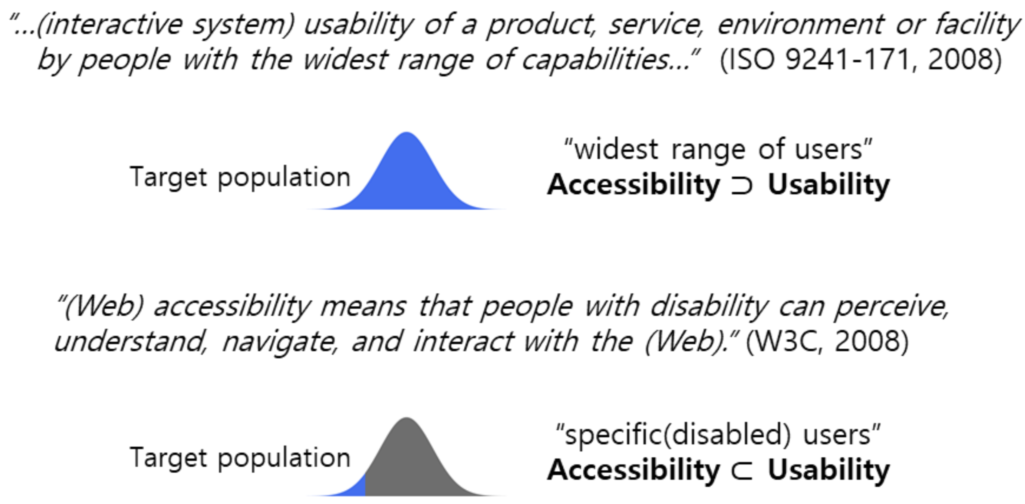


Figure 2.7. The relationship between usability and accessibility by each definition

Once the target user group is extended to encompass the disabled and elderly users, the difference between the definition of usability and accessibility becomes insignificant though the precedence relationship becomes equivocal according to the definitions above. As the usability studies are based on the User-Centered Design (UCD) methodology, the accessibility research method should also be in line with the usability research method (Petrie & Bevan, 2009). Therefore, accessibility and usability are interchangeably usable. However, usability and accessibility are not the same though they are related (Erlandson, 2008). There can be a clearer classification if the definition focuses on the user's task instead of the user population.

Accessibility is a "necessary precondition(prerequisite)" for usability (Iwarsson & Ståhl, 2003). Implied within this statement, something usable means that it is already accessible. This also indicates that there is a threshold of accessibility that a user must surpass to proceed to the usability realm. If a product is not accessible, it is indeed not usable. This study assumed that accessibility questions whether a user can break through a threshold of effectiveness, in other words, a threshold to complete the desired task. Therefore the following question can be asked when evaluating the accessibility of a product, "Can a user accomplish the desired task/goal when using a product?"

Accordingly, this study relates accessibility to one of the attributes of usability, effectiveness. Effectiveness is accuracy and completeness with which users achieve specified goals (ISO 9241-11, 1998; ISO 9241-210, 2010). Such definition can also correspond with that of ease of operation from (ISO 20282-1, 2006). It may be more appropriate to consider the definition of ease of operation since it specifically copes with the everyday product. However, the ease of operation only focuses on the main task, and main goal, leaving the subtasks and goals untouched whereas the effectiveness of usability considers all tasks and goals. The efficiency and satisfaction – the other two attributes of usability – can be considered when the user can accurately and completely accomplish a task, meaning if a user passes the threshold of effectiveness.

Therefore, accessibility is defined as the threshold that the user must overcome in order to accurately and completely achieve the desired goal, as shown in Figure 2.8. Unlike the ISO and W3C, this study will focus on user tasks instead of user accommodation. It will consider the widest range of users like (ISO 9241-171, 2008) yet consider accessibility as a sub-attribute of usability by considering that accessibility is the evaluation of effectiveness. The other two attributes (efficiency and satisfaction) can be evaluated after a user satisfies effectiveness. It corresponds with the characteristics of accessibility that it's a precondition of usability.

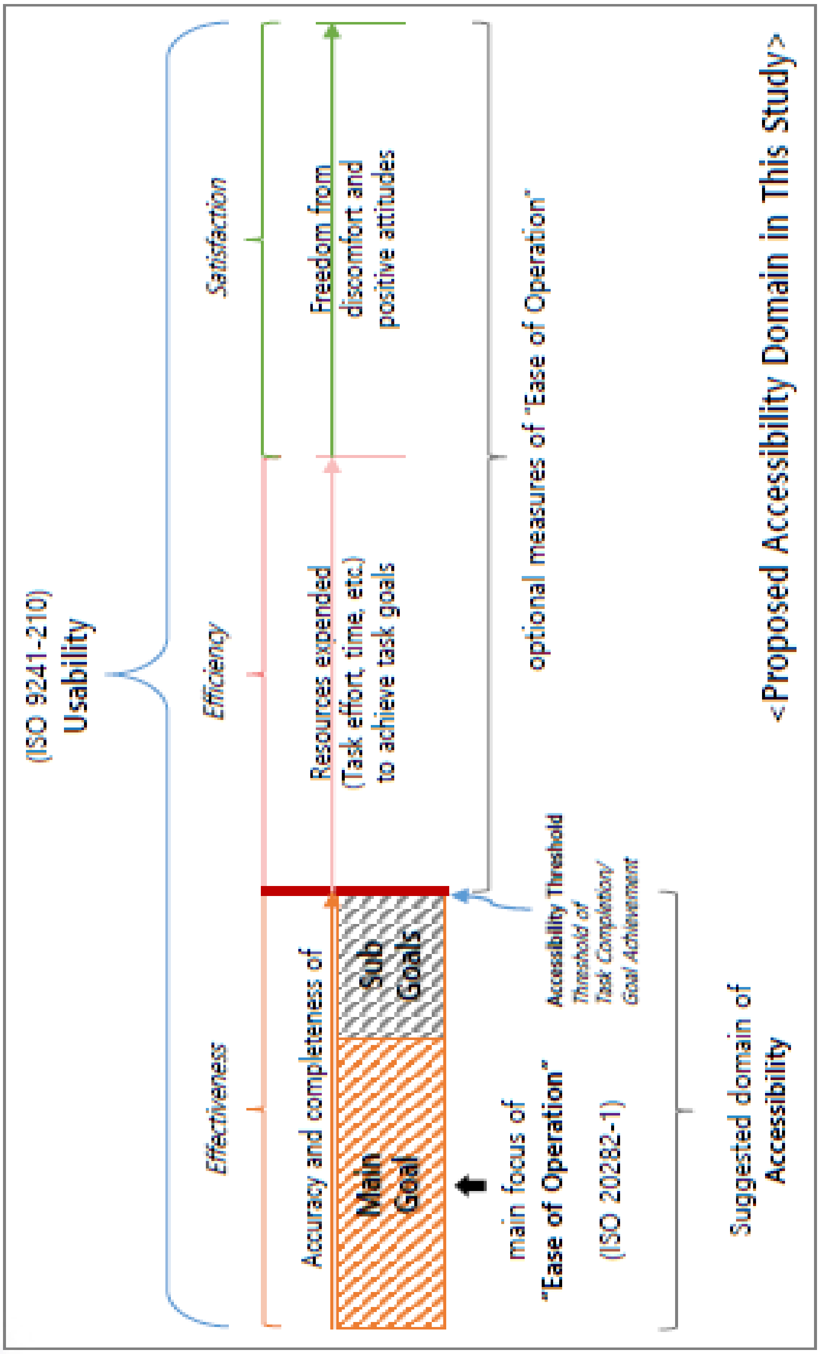


Figure 2.8 Definition of accessibility and the scope of this study

2.3 Design Approach

2.3.1 Accessible and Universal Design

The concept, accessibility, can be embodied in the real world through a work of art called design. Different names like Universal design, Inclusive design, Barrier-free, Design for all, and Accessible design represent a design technique to assure accessibility for product service. It is undeniable that all these design methods uniformly aim to provide more accessible and usable products for disabled and elderly user groups. Most studies interchangeably use those terms, however, Persson et al. (2015) and Erlandson (2008) well clarified the difference among those design approaches.

Barrier-free is highly focused on the development of assistive technologies to enable their users to participate in everyday life whereas Adaptable design is toward the modification of a product or compartment from its original/standard design to fit the needs of an individual. Accessible design, according to ISO Guide 71 (2014), also extends standards to fit the needs of a person with some type of performance limitation. Universal design is the design to provide a user the easy and safe access to the product regardless of their disability or age based on the 7 principles (Story, 1998, 2001) it pursues. Design for all is more ideological than the Universal design while Inclusive design focused more on its phrase, "reasonably possible" to be more practical.

Likewise, every design approach seems similar yet different. However, the biggest differences are the target products and target users. In terms of target products, Barrier-free is focused on assistive technology, which is apart from a product (in this case, home appliance) itself; it is a third-party product in the end. Other design approaches redesign the product itself to achieve direct access. In terms of target users, the latter design methods like Universal design, Inclusive design, and design for all target their users as extensively as possible, whereas barrier-free and adaptable design concentrated on the needs of each individual to be more customized. Accessible design is also focused on an individual, however, it also advocates the maximum number of potential users. The difference is that accessible design should satisfy specific legal mandates, guidelines, or code requirements.

In this study, the term Universal Design will be used mostly, as it aims to redesign products for all target user groups (visually impaired, hearing impaired, spinal cord impaired, and elderly users). Also, the term accessible design may be used to represent a design that is accessible, literally.

Chapter 3

Persona to Investigate the Accessibility Issues of Disabled and Elderly Users Under the Context of Home Appliances Usage

3.1 Overview

Recruitment and conducting direct user research for disabled and elderly users are challenging; it is inaccessible for the stakeholders to interact with their target users. By considering the difficulties of conducting user researches stated in Chapter 2, this study adopted Focus Group Interview (FGI) and On-site observation. Furthermore, personas for each group by the collected data from FGI and observation to highlight the user issues were developed. When it is inaccessible for a manufacturer to obtain actual users' needs and their behaviors toward a product, personas can be a great substitute for the target users because personas help stakeholders to empathize with their users with more profound understanding (Goodman et al., 2006; Goodman et al., 2007; Winter et al., 2012) and are especially useful when it is challenging to recruit the target users (Cooper, 2004).

A persona is a realistic but fictitious individual user that represents the target user's characteristics, needs, behaviors, objectives, and expectations (Cooper et al., 2003; Grudin & Pruitt, 2002). Personas based on user research can help manufacturers recognize and empathize with the needs in accessibility for people with disabilities since the personas define not only the users and user characteristics but also the problems they experience throughout given scenarios. The personas are presented in the form of a designer's language rather than cold, unempathizeable tables and charts.

Recently, there have been new techniques with a quantitative approach adopted for persona development, such as survey statistics and text-mining (An et al., 2017; Lee et al., 2020). However, most of the persona studies still use a qualitative approach. Studies with a qualitative approach are highly focused on the persona's use case scenarios and probable frustrations and needs while lacking an explanation of how personas are made. Furthermore, the data collected from the disabled and elderly users in this study are best suited to the qualitative approach as well. Thus, this study borrowed one of the traditional methods to create personas from Pruitt and Adlin (Pruitt & Adlin, 2010).

Previous studies created personas for disabled users (Carmichael et al., 2005; Goodman et al., 2006; Henry, 2007; Kelle et al., 2015; Marshall et al., 2015; Schulz & Fuglerud, 2012) and also approved the effectiveness of personas when applied in studies on disabled people. In particular, Schulz and Fuglerud (2012) suggested targeting four main groups of disabilities when developing disability personas: people with vision, hearing, movement, and cognitive impairments. They also recommended considering the elderly as well, if possible, since the elderly populations suffer from a combination of several milder versions of impairments from these four groups. Therefore, by taking the suggestions, this study developed personas of disabled people under the context of home appliance usage to investigate their user needs and frustration, presented in forms of stakeholder's (manufacturers and designers) language so that they can empathize with the disabled users.

Overall, this study aims to extract accessibility issues of disabled and elderly users within the context of home appliance usage via the persona approach. This study created personas representing target user groups from FGIs and observations. Each persona addresses accessibility issues and possible solutions.

3.2 Methods

3.2.1 User Data Collection

This study developed personas for four groups of disabled and elderly users based on the procedure described in Figure 3.1. The basis of personas comprises qualitatively selected insights from the focus group interviews and observation. This study collected the user experience data from both Focus Group Interviews and observation and qualitatively analyzed them. Finally, this study created personas representing each user group, which indicate their user characteristics, behaviors, task barriers and goals, needs and frustration, and accessibility issues.

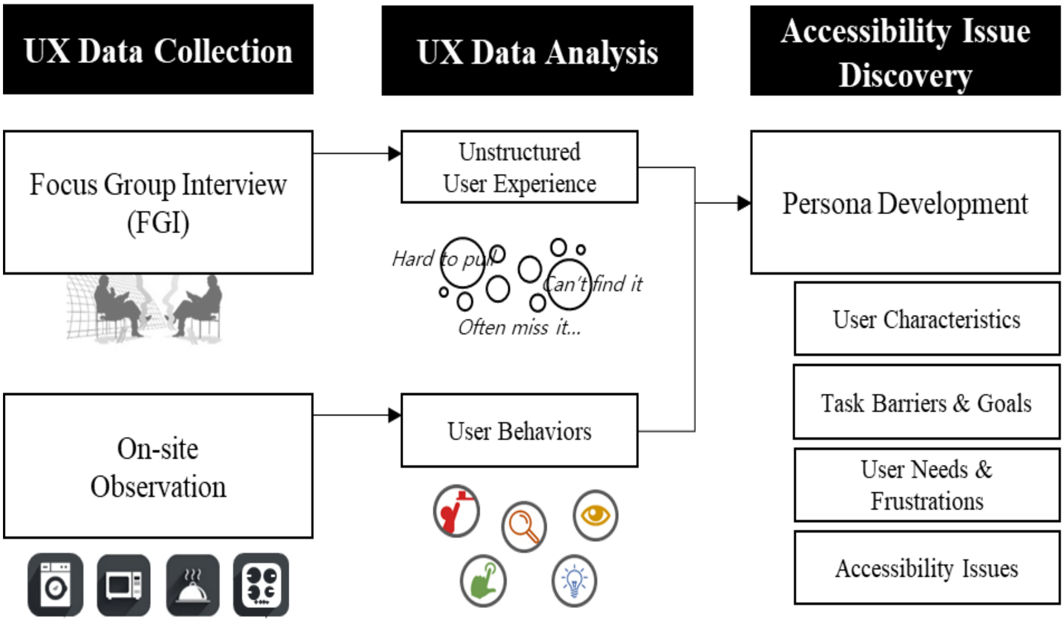


Figure 3.1. Overview of study procedure to investigate the accessibility issues

A total of 52 people with different disabilities and ages (14 visually impaired, 13 hearing impaired, 9 spinal-cord impaired, and 16 elderly users) participated. All participants were invited to an interview site with pre-installed home appliances. In advance of the site visits, visually impaired participants and elderly groups were verbally instructed through phone calls, along with documented instructions. There were special transportations prepared for visually impaired and spinal cord impaired people. Also, a sign language translator was hired for the hearing impaired group as well.

All participants completed a set of basic survey questionnaires on their daily behaviors with the target appliances and frustration and needs in advance of the interview and observation. The questionnaires ask demographic characteristics such as gender, age, family member, currently using assistive devices, acquisition of disability, dependent sensation, the activeness of household work (7-Point-Likert scale), and perceived-ICT-ability (7-Point-Likert scale).

Focus Group Interviews (FGI) for each target group were conducted so that the users with similar challenges could share their various experiences and either agree or disagree on the accessibility issues that each individual experienced. Furthermore, the participants could try out pre-installed home appliances during the interview to recall specific needs and frustrations, which they could have forgotten to provide for a survey. All participants tried out the washing machine, microwave, oven, and gas and electric stoves, and freely expressed both poorly designed and well-designed aspects of pre-installed appliances in terms of their disability and age characteristics. Consequently, all of their responses were recorded with the corresponding appliance. Their behaviors of using the appliances were observed and documented.

Each interview session asked the participants to share their experience and opinions on the inconvenience of using the target home appliances based on five different task phases for the chronological sequence of product usages: pre-usage (preparation or set-up), usage (input control), mid-usage (monitoring in the midst of operation process), post-usage (wrap-up), and maintenance phase. The definition and example of each phase are given in Table 3.1.

Table 3.1 Definition and examples of timely phase when using home appliances

Timely Phase	Definition	Example Tasks
Pre-Usage (Preparation)	A preparation-related phase for a user to load an object in/on an appliance	Opening/closing a door, Carrying, Placing an object
Usage (Control)	A control-related phase for a user to give an operational command to an appliance	Searching, Selecting, Feedback-receiving, Operating
Mid-Usage (Monitoring)	A monitoring phase for a user to check an appliance's operational or error status	Feedback-receiving, Planning, Status-checking
Post-Usage (Wrap-up)	A wrap-up phase for a user to unload an object from an appliance	Same as that of pre-usage but in reverse order
Maintenance /Installment	A phase where an appliance is not under operation until the next cycle	Cleaning, Status-checking, Assembling/disassembling

3.2.2 Data Analysis for Personas

Some existing studies have created personas for disabled people (Fuglerud, 2014; Fuglerud et al., 2020; Hannay et al., 2020; Schulz & Fuglerud, 2012; Sulmon et al., 2010); however, there is no detailed explanation of how the personas were created, though they are rich in personal information about their personas. This study burrowed the persona creation method developed by Pruitt and Adlin (2010), as shown in Figure 3.2.

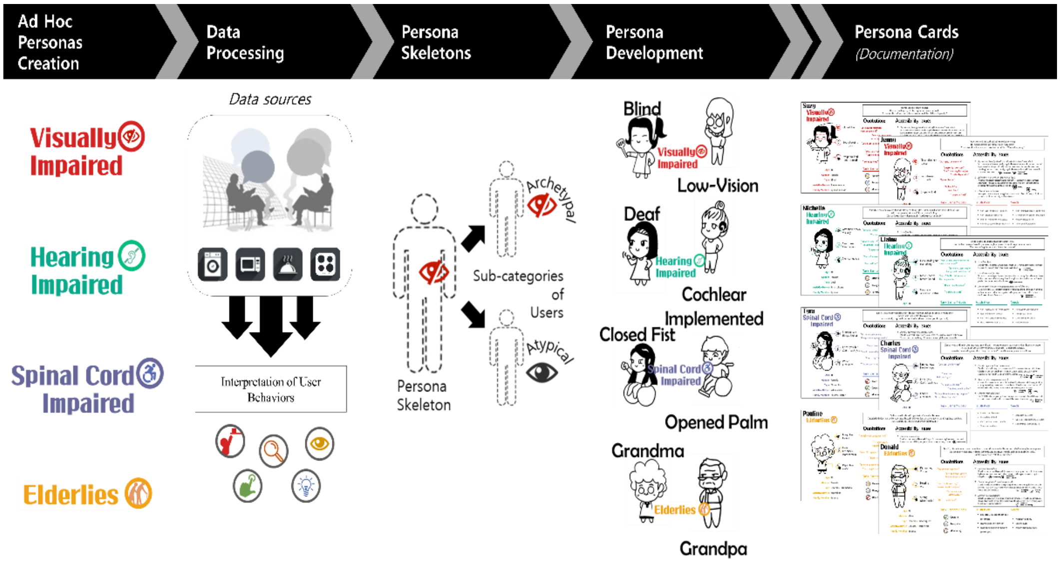


Figure 3.2 The flow of persona creation borrowed from Pruitt and Adlin (2010)

They suggested identifying the "ad hoc" persona in the beginning. The development of ad hoc personas helps articulate the initial assumption toward the target users. It also helps set up the starting point of persona creation. This study chose the visually impaired, hearing-impaired, spinal-cord-impaired, and elderly users as the target users in accordance with the suggestions made by Schulz and Fuglerud (2012) for creating personas for disabilities, which became the ad hoc personas for this study, the first step of persona creation.

Consequently, for data processing, verbally recorded audio from both FGI and observation sessions were manually transcribed and translated by four ergonomic professionals. For the investigation of the accessibility issues under the context of home appliance usage, each meaningful sentence representing their user experience and behavior was scrutinized and sorted based on the characteristics of target user groups, relevant product and compartment, usage phase, and task characteristics. In terms of task characteristics, this study borrowed the five accessibility operational tasks (perceive, recognize, monitor, reach, operate) from IEC 63008 (2016) to sort the relevant tasks. The five tasks consist of three informative tasks (perceive, recognize, and monitor) and two physical tasks (reach and operate). Table 3.2 describes the extended definition of user tasks borrowed and edited from the accessibility operational tasks of IEC 63008 used in this study. This study counted each issue regarding its task characteristics and context to understand the representative accessibility issues within the user groups.

There was a need to split the ad hoc persona in the persona skeleton development procedure, where it verifies the categories of users and identifies subcategories of users. The following criteria were considered when segregating the user groups: (1) differences in the level of utilization of body parts with a disability; (2) physical differences such as height, strength, or shape; and (3) differences in experience and attitude regarding the use of home appliances. Consequently, it is considered whether these differences potentially lead to different and distinct accessibility issues (frustrations and needs) and solution approaches. Of course, the number of personas can diverge, and there is no magic number of personas (Pruitt & Adlin, 2010). However, personas are not for describing every single user, but for the representative user groups. Moreover, the number of personas should be manageable. Therefore, based on the data collected, this study aimed to develop each archetypal and atypical persona within a user group.

Table 3.2 Definitions of accessibility operational tasks

Tasks	Definitions from IEC 63008 (2016)	Extended definitions used in this study
Perceive	To find the product and its parts required to perform the task	Searching task for information and product compartment of interest via sensory channels.
Recognize	To identify/understand the parts required to perform the task	Identification and comprehension of perceived information or product compartment, including prediction or planning for consequent tasks
Monitor	To receive feedback on the operation	Reception of feedbacks and inspection of the current status
Reach	Physical access to the parts required to perform the task	Partial or whole body access (reach and clearance) to product compartments of interest, including the positioning and grasping
Operate	To perform the task	Any physical movements related to the achievement of main goals, including pulling, pushing, pressing, etc.

3.2.3 Persona Creation for Identifying Accessibility Issue

Consequently, consistent organized data and insights were leveraged to create personas conveying the frustration and needs of each user group. Each persona visualized their accessibility issues in a form of a persona card for easier comprehension and empathy. This procedure belongs to the later phase of the persona creation flow in Figure 3.2

As shown in Figure 3.3, a persona card template was developed. It consists of the collected demographics and task characteristics in terms of task barriers and goals, user frustrations and needs, representative quotations, and cartoon characters representing the virtual users of each disabled or elderly group.

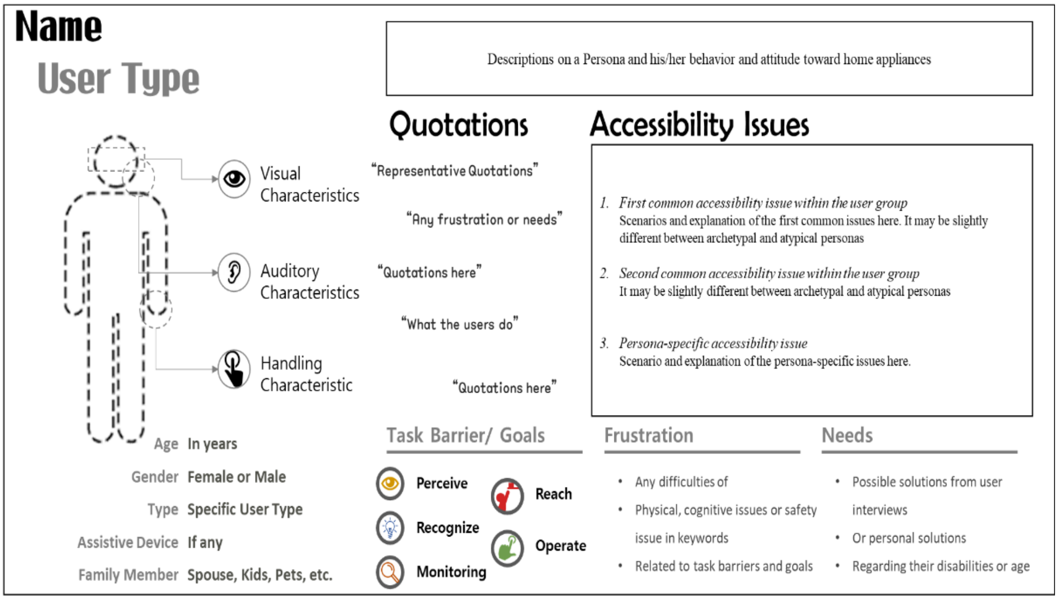


Figure 3.3. Persona Card Template

The cartoon characters represent the physical characteristics of disabled users and elderlies along with assistive devices if any. The task barriers and goals specify the context, whereas the quotations along with the frustration and needs of a specific persona de-scribe the actual accessibility issues of using home appliances under the context. Therefore, we intended that one can grasp the overall accessibility issues by personas since each persona reflects the majority of demographics and accessibility issues to be a representative persona. It is also worth noting that based on our research, we developed additional personas representing some specific issues and characteristics, though they may not be the majority of collected data within their user group since the difference in user characteristics was the main criterion for the within-group persona segregation. Personas for the users with informational disabilities (visual or hearing impairment) diverged based on the level of dependency in their disabled sensations, that is, whether they can still utilize their disabled sensory channel to retrieve information. For spinal-cord-impaired personas, who represent physical disability, the differences in hand shape and gender were the key distinctive features to specify their personas, which indicate the different height and reach/clearance issues. Finally, gender was the main criterion to differentiate two elderly personas who have different anthropometric characteristics and experience in household works.

Finally, each persona was given three accessibility issues: two as common issues within its user group, and the other as persona-specific. For the common issues, the number of issues was counted, and the issue with a high number was chosen as the common issue. On the other hand, the persona-specific issue is assigned to each persona with similar criteria to that of persona segregation because this issue does not overlap with the issues for the other personas. The persona-specific issue must be led by (1) the differences in the level of utilization of disabled/diminished parts;

(2) physical differences such as height, strength, or shape; and (3) differences in experience and attitude regarding the use of home appliances. When prioritizing the issues for both common and persona-specific, an issue arises related to the prevention of autonomous usage, safety issue, and its potential to induce different and distinct design solutions. The issues in persona cards are written in a narrative or scenario-like form.

3.3 Persona Development

3.3.1 User Behaviors and Characteristics

The demographics of the participants are shown in Table 3.3. There were relatively more female users among the user groups, other than the spinal-cord-injured users. The average ages of visually impaired, hearing impaired, spinal-cord-impaired, and elderly users were 41.6, 38.1, 33.6, and 73.1 years old, respectively. Approximately 77% of participants had acquired disabilities, while the participants with a congenital disability were 23%. In addition, two of the elderlies had acquired disabilities, namely hearing loss and brain lesion. The activeness of household work was over 5 out of 7 points for all user groups, other than the spinal-cord-impaired user group. The perceived ICT-ability of each user group was 5, 5.69, 5, and 3.93 for visually impaired, hearing impaired, spinal-cord impaired, and elderly users, respectively. In terms of an assistive device, visually impaired users use a screen-reader and magnifier the most, while hearing-impaired users use hearing aids and cochlear implant devices. Spinal-cord impaired users were all equipped with wheelchairs, and elderly users used glasses and hearing aids.

Table 3.3. Demographics of participants

Demographics		Visually Impaired (n = 14)	Hearing Impaired (n = 13)	Spinal-Cord Impaired (n = 9)	Elderly (n = 16)
Age	Average	41.6	38.1	33.6	73.1
	Min	24	25	20	67
	Max	65	64	45	81
Gender	Female	9 (64%)	8 (62%)	3 (33%)	11 (69%)
	Male	5 (36%)	5 (38%)	6 (67%)	5 (31%)
Disability	Congenital	5 (36%)	7 (54%)	0 (0%)	14 (0%)
	Acquired	9 (64%)	6 (46%)	9 (100%)	2 (12.50%)
Dependent Sensation	Visual	8 (57%)	10 (77%)	9 (100%)	-
	Auditory	11 (79%)	5 (38%)	6 (67%)	-
	Tactile	11 (79%)	3 (23%)	4 (44%)	-
Household work activeness		5	5.63	3.33	5.5
Perceived ICT-ability		5	5.69	5	3.93
Assistive Devices		Screen reader, Magnifier	Hearing aids, Cochlear implant	Wheelchair	Glasses, Hearing aids

The number of accessibility issues found during the interview and observation sessions regarding the user groups is as shown in Tables 3.4 to 3.7. All the accessibility issues were organized based on the five accessibility tasks and chronological product usage phases. The total number of issues from each user group was 89, 55, 92, and 59 for visually impaired, hearing impaired, spinal-cord impaired, and elderly users, respectively. For the visually impaired users, accessibility issues with ‘monitoring’ tasks appeared the most, followed by ‘recognize’, ‘perceive’, ‘operate’, and ‘reach’ tasks (see Table 3.4). For example, visually impaired users have a hard time monitoring the current position or status of home appliances and recognizing what they touched and were afraid to reach out or touch a surface with heat. The hearing-impaired users also showed a similar trend of ‘monitoring’ tasks being the most frequent, followed by ‘recognize’, ‘operate’, ‘reach’, and ‘perceive’ tasks (see Table 3.5). On the other hand, there were accessibility issues with ‘reach’ tasks the most with spinal-cord impaired users, followed by ‘operate’, ‘monitor’, ‘recognize’, and ‘perceive’ tasks (see Table 3.6). Finally, for the elderly users, the accessibility issues were comparably balanced among the four tasks except for the ‘perceive’ task, while the ‘operate’ task was the most frequent issue (see Table 3.7). Most of the comments from participants dealt with in-accessible issues.

Table 3.4. Accessibility issues counted for visually impaired users

Timely Context	IEC 63008 Accessibility Test Task					Counts
	Perceive	*Recognize*	*Monitoring*	*Reach*	*Operate*	
Pre-Usage	4	3	4		3	14
Usage	9	17	21		5	52
Mid-Usage	1	2	8			11
Post-Usage	1		4	1	1	7
Maintenance		2	3	1		5
Counts	15	24	40	1	9	89

Table 3.5. Accessibility issues counted for hearing impaired users

Timely Context	IEC 63008 Accessibility Test Task					Counts
	Perceive	*Recognize*	*Monitoring*	*Reach*	*Operate*	
Pre-Usage		1	1	1	2	5
Usage	3	11	8	1		23
Mid-Usage		1	11			12
Post-Usage			2	4	2	8
Maintenance	1		3		3	7

Counts	4	13	25	6	7	55

Table 3.6. Accessibility issues counted for spinal-cord impaired users

Timely Context	IEC 63008 Accessibility Test Task					Counts
	Perceive	*Recognize*	*Monitoring*	*Reach*	*Operate*	
Pre-Usage	2	3		23	5	33
Usage	2	2	7	9	12	32
Mid-Usage	1				2	3
Post-Usage				15	2	17
Maintenance			1	3	3	7
Counts	5	5	8	50	24	92

Table 3.7. Accessibility issues counted for elderly users

Timely Context	IEC 63008 Accessibility Test Task					Counts
	Perceive	*Recognize*	*Monitoring*	*Reach*	*Operate*	
Pre-Usage		6	4	3	5	18
Usage	2	6	3	1	2	14
Mid-Usage			4		1	5
Post-Usage			1	3	1	5

Maintenance	1		2	5	9	17
Counts	3	12	14	12	18	59

3.3.2 Created Personas

We developed a total of eight personas covering the four target user groups of visually impaired, hearing impaired, spinal-cord-impaired, and elderly people. In the results, each group has two personas representing remarkable differences within the group: one for an archetypal case and the other for an atypical case. In other words, one persona in a group represents a well-known or often-considered case of disabilities or elderlies, while the other represents the case that may be considered rarely. Hence, the archetypal personas are blind, deaf, closed-fist, and grandma personas, whereas the atypical personas are low-vision, cochlear implemented, opened-palm, and grandpa personas, as shown in Figure 3.4.

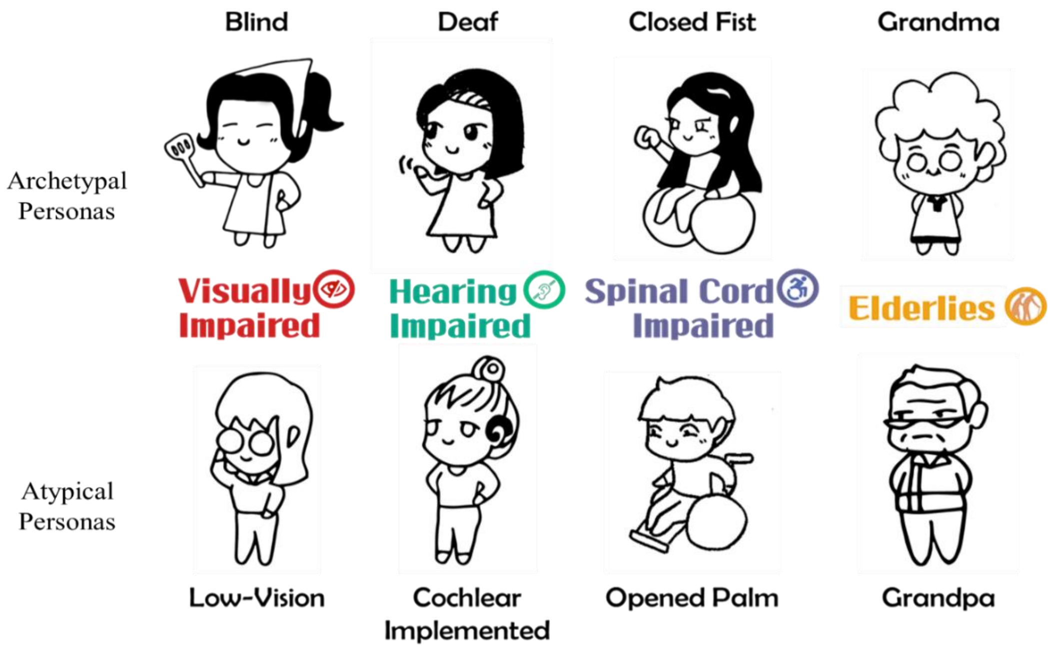


Figure 3.4. Archetypal and atypical personas for the target user groups

As mentioned above, each persona is represented in a form of a persona card. For example, Ms. Suzy is the archetypal visually impaired persona representing the blind users. As shown in Figure 3.5, Her persona card describes who she is on the left: her physical characteristics and how she uses them, an assistive device she uses, and family members. On the right side are her behavior and attitude toward home appliance usage along with a relevant quotation and accessibility issues. Her task barriers and goals are expressed iconically in terms of IEC 63008 tasks, in her case, they are ‘perceive’, ‘recognize’, and ‘monitoring’.

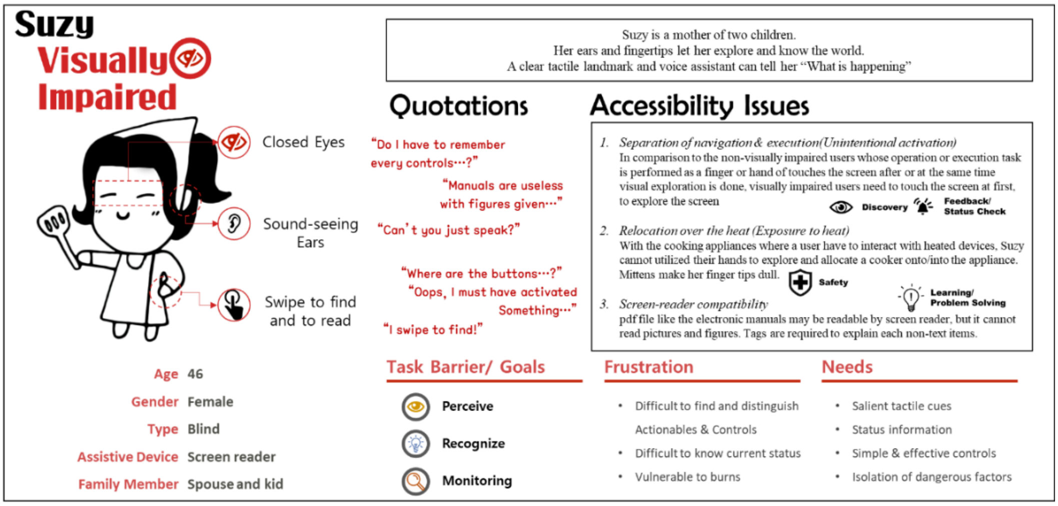


Figure 3.5. Persona card of Ms. Suzy, the blind persona.

At the bottom of her persona card is summarized her accessibility issues in a brief manner—frustration and need. She is frustrated when the operable parts and controls are difficult to find or distinguish due to a lack of auditory explanation and tactile cues. In addition, she struggles to comprehend the current status of home appliances, whether it is running or how it changed after her control inputs. Suzy is also more susceptible to burns since some of the home appliances related to cooking deal with the heat but her awareness cannot protect her enough due to limited monitoring capability. Moreover, her quote, "manuals with many figures are useless" represents the incompatibility of her assistive device: a screen reader. Unless there are corresponding tags given to explain the figures in a screen-reader in compatible text-form, she cannot access any relevant information. The rest of the personas with persona cards are provided below (see Figure 3.6 to 3.12).

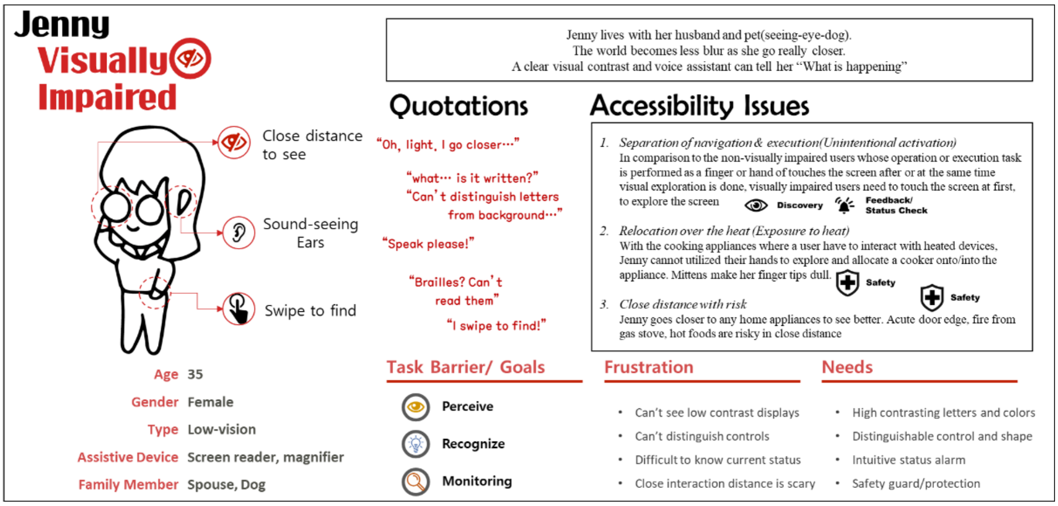


Figure 3.6. Persona card of Ms. Jenny, the low-vision persona

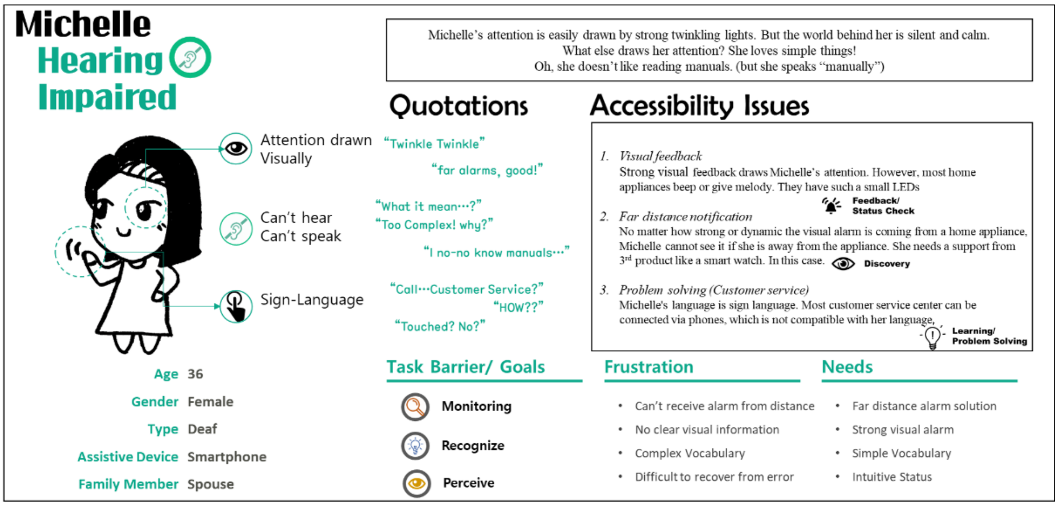


Figure 3.7. Persona card of Ms. Michelle, the deaf persona

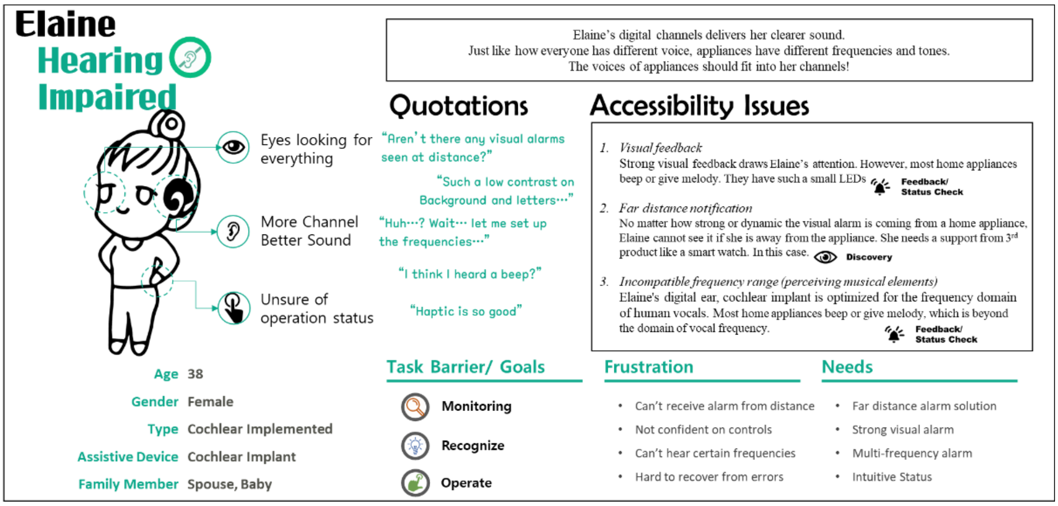


Figure 3.8. Persona card of Ms. Elaine, the cochlear implemented persona

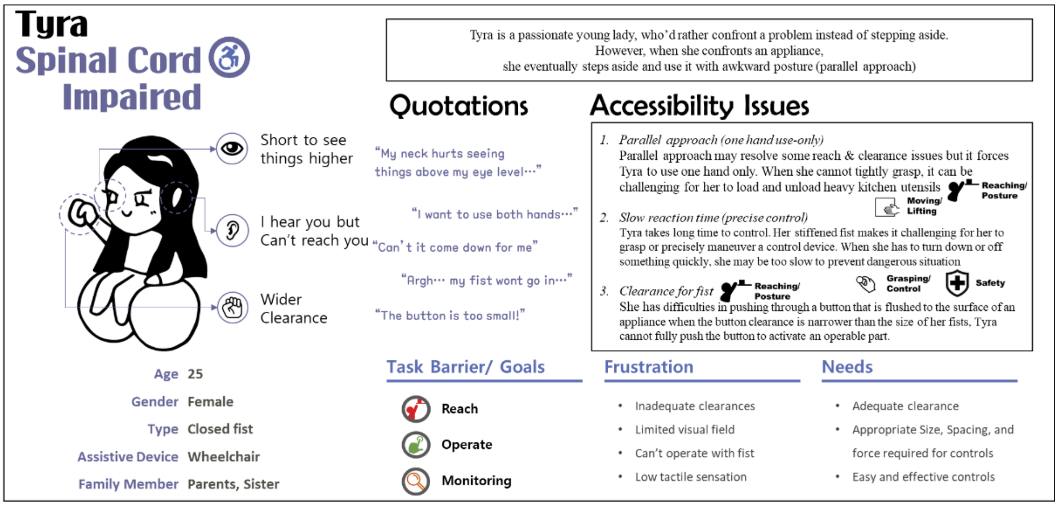


Figure 3.9. Persona card of Ms. Tyra, the closed fist persona

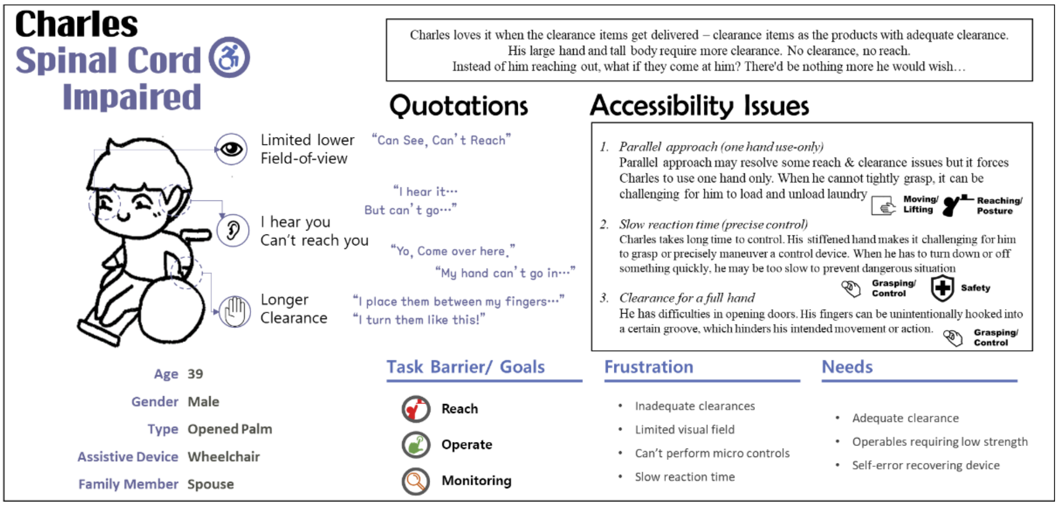


Figure 3.10. Persona card of Mr. Charles, the opened palm persona

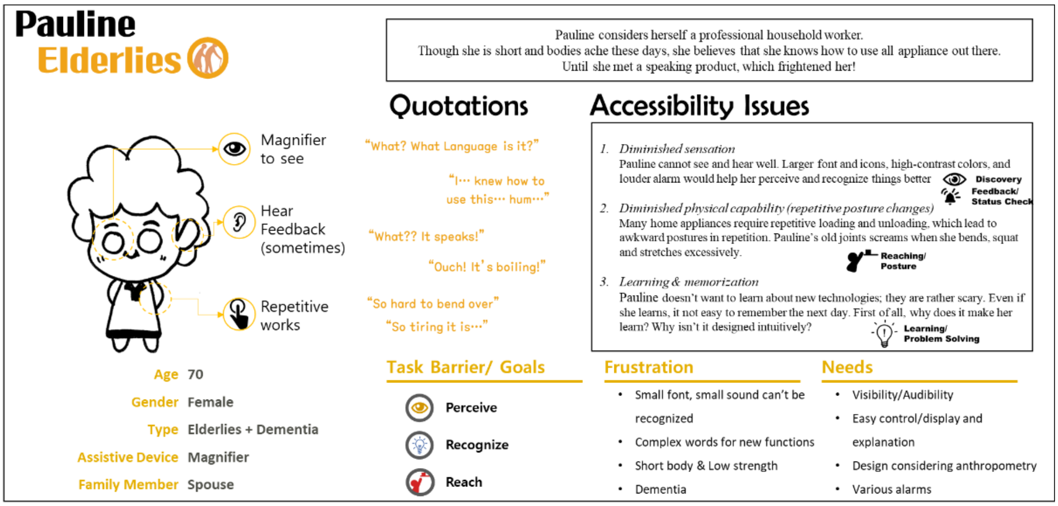


Figure 3.11. Persona card of Mrs. Pauline, the grandma persona

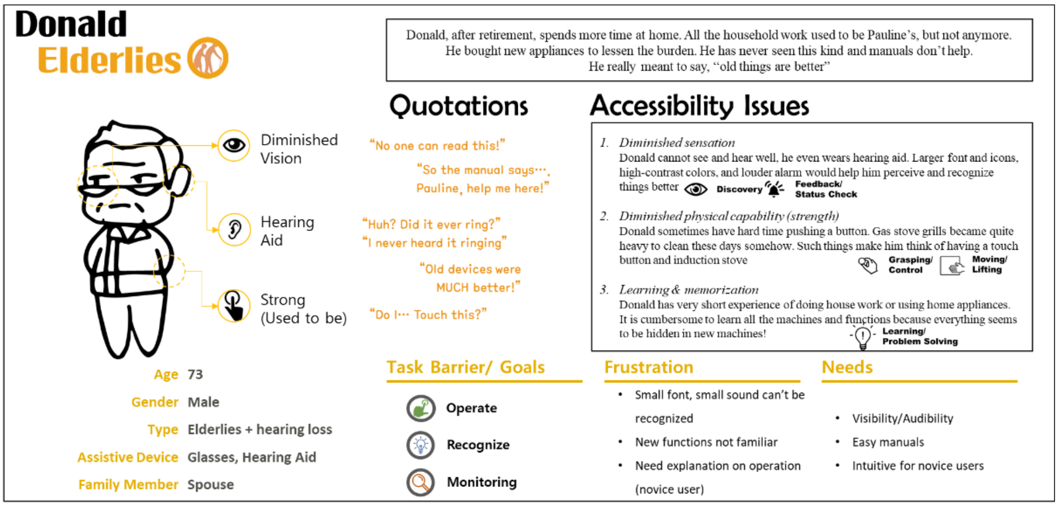


Figure 3.12. Persona card of Mr. Donald, the grandpa persona

3.4 Results and Discussion

The accessibility issues regarding the five accessibility tasks and operational phases allow a manufacturer to grasp the relative frequencies for issue occurrence within the context of home appliance usage. In Tables 3.4 to 3.7, regardless of this relative difference in numbers, one must not assume that the severity of the disability caused the difference in total issue counts, but keep in mind that it took longer for the hearing impaired group to share their experience within a limited interview time since it required a sign language translator to translate their opinions simultaneously. In contrast, the visually impaired and spinal-cord-impaired groups could verbally express their issues, allowing them to utilize the interview time more. In this section, we defined the distinctive behaviors and characteristics of personas and discussed corresponding accessibility issues.

3.4.1 Behaviors and Characteristics of Personas

This section explains the basis of persona segregation within each user group. Each persona representing eight different user types describes its general yet unique behaviors and characteristics under the context of home appliance usage (see Figures 3.5 to 3.12). The difference between archetypal personas and atypical personas is discussed.

3.4.1.1 Personas with Visual Impairments

The personas for visual impairments are the blind persona and the low-vision persona. When people generally think of a visually impaired person, they tend to think of a blind person and usually come up with basic ideas such as the implementation of braille, which is fully tactile-dependent yet excludes visionary solutions. However, one must not hastily assume that every visually impaired user can read braille (Lee & Lee, 2019), as 64% of the visually impaired participants have acquired disability as shown in Table 3.4. Moreover, visually impaired people with low vision showed a high dependency on visual information though the visual information may not be lucid for them. It is important to include a low-vision persona when considering the accessibility issues for visually impaired people so that the idea generated can reflect a multi-modal information provision such as visual supports along with tactile and auditory supports. Thus, we provide common issues for both blind and low-vision personas, along with some dedicated issues per personas

Ms. Suzy, as shown in Figure 3.5, is the blind persona representing the archetypal visually impaired users. Her eyes are closed to represent that she is blind, while her ears are exposed to show that she highly relies on auditory sources. Her quotations and marks on her hand describe her swiping behavior when she explores the product. Ms. Suzy uses a screen reader as her assistive device, which is her verbal companion.

Ms. Jenny, as shown in Figure 3.6, is the low-vision persona representing the atypical visually impaired users. She wears glasses to represent that she does rely on visual sources. Her ears and hands are noted in the same manner as Ms. Suzy. She also swipes her hands over a product just like Ms. Suzy; however, she also approaches a product at a close distance so that she can visually see and comprehend.

3.4.1.2 Personas with Hearing Impairments

The personas for hearing impairments are the deaf persona and cochlear implemented persona. The common misconception toward people with hearing impairments is that textual information can solve their information accessibility issues as mentioned above. Another common misconception is that installing a lighting feedback system can resolve their issues. This misconception disregards the context when the users are far away or turned away from the product, which frequently happens with home appliance usages; users do not stand right in front of the appliances all the time while they are running in operation.

Ms. Michelle is the deaf persona representing the archetypal hearing-impaired users. Her ears are covered by her hair and not exposed to show that she does not rely on auditory feedback, as shown in Figure 3.7. In contrast, her eyes are well-shown, and so are her hands, because she utilizes them well. Moreover, her hands are wiggling and her quotations are simpler in vocabulary to represent that she is a sign language user. A sign language user usually has comparably smaller vocabulary, since the language spoken in their nation is not their mother tongue, but sign language is. Moreover, sign language vocabularies are not fully compatible with common dictionaries. Sign language users tend to have a smaller vocabulary as if they are foreigners (Seo, 2013).

Ms. Elaine is the cochlear implemented persona representing the atypical hearing impaired users. As shown in Figure 3.8, she has a cochlear implant on her ear, and her hairs are tied in the shape of zero and one, representing digital signals because the cochlear implant device converts outer acoustic sound into a digital signal which stimulates her auditory neurons so that she can hear the sound from her circumference. In contrast to Michelle, Elaine's quotations have complete grammar, and she does not wiggle her hands since she prefers to communicate verbally instead of with sign language.

3.4.1.3 Personas with Spinal-Cord Impairments

The archetypal and atypical personas for spinal cord impairments are closed fist persona and opened palm persona, respectively. Other personas are segregated in terms of sensational dependency or difference in household work experience, whereas the personas of spinal cord impairments are segregated based on their hand shapes. Anatomically or physiopathologically, it would be sensible to segregate spinal cord impaired personas based on the damaged area on their spinal cord, which causes a different level of neural communications via their spine

(Association, 1984; Maynard et al., 1997). Thereby, the level of freedom on the upper limb would have named personas such as tetraplegia with C6 injury or paraplegia with T6 injury or L1 injury. However, such names are too technical for the stakeholders to easily comprehend the specific characteristics of personas. In addition, tetraplegia user with C6 injury is simply in worse condition than the paraplegia with T6 injury with lower sensory level and less freedom of body movement (Maynard et al., 1997), so the difference among personas would be minimal, and one persona can inclusively embrace all issues of the other persona.

The reason for creating two different personas for a disability type is to represent different frustrations and needs within the disability group. As we observed and interviewed the real users with spinal cord impairments, the difficulties in the use of the lower back to bend, to reach an object or operable located below or far, or to obtain visual access with limited sight were common throughout the users. However, hands were used, depending on their hand shapes when operating different types of operable parts like controls, doors, etc. Closed-fist users needed wider clearance for their fists to go through, while opened palm users required deeper clearance. Moreover, each persona has the opposite gender with height differences to emphasize the accessibility issues that might occur due to physical differences, such as the difference in height reach and sight.

Ms. Tyra, the closed-fist persona, and Mr. Charles, the opened-palm persona, are the archetypal and atypical personas for the spinal cord users, respectively. The closed-fist type of disabled user is addressed in the ADA checklist (US Department of Justice, 2010), while the opened-palm type of user is not; the opened-palm user is often not considered. Thus, we defined Tyra, the closed-fist persona, as the archetypal persona for spinal cord impaired users.

As shown in Figure 3.9, Ms. Tyra is short in height, and sitting in a wheelchair makes her shorter and therefore less able to perceive items or appliance compartments located above her eye level, without extending her neck. Her hands are stiffened in the shape of a fist, requiring wider clearance for her whole fist to go through when she tries to operate an appliance in particular. Also, her fist does not allow her to precisely control a button or touch type interface, resulting in unintentional activation. She prefers to have an appliance that allows her to utilize both of her hands since it is not easy to grasp or hook her fist through a handle, especially by one hand.

Mr. Charles from Figure 3.10 is comparably taller than Tyra, making it harder for him to perceive or reach items located on a floor. A longer arm may allow him to reach further and higher, but his thicker body requires larger clearance than Tyra. Moreover, his hands stiffened in the shape of an opened palm, requiring longer and deeper clearance to operate an appliance. Moreover, his fingers are more vulnerable to being jammed.

3.4.1.4 Elderly Personas

Both elderly personas share many characteristics and issues with other user groups. For example, their diminished sensation correlates with the disabled sensation of visually impaired and hearing-impaired users. Furthermore, their diminished physical capability correlates with that of spinal-cord impaired users. However, certain points make elderlies distinctive from the other groups. The expertise and experience in household work mainly segregate the elderly personas into two: grandmother persona and grandfather persona. Although the grandmother persona may be weaker in strength and shorter in reach and height, she is more experienced with the household work, so she can operate most of the appliances as long as they work in a fashion familiar to her. On the other hand, the grandfather persona is physically taller and stronger, yet his knowledge of the household is far behind that of the grandmother persona. Both personas struggle from diminished abilities to see, hear, and move at a low level (Cruickshanks et al., 1998; Gerson et al., 1989; Pitts, 1982; Schulz & Fuglerud, 2012), and they prefer dials and buttons to touch screens since they are not familiar with the new technologies like ICT devices (Gregor et al., 2002; Harrington & Haaland, 1992; Koncelik, 1982; Laguna & Babcock, 1997; Virokannas et al., 2000).

Mrs. Pauline from Figure 3.11 is the grandma persona representing the archetypal elderly user. She is comparably shorter in reach and height, and she is weaker in strength. She also suffers from light dementia (Gregor et al., 2002); she keeps forgetting what she was doing. Moreover, the prevalent neologisms throughout the control panel of home appliances make it harder for her to memorize their functions.

Mr. Donald is the grandpa persona representing the atypical elderly users, shown in Figure 3.12. He is comparably taller and stronger than Mrs. Pauline, but weaker than the younger users; he can be categorized as a "fit older person" from a previous study (Gregor et al., 2002). He suffers from hearing loss along with his diminished vision; he tends to miss both visual and auditory alarms. It has been a long time since he did household work, and the modern home appliances evolved so much, making him re-learn everything. Although men participate more in household works these days (Sayer, 2010), a study from two decades ago (Doucet, 1995) confirmed that men are less participatory in household work, and Mr. Donald surely is from such an era. Moreover, this was verified in the interview, revealing their comparably lower expertise in household work than their female counterparts.

3.4.2 Accessibility Issues from Personas

There are various accessibility issues across eight personas; some share the same issues, while some have unique issues. There are at least two common issues and two persona-specific issues provided within each user group. The summarized accessibility issues are as shown in Figure 3.13. More specific accessibility issues are given in persona cards (see Figure 3.5 to 3.12).

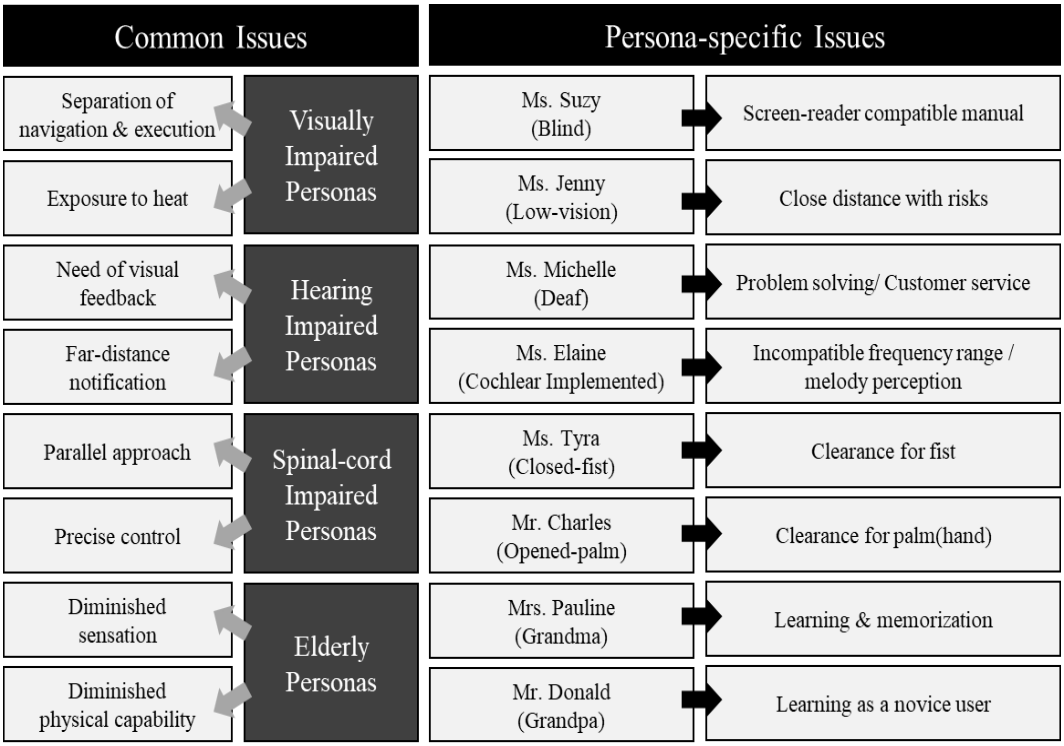


Figure 3.13. Accessibility issues of Personas - common and persona-specific

As we scrutinize the issues of each persona to categorize them, there was a need to expand the five accessibility issues in the following seven terms: (1)

discovery, (2) learning/problem-solving, (3) feedback/status-check, (4) reaching/posture, (5) grasping/control, (6) moving/lifting, and (7) safety. We used these seven terms representing the accessibility context-of-use shown in Figure 3.14 to categorize the accessibility issues. Their names are more task- and context-oriented and self-explanatory than those of IEC 63008 tasks.

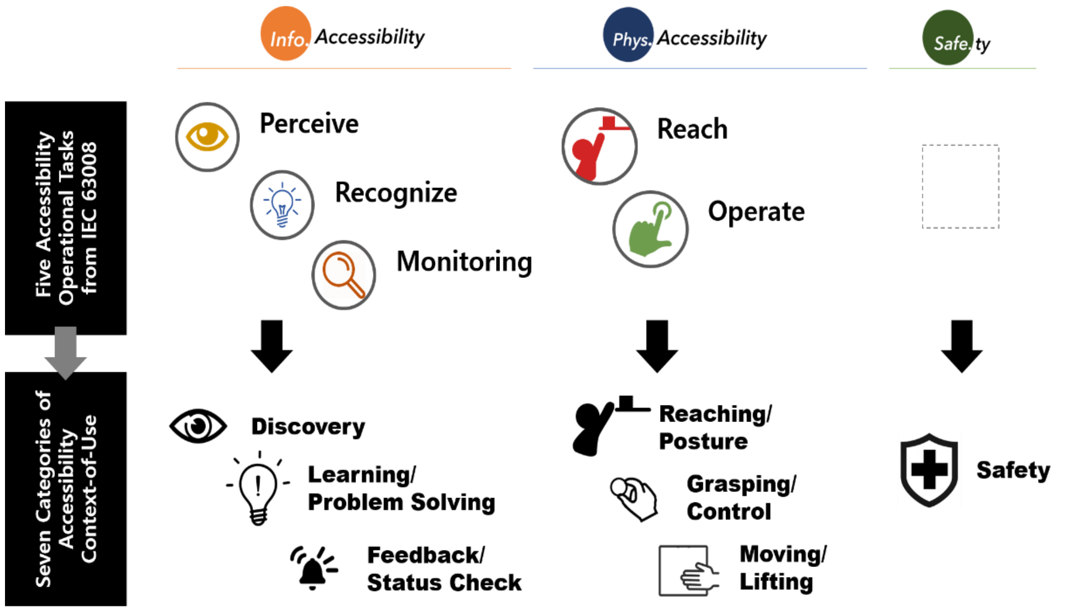


Figure 3.14. Seven categories of accessibility context-of-use expanded from the five tasks in IEC 63008

Firstly, we have three informational accessibility terms: discovery, learning/problem-solving, and feedback/status-check. Discovery is equivalent to that of 'perceive'; it represents the searching task for information and product compartment of interest via sensory channels. The learning/problem-solving took a partial definition of 'recognize', and it is dedicated to the comprehension and planning for consequential tasks. Finally, the feedback/status-check is mostly equivalent to the monitoring task, yet it also partially borrows a definition from ‘recognize’ to represent the identification task. Simplifying, we segregated the ‘recognize’ task into two, merging one part and keeping the other independent.

For the physical accessibility terms, we have reaching/posture, grasping/control, and moving/lifting. Reaching/posture is equivalent to that of the ‘reach’ task. However, the positioning and grasping part of the ‘reach’ task was taken apart from it and was merged with a part of the ‘operate’ task, resulting in grasping/control. This required segregation because the reach issue and grasping/control issue could be investigated independently. Finally, the ‘operate’ task was segregated into two; grasping/control and moving/lifting. The former part is merged with reach to become grasping/control as mentioned, and the latter stayed independent as moving/lifting. The ‘operate’ task was a broad term that represented any arbitrary physical movement to achieve a user’s goal. The segregation into control and movement could clarify the behavioral differences.

Finally, we added the term “safety”, which was originally not included in the IEC 63008 tasks. There is a risk from heat since the users have to deal with the heat when using home appliances such as cooktops, ovens, and microwaves. Moreover, due to the slower reaction time of our target users, acuminate edges of moving parts may cause a safety issue as well. The safety term may seem to overlap with other terms since it occurs while a user performs an interaction related to the rest of the six contexts of use. However, the result is related to the safety of the user, whereas the results of other issues are related to the completion of a task. Therefore, the term safety is worth adding. Based on these seven terms and relevant accessibility issues investigated, a list of checkpoints for accessibility issues in the home appliance context is given in Table 3.8.

Table 3.8. Accessibility checkpoints for the home appliance context

Accessibility Context-of-Use		Checkpoints
Information Accessibility	Discovery	• Can one successfully search for a target or perceive relevant information at any point? • Can one successfully activate a target function or control without accidentally/unintentionally activating the other surrounding components?
	Learning /Problem-solving	• Can one successfully learn or solve errors without the help of others or an assistive device? • Can one easily access the help (customer center, manual) that is compatible with one's condition?
	Feedback /Status-check	• Can one successfully distinguish a target from its surroundings? • Can one successfully understand the current status from feedbacks by any means?
Physical Accessibility	Reaching/Posture	• Can one reach a target without an awkward posture? • Can one reach a target without its surroundings interfering?
	Grasping/Control	• Can one successfully maneuver a control? • Can one utilize a contact grip (no grasp) instead of grasping?
	Moving/Lifting	• Can one lift or move a target to the desired location without excessive force? • Can one allocate a target without the need for a precise maneuver?
Safety		• Can one be isolated from acuminate edge or heat while using a home appliance? • Any safety or automatic error-proof feature built for user's safety?

Note 1: All these checkpoints must be checked with visually impaired, hearing-impaired, spinal-cord-impaired, and elderly users.

Note 2: All these checkpoints must be checked throughout all phases of usage: pre-usage, usage, mid-usage, post-usage, and maintenance.

3.4.2.1 Common Issues across Personas

There were common issues found across the archetypal and atypical personas when using home appliances. There is a total of four accessibility issues related to the discovery and feedback/status-check, two accessibility issues related to reaching/posture and moving/lifting, one issue relevant to grasping/control and safety, and finally, one safety issue. There was no learning/problem-solving context across the common issues across the personas.

The discovery issue combined with the feedback issue is mostly related to the usage phase, where a user tries to find controls and operate them. Visually impaired personas can unintentionally activate the control parts as they swipe over a control panel (Grussenmeyer & Folmer, 2017; Hakobyan et al., 2013; Kane et al., 2008). Furthermore, this issue may occur more frequently because more modern appliances are equipped with touch screen interfaces (Grussenmeyer & Folmer, 2017; Kane et al., 2008). However, an accessibility support feature with a voice assistant like a smartphone (Grussenmeyer & Folmer, 2017; Hakobyan et al., 2013; Vatavu, 2017) can solve this issue by providing a unique strategy of separating the navigation and performance (Kim et al., 2016a).

On the other hand, the information presented in a larger size, higher contrast, and given with multi-channel sensory methods (Connolly & Wilson, 1990; ISO TR 22411, 2008; ISO TR 29138-1, 2008) can be greatly appreciated by both the hearing-impaired personas and elderly personas with diminished sensation. Moreover, especially for the hearing impaired, it may be beneficial to provide tactile feedback with a wearable device when they need noticeable feedback at a far distance from home appliances. The wearables are always in contact with a user (Alkhalifa & Al-Razgan, 2018; Jain et al., 2015), unlike a smartphone sitting on a counter or a table (Hannukainen & Ho¨ ltta¨-Otto, 2006; Hermawati & Pieri, 2019). Tactile feedback can draw their attention much quicker and efficiently (Merat & Jamson, 2008). This solution can also be in the same domain of solution for visually impaired personas.

In terms of physical accessibility issues, both the spinal-cord-impaired and elderly personas have difficulties in reaching/posture and moving/lifting context. The main reasons for this issue are the awkward posture created by the parallel approach (US Department of Justice, 2010) taken by the spinal-cord-impaired personas and the diminished physical capability of elderly personas. Moreover, both the spinal-cord-impaired and elderly personas are comparably slower in reaction time or longer control time—the grasping/control issue. The spinal-cord-impaired personas have stiffened hands, and accordingly, it is challenging for them to grasp or precisely maneuver a control device (Chourasia et al., 2013; Duff et al., 2010; Sarcar et al., 2018; Sollerman & Ejeskär, 1995).

Finally, there was a safety issue found across both visually impaired personas. They encounter re-loading/re-allocation issues during the mid-usage phase under the home appliance context. Specifically, a user interacts with heated utensils or appliances without noticing which part is hot or not. Both blind and low-vision personas cannot utilize their hands to explore and allocate a cooker inside a heated home appliance. One of the interview participants said, "I can wear mitten, but the sensitivity of my fingertip becomes dull." Such an issue hinders the users from successfully following a cooking recipe and discourages them from using the appliance.

3.4.2.2 Persona-specific Issues

Four out of eight persona-specific issues were related to the learning/problem-solving context. These issues may seem alike. However, they were different in terms of the aforementioned criteria: 1) the differences in the level of utilization of disabled/diminished parts, 2) physical differences, and 3) differences in experience and attitude regarding the use of home appliances. The learning/problem-solving issue is a severe problem in terms of autonomy because it requires not only the use of an assistive device but also help from others. In other words, a solution to this issue can drastically enhance the autonomy of the elderly and disabled users.

Reading a manual is problematic when the blind persona—Ms. Suzy—wants to learn about appliances. Most manufacturers these days provide an electronic copy of manuals so that visually impaired people can read them via their screen readers. However, many of them miss providing tags of explanation for figures in manuals. Screen readers cannot read something that is not textified, and the readers are not compatible with manifold pictorial figures to read them like a text (Grussenmeyer & Folmer, 2017). Moreover, manuals are simplified in terms of text, not providing enough information for the blind persona when they cannot refer to pictorial figures. Therefore, manufacturers must provide screen-reader-compatible manuals.

On the other hand, Ms. Michelle, the deaf persona, encounters difficulties in problem-solving when an error occurs. Error codes are mostly in incomprehensible form, and manuals are useless because they are written in a verbose and untranslatable manner for sign language users. When an error that cannot be solved by a user alone occurs, the user will feel frustrated and discouraged from using the product. Such an issue can frequently occur as there can be unintentional activation from a deaf user who cannot hear feedback from what one activated. Eventually, this can cause an error or an error-like incomprehensible state of an appliance. Michelle cannot ask for help from a customer service agent since she cannot make a phone call (Balch & Mertens, 1999; Zafrulla et al., 2008)-verbally. When an error that cannot be solved by a user alone occurs, the user will feel frustrated and discouraged from using the product. Such an issue can frequently occur because there can be unintentional activation from a deaf user who cannot hear feedback from what one activated. Eventually, this will cause an error or error-like incomprehensible state of an appliance. In response, a manufacturer can implement QR codes on their appliances for sign-language-compatible video manuals if they cannot afford to have a sign language translator in their customer service department 24/7.

For the elderly personas, it is challenging for Mrs. Pauline to adopt a new technology or learn about it. This is not only due to the fear of using an ICT device (Laguna & Babcock, 1997; Virokannas et al., 2000) but the light dementia she suffers as well. Such memory loss combined with incomprehensible neologism used in modern appliances makes it harder for her to memorize all the function names written in the control panel of home appliances. She is therefore restricted to use the one function that she frequently uses. Furthermore, she tends to forget about the household works she was doing due to light dementia (Gregor et al., 2002), so she is also exposed to possible risk and repetitive work; mild color coding on controls and timers with alarm for safe use can help her (Connolly & Wilson, 1990; ISO TR 22411, 2008; ISO TR 29138-1, 2008).

On the other hand, Mr. Donald also suffers from learning home appliances but for a different reason. He has comparably short experience of doing household work or using home appliances. It is cumbersome to know which part corresponds to a specific feature or function since he is not familiar with products and their structures. However, his obstinate personality does not allow him to ask for help from others. Nevertheless, his diminished visual and hearing capability hinders him from proceeding with the task without a doubt. He is simply a novice user; the appliances must be more intuitive and self-explanatory.

The persona-specific issue under the feedback/status-check is assigned to Ms. Elaine, the cochlear-implemented persona. A hearing-impaired person with a cochlear implementation does rely on auditory information similar to how a low-vision person is also dependent on visual information. The cochlear implant is optimized for the vocal domain frequency range, which is narrower than that of music or melody (Drennan & Rubinstein, 2008; Khing, 2013; Zhou et al., 2012). Many home appliances implement non-verbal auditory feedback, which has a frequency domain beyond the optimized domain of a cochlear implant, resulting in an incompatible frequency range for Ms. Elaine. Therefore, home appliances with auditory feedback should allow such users to customize the frequencies of feedback alarms at their preference, in other words, at their perceivable range.

For the reaching/posture and grasping/control issues, both the spinal-cord-impaired personas have dedicated clearance issues. These two personas require two different design approaches, though both the issues point toward the clearance issues. Therefore, they are sorted as persona-specific issues. The closed-fist persona (Ms. Tyra) has difficulties in pushing through a button that is flushed to the surface of an appliance when the button clearance is narrower than the size of her fists. In this case, Tyra cannot fully push the button to activate an operable part. Furthermore, most of the handles—even the protruding bar type—do not provide enough clearance for her fist. Therefore, Tyra—the closed-fist type—requires a clearance design based on her fist circumference unless she can hook her wrist on an operable without her fist interfering.

On the other hand, for the opened-palm persona (Mr. Charles), it may seem more accessible to achieve operation in comparison to Tyra's case. The clearance design for him is based on his fingers or hand blade size, which are comparably smaller or thinner than the fist circumferences. However, his fingers can be unintentionally hooked into a groove, which eventually hinders his intended movement or action. The fingers of Charles will prevent doors from opening like a hinge lock. The gap between the two handles should be wider than his finger length or hand length.

Lastly, there is a safety issue for the low-vision persona. A previous study (Granquist et al., 2018) and the observation we conducted demonstrated that the lower-vision users have shorter viewing distances than those of normally sighted users, meaning they have a closer distance to interact with devices. Under the home appliance context, this means they are in close contact with possible risks such as heat and abruptly moving parts—especially when considering unintentional activation is one of the other issues they have.

3.5 Probable Applications and Future Studies

This study aims to investigate accessibility issues under the context of home appliance usages for the target user groups: visually impaired, hearing impaired, spinal cord impaired, and elderly users. Consequently, this study reformed the data collected from the FGI and observation into eight different personas to help stakeholders deeply comprehend and empathize with their users, instead of letting them proceed with stereotypical misconceptions of their target users. Any stakeholders who have not contacted their users with disabilities can have stereotypical misconceptions about their users. They might impetuously conclude that a person with visual impairment will need braille, that a person with hearing impairment can read instead if not heard, that people with a spinal cord impairment only need knee clearance for their wheelchairs, and that elderly people are not active in household work. In addition, designers and manufacturers tend to think of direct resolution under the engineer's perspectives (Broberg et al., 2011) before they adequately scrutinize and define the problem at a deeper level to investigate the actual needs. When the target users are disabled or elderly users whom they do not yet understand, the situation only gets worse. Therefore, this study aims to deliver personas of disabled and elderly users so that the stakeholders not only overcome the difficulties in recruitment but also derive resolutions with clarified and well-defined accessibility problems.

Surely, this study result does not mean that real user involvement is unnecessary when personas are created. However, personas can play a role as a cognitive guideline before conducting a user study on a vulnerable population from scratch. The persona can be used in not only the early stage of product development but also in the later stage, as a scenario of using a newly developed product can be evaluated based on the personas. Personas help manufacturers to narrow down, specify, and define issues with their target users, which would allow them to conduct more efficient and effective user studies. Again, the persona is a user research method for problem definition. Problem definition is more critical to develop an innovative product than solution generation because a well-defined problem can lead to clear solutions (Root-Bernstein, 2003) throughout the overall product development process.

Although Schulz and Fuglerud (2012) recommended creating personas for disabilities, a study from Goodman et al. (2006) pointed out that the focus on stereotypical users can make it hard to communicate detailed information about the range of abilities within a population; thus, personas may provide a limited amount of information only. However, this study provided two types of personas for each user group of disabilities and the elderly to represent the range of abilities within each user population. Each persona spoke of themselves; who they are, how they interact with home appliances, and what they need across all the usage phases from pre-usage to maintenance. There were various accessibility issues, which were both expected and unexpected within their first mile to last mile of usage. Moreover, under the context of home appliance usage, we believe these personas create social links and rapport for stakeholders to empathize with the personas as individuals of a family or neighbors sharing the same life routines—using the same types of home appliances but with difficulties—since the home appliances are the everyday product.

It is undeniable that home appliances are everyday products in general since we use home appliances on a daily basis: to cook, to keep our food being stored, to wash our clothes, and so on. However, are home appliances really the "everyday product" for the disabled and elderly population as well? According to

ISO 20282-1 (2006), the definition of an everyday product is a consumer product or walk-up-and-use product designed for use by members of the general public. Unless the term "general public" is to discriminate against the disabled or elderly population, a simple statement like "home appliances are everyday products" must remain true for disabled users as well; however, this is not presently the case. To design a home appliance that is truly an everyday product, manufacturers and designers are responsible for considering the disabled population in their minds throughout product development; this needs more attention from manufacturers.

There are two limitations of this study in terms of implication. Firstly, the personas we created may be applicable to represent the users who have had their disability for the long term. This study asked the participants whether their disabilities are acquired or congenital. However, the difference was the key factor in neither persona segregation nor the accessibility issue. This may imply that the participants who acquired their disability would have been in the same condition for a long time. On the other hand, the users who newly acquired a disability may have different accessibility issues when compared to users with long-term or congenital disabilities. Unfortunately, the data on impairment duration was not collected in this study; therefore, such a difference could not be investigated. However, such segregation, on top of the archetypal and atypical segregation made in this study would have created too many personas, which is not manageable. Still, we highly recommend investigating meaningful insights on the behavioral differences and consequent differences in accessibility issues within the same user group in a future study.

Secondly, when focusing on the persona characters only, the personas created for this study may be applicable in the domain of home appliance design. This is because any persona created has its dedicated purpose and context-of-use;

therefore, its application can be limited in a certain context. However, in a future study, we believe it is possible to recycle the personas—especially the persona skeletons—created in this study, by implementing proper task analysis with representative tasks such as the five assessment tasks of IEC 63008.

Although previous studies stated that it is not recommended to recycle personas in order to engage stakeholders to know and to empathize with the personas (Pruitt & Grudin, 2003; Schulz & Fuglerud, 2012), a persona with fixed characteristics must be able to interact with multiple products, just like a real user whose characteristics remain constant interacts with multiple products if a persona truly represents a potential real-user. We believe that a persona correspondingly provides new insights or problematic issues in various contexts. If a persona really represents a real user, and it can be reused or recycled for other contexts of use and product usage cases. Furthermore, it can be more valuable to recycle the personas of disabled users created in this study as either skeleton of personas or ad hoc personas to start with for other contexts of use or projects, since the stakeholders will encounter the recruitment issue whenever they try to conduct new user research.

However, the persona is not only the end-result itself but also an analysis tool. The significant results are the investigated accessibility issues represented through personas. As an analysis tool, one may conduct future studies to create personas for other domains by following through with the procedure in this study. Also, a future study to resolve the investigated accessibility issues from this study can be conducted.

Chapter 4

TAT: Therbligs as Accessibility Tool

4.1 Overview

The development of technology has enriched consumer products with various functions and features to enhance the quality of life, albeit with increased complexity. Amongst the various consumer products available, home appliances play a vital role in fulfilling the core needs of humans and enabling people to live independently (Lee et al., 2018). Lately, the common trend with consumer products is to add more functions and features to satisfy the needs of a broader spectrum of users, however, this creates increased complexity, reduces accessible use cases, and hinders the autonomous lives of the elderly. According to the report from the Korean Ministry of Trade (2014) that people with disabilities struggle to use home appliances and the World Health Organization (2011) estimates more than one billion people fall into this category who are alienated from using these core products. Technology requiring new and non-feasible interactions discriminates against users with disabilities from equal opportunity.

In terms of interfaces, people in need of accessibility supports prefer to use devices in an old fashion way because the new layouts, new form factors, and an abundance of features are beyond what they can handle (Whitney, 2017).

Conventional products require their users to perform simple and familiar tasks. On the other hand, such new designs may require whole new different tasks in terms of their difficulties and complexity. It requires the users to perform a task that can be challenging to perceive, understand, learn, reach, accommodate with their range of motion. For example, traditional consumer products consist of a few buttons to press and knobs to rotate, resulting in simple and short user tasks. Disabled and elderly users could have bared with such designs. However, modern-day consumer products with a touch screen interface require a user to touch once, twice, or long-press, navigate the menu hierarchy, etc. The tasks now require more prolonged and cumbersome steps. With physical or cognitive challenges, the burden of the task can increase drastically, but not every single task step is impossible to proceed with. It is important to note that some tasks cause bottlenecks or even hinder progress completely, so a task analytical approach is quintessential to resolve these problems.

Previous studies addressed the importance of the task analytic approach toward the fundamental interactions of disabled users (Browder et al., 1993; Gaylord-Ross & Holvoet, 1985; Lin & Browder, 1990; Maschette et al., 1998; Sailor & Guess, 1983). Accordingly, it is quintessential to scrutinize how the elderly and disabled users interact with a product differently (Browder et al., 1993) and what problematic interaction – in other words, task – makes it inaccessible for the users to use the product - in this case - home appliances.

4.1.1 Task Analysis

Task analysis is a method to meticulously understand both the physical and cognitive perspectives of user's interaction when a user uses a specific product or system to achieve one's desired goal (Kieras & Butler, 1997; Shepherd, 1998). In ISO 9241-11 (1998), it recommends conducting task analysis to investigate the major task and subtasks when evaluating the usability and accessibility of a product or system. Task analysis breaks down a task into subtasks and scrutinizes specific actions, knowledge, or capability required to accomplish the task. Task analysis provides insights on the task itself and methods to accomplish the task (Diaper & Stanton, 2003). Task analysis can be used as a tool to list up and add structures to the tasks that users desire to achieve (Shepherd, 1998) for home appliance usage, and to visualize which of the detailed tasks listed causes accessibility problems.

With such information, it allows a researcher to acquire the user's natural behavior, purpose, limitation, and context of use. However, in this study, the perspectives of constructing the task structure are rather on the appliance perspective, instead. The list of the task sequence and their hierarchical structure not only describes the user's behavior, but also the user interactions that the appliances demand from the users. It is because a user is often demanded to operate a machine with a given design, instead, an appliance is designed for the user's demand. Consequently, it is possible to assess whether a user can accomplish or perform an action or task that an appliance is demanding, otherwise, the appliance is designed badly because it requires a user what a user can't afford to perform. Such analytical assessment procedure through task analysis can scrutinize every single task involved in product usage holistically; which specific task is creating a barrier for a user. Moreover, Stanton and Baber (2005), Stanton et al. (2009), and Al-Hakim et al. (2015) utilized task analysis as a human error identification (HEI) and prediction method. Under the accessibility context, one can consider all problematic tasks as human errors. Therefore, task analysis is a suitable approach to analyze accessibility in terms of user interactions.

Task analysis is fairly easy and applicable (Diaper, 2004), does not require specialized software. It may be time-consuming, however, not as much as the observation or interview may take. Sometimes, it is rather time-efficient. Moreover, its approach is analytical. Thus, in this chapter, the general task sequence of disabled and elderly users was defined via Hierarchical Task Analysis based on the user interaction collected from observation. This study adopted HTA because it is an analytical method for identifying hierarchical sequences and structures of the user's task procedures to achieve the desired task goal, by dividing the task procedure into multiple tasks sequentially, and each divided task is again divided into detailed subtasks or operations (Diaper & Stanton, 2003; Philip et al., 1980; Stanton, 2006). It can be analyzed as a simple unit of the task and has the advantage of being able to easily identify incomplete, illogical, bottle-necking, and conflicting tasks. These so-called inefficient or maleficent tasks investigated cause hindrances and problems in the task goal accomplishment – in this case, the complete use of home appliances- generating accessibility issues. As stated in Chapter 2, such issues are the problems with the effectiveness that prevent users from achieving their desired objectives. Therefore, applying task analysis can investigate and assess the task components that undermine effectiveness, particularly those that make it harder for users to accomplish their task goals, in other words, the accessibility inhibition factors.

4.1.2 Therbligs and Motion Studies

In the late 19th century, Frank and Lillian Gilbreth introduced the motion study to analyze the motion of workers and contributed to the improvement and elimination of unnecessary motion of workers (Niebel, 1958). In the early 20th century, Gilbreath and Gilbreth also introduced "Therbligs" (backward variation of their name, Gilbreth, considering 'th' as one character), which is the unit of basic motions required for manual operation. Although the therblig originates from the operations in factories, the operations of home appliance usage will not deviate too far from that of the manufacturing process when considered in the light of its basic divisions (Niebel, 1958) because therbligs describe basic motions. A user would be searching, reaching for an object to move, use, disassemble, inspect, and assemble.

Therbligs are 18 in total. They consist of both the mental (cognitive) and physical motion of an operator. 18 may seem many in numbers, however, they are the basic motion element and able to represent most of the user interaction. The five tasks of accessibility assessment from IEC 63008 used in Chapter 3 surely correspond to the core interaction of users with disabilities or age. However, they need to be further refined to elaborate on the characteristics and behavior of disabled and elderly users to enhance evaluator's comprehension of how their target users interact with home appliances. For example, in the case of "operate" in which a user performs physical interactions with the product to achieve their desired goals, the user behavior may be as simple as button-pushing or rotating or it can be subdivided into pulling, pushing, assembling, and disassembling specific target objects to the extend. Thus, this study subdivided a single chunky task of "operate" into grasp, move, use, assemble, or disassemble by replacing it with therbligs. In the same manner, there are therbligs equivalent to the five accessibility tasks of

IEC 63008, and non-equivalent therbligs also, as shown in Figure 4.1.

The therbligs in non-equivalent tasks in Figure 4.1 are all essential tasks in the home appliance usage context such as position, pre-position, grasp, hold, select, etc. It is because the IEC 63008 solely focused on the controls or operable parts individually; no consideration on non-moveables, displays, etc. The figure above indicates that therbligs can describe or express user tasks in more detail than IEC 63008 accessibility tasks can do.

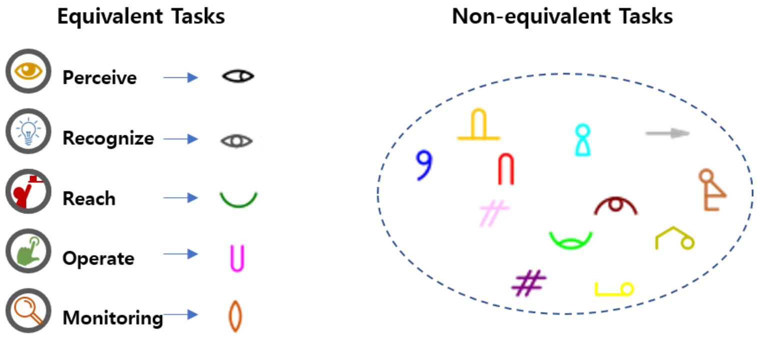


Figure 4.1. Five tasks from IEC 63008 and equivalent/non-equivalent therbligs

Traditional therblig analysis or motion study usually focuses on the investigation of ineffective therbligs within a work cycle to remove them, especially under the context of manual works in assembly lines (Barnes, 1949; Niebel, 1958; Salvendy, 2004). However, recent studies utilize the concept of therblig and motion study to apply in various fields of studies (Al-Hakim et al., 2015; Browder et al., 1993; Jia et al., 2014; Oyekan et al., 2019). Al-Hakim et al. (2015) redefined and applied the principles of motion economy in a surgical context. Browder et al. (1993) combined therblig and task analysis and used therbligs as an instructional tool for people with intellectual impairments for better and efficient learning/instruction tools. Jia et al. (2014) and Oyekan et al. (2019) applied the concept of therblig as a unit of motion beyond the field of human work, they applied their newly developed and defined therbligs in operational machines. The potential of therblig and motion study is unlimited.

Likewise, this study conducted the therblig-based HTA to establish the task sequence and structures for each target user under the home appliance context. It investigates the ineffective therbligs along with the task structure for each user type, analyzes probable design improvement based on the principles of motion economy, and proposes newly developed therbligs if needed. In other words, this study will show how therbligs can be a versatile tool to assess accessibility issues and provide design guidance. Besides, this chapter will compare the results from the therblig analysis to the previous interview results from Chapter 3 and verify whether the time and resource-consuming interview procedure can be supplemented with a simpler task analysis based on therbligs when aiming to investigate the problematic issues in terms of accessibility. This study would like to show that therbligs can be a great accessibility tool for accessibility, rather than a mere operation unit in a factory.

4.1.3 Redefining Therbligs

Researcher by researcher, there can be various definitions of therbligs. However, in the case of the original therbligs, they are used for the operation process at factories, which means that it may not be appropriate to apply them directly to the context of home appliances. This study borrowed the definitions from Ferguson (2000) because Ferguson combined the definitions of therbligs assigned by Gilbreth, Alan Mogensen, Ralph Barnes, and provide more systematic and broader perspectives of therbligs application. Also, the therblig definition from Oyekan et al. (2019) is borrowed because they clarified when the motion begins and ends. Consequently, the definition of therbligs should be modified in accordance with the context of home appliance uses as shown in Tables 4.1 and 4.2.

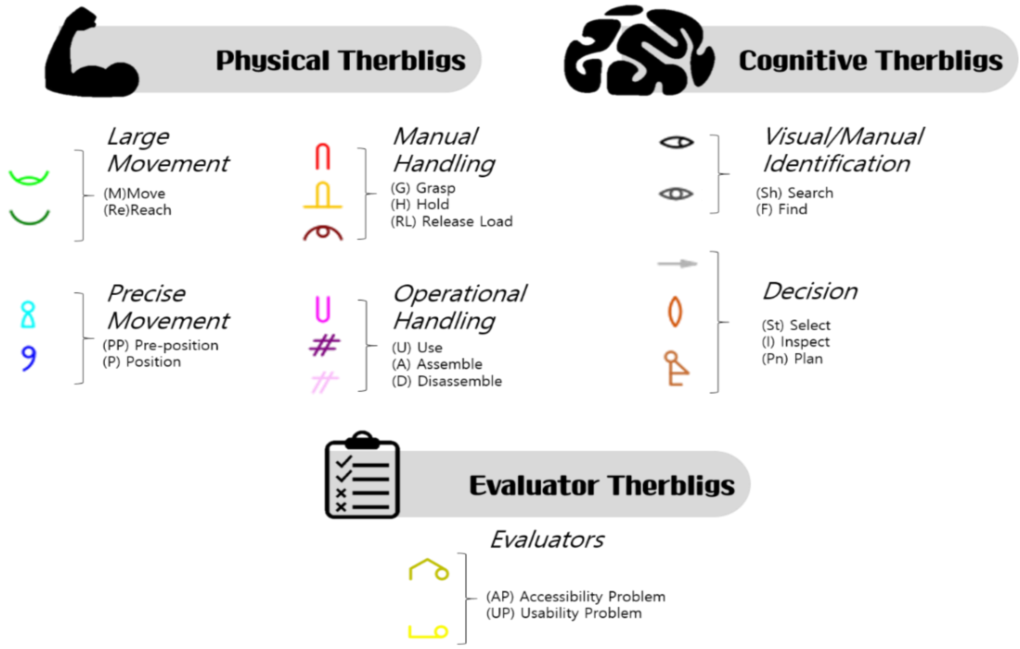


Figure 4.2. Therblig Categorization

Physical Therbligs. Physical therbligs require the user's hand or upper limb manipulation: grasp (G), hold (H), reach (Rh), move (M), release load (RL) position (P), pre-position (PP), use (U), assemble (A), and disassemble (DA). The physical therbligs are sub-divided into two movements (large movement and precise movement) and two handlings (manual handling and operational handling). Large movements are reach and move therbligs. They require a user to move not only their hands but their upper limb or even whole body. Thereby, the displacement of a corresponding product component is relatively larger. Precise movements, on the other hand, are position and pre-position. A user's action occurs within a specific spot and the displacement of a corresponding component is relatively smaller. For position, which originally includes simultaneous inspect task as a user positions, it is now only in charge of precise movement, if necessary, it accompanies with inspect therblig after it. Manual handling therbligs are grasp, hold, and release load. These therbligs are associated with clenching and the opening of a hand. Finally, the operational handlings are use, assemble, and disassemble. They indicate the sub-task or task goals.

Other than position and hold, the rest of the physical therbligs are all effective, meaning they are necessary to achieve the task goal, and cannot be removed. When the effective therbligs are problematic, a researcher would enhance the operation by shortening the time or route required for the task instead of removing the operation. Most of the time, they will be troublesome for spinal cord impaired users and elderly users.

Cognitive Therbligs. Cognitive therbligs do not involve the user's body motion but cognitive processes: search (Sh), find (F), select (Sl), inspect (I), and plan (Pn). They are sub-divided into identification and decision. Identification therbligs are 'search' and 'find' so they perceive, recognize, and distinguish a target object. Decision therbligs are select, inspect, and plan so they the tasks that a user compares the target object with peripherals, criteria, or their expectation. The cognitive are all ineffective therbligs. Thereby, the solution aims to eliminate them as much as possible.

Many recent studies omit the find therblig since it is a spontaneous mental reaction at the end of the search task, which means a user recognizes what they searched for. Nonetheless, disabled or elderly users with limited sensation capability may not able to “find out” what they searched. For example, a visually impaired, the blind user successfully searched a target and knows something is there, yet may not find out what the object is. Moreover, the segregation of search and find is equivalent to the segregation of ‘perceive’ and ‘recognize’ from IEC 63008. Therefore, the use of find is critical when assessing the accessibility issue. The comprehension part is originally involved in the plan therblig, however, the task representing comprehension of a target is assigned to the find therblig instead to clarify the identification and decision and to smoothen the therblig sequence (search to find instead of search to plan). Plan therblig is dedicated to error resolutions, instead.

Evaluator Therbligs. Unavoidable Delay (UD) and Avoidable Delay (AD) were considered as barriers causing discontinuity of product usage rather than simple delays by extending their definitions. To establish the levels or priorities of evaluation, this study used these two therbligs to evaluate whether the cause of inhibition was an accessibility issue that prevented the task completion or the usability issue that took a prolonged time to complete a task. The unavoidable delay beyond the operator's control in the original therblig is now defined as the accessibility problem (AP) beyond the user capability.

These newly defined therbligs can indicate the relative importance among the evaluated tasks and determine the design improvement priorities and direction accordingly. If required, rest (R) therblig may be redefined to indicate a viable task. However, the symbol will no longer be intuitive for the new meaning, and its abbreviation needs change; R may represent "reasonable" but changing its symbol and letter with "V" meaning viable sounds more valid though that would be totally indifferent new therblig apart from the original rest therblig. Moreover, the indication of accessible or usable tasks is not the aim of this evaluation tool but the indication of bottlenecking tasks is.

Table 4.1 Traditional and Redefined Therblig Definitions

No	Name	Symbols		Definitions	Redefined definitions for the context of home appliance/consumer product	Types
1	Search	Sh		Attempting to find an object using the eyes and hands	Searching for/Exploring through an object via eyes or hands	Ineffective Cognitive ID
2	Find	F		A momentary mental reaction at the end of the search cycle	A momentary recognition of what the searched/explored object is, as a result, comprehension on how to (dis)assemble or use it ("Find-out")	Ineffective Cognitive ID
3	Select	St		Choosing among several objects in a group	Navigating with the purpose of selecting/choosing among several objects in a group	Ineffective Cognitive DC
4	Grasp	G		Grasping an object with the activated hand	Grasping an object with the active hand/body parts	Effective Physical MH
5	Hold	H		The retention of an object after it has been grasped, [with] no movement of the object taking place	The retention of an object after it has been grasped by one hand, [with] the other hand to operate on the object	Ineffective Physical MH
6	Reach	Rh		The motion of moving the unloaded hand from the point of "Release Load" to the next function within the sequence	The motion of approaching/reaching by moving the unloaded hand or body to a certain point to the next function within the sequence	Effective Physical LM
7	Move	M		Moving an object using a hand motion	Moving an object using a hand/body motion to a certain place/position	Effective Physical LM
8	Release Load	RL		Releasing the object when it reaches its destination or releasing control of an object	Releasing whatever that was grasped in advance	Effective Physical MH
9	Position	P		positioning and/or orienting an object in the defined location for "Use"	(Precisely) positioning and/or orienting an object in the defined location for the very next task	Ineffective Physical PM

*LM= Large Movement; PM= Precise Movement; MH= Manual Handling; OH= Operational Handling; ID= Identification; DC=Decision; EV=Evaluator

Table 4.2 Traditional and Redefined Therblig Definitions (Cont'd)

No	Name	Symbols		Definitions	Redefined definitions for the context of home appliance/consumer product	Types
10	Pre-position	PP		Positioning and/or orienting an object for the next operation and relative to an approximation location	(Approximately) Positioning and/or re-orienting an object for the next operational sequence	Effective Physical PM
11	Use	U		Manipulating a tool in an intended way during the course working	Operating an object/tool for its intended use	Effective Physical OH
12	Assemble	A		Joining two or more parts together	Joining two or more parts together	Effective Physical OH
13	Disassemble	DA		Separating multiple components that were joined	Separating multiple components that were joined	Effective Physical OH
14	Inspect	I		The act of comparing the object with a predetermined standard by employing all human senses	The act of comparing received/perceived feedback with a predetermined/intended action performed by employing all human senses	Ineffective Cognitive DC
15	Plan	Pn		A mental function, which may occur before "Assemble"(deciding which part goes next) or prior to "Inspection", noting which flaws to look for	A mental function which precedes error resolution, deciding which course of action to take (Comprehension on how to (dis)assemble or use is assigned for "Find")	Ineffective Cognitive DC
16	Unavoidable Delay	UD		Waiting due to factors beyond the worker's control and included in the work cycle	Incompletion of work due to factors beyond user's control or capability	Ineffective EV
17	Avoidable Delay	AD		Waiting within the worker's control, which causes idleness that is not included in the regular work cycle	Incompletion of work due to cumbersome or counter-intuitive product design	Ineffective EV
18	Rest	R		Resting to overcome fatigue, consisting of a pause in the motions of the hands and/or body during the work cycles or between them	N/A (Removed)	N/A (Removed)

*LM= Large Movement; PM= Precise Movement; MH= Manual Handling; OH= Operational Handling; ID= Identification; DC=Decision; EV=Evaluator

4.1.4 Changes in the Principles of Motion Economy

The use of therbligs - or the concept of motion study for accessibility - is not a new nor a totally obscure idea although it was barely studied by the researchers. The inventor of Therbligs - Gilbreth and Gilbreth (1920) - stated its possible use for the accessibility evaluation with substantial impact. In their study of motion study for the handicapped, their focus was to investigate bottlenecking tasks and reclassify the work cycle to improve the productivity of disabled workers so that shall be of permanent value to the handicapped and to the community of which they form a part.

In traditional therblig analysis, a researcher checks for the ineffective or problematic therbligs and proposes the elimination or shortening of the time taken for those therbligs by the principles of ECRS (E: eliminate / C: Combine / R: Rearrange / S: Simplify). However, in this therblig study, a researcher checks for the inaccessible therbligs with accessibility or usability problems, and proposes the elimination of them or replacement of the task routine by design changes. Although this study advocates the motion study, it did not measure the time taken by users because the target investigation was the binary, discrete possibility of work performance indicating whether they can perform or not, instead of the length of continuous-time span which represents the relevant performance given that they can perform a task goal completely. It focused more on the task behaviors and their probable improvements, instead. Such difference also led to the modification of principles of motion economy when applied for disabled and elderly users. The list of 22 principles of motion economy under three large categories is given in Table 4.3. The definitions were borrowed from Barnes (1949) and Kanawaty (1992).

Table 4.3. Principles of Motion Economy

A. The use of the human body		
1	The two hands should begin as well as complete their motions at the same time	Not Applicable
2	The two hands should not be idle at the same time except during rest periods	Not Applicable
3	Motions of the arms should be made in opposite and symmetrical directions and should be made simultaneously	Not Applicable
4	Hand motions should be confined to the lowest classification with which it is possible to perform the work satisfactorily	Partially Applicable
5	Momentum should be employed to assist the worker wherever possible, and it should be reduced to a minimum if it must be overcome by muscular effort	Applicable
6	Smooth continuous motions of the hands are preferable to zigzag motions or straight-line motions involving sudden and sharp changes in direction	Applicable
7	Ballistic movements are faster, easier, and more accurate than restricted (fixation) or controlled movements	Applicable
8	Rhythm is essential to the smooth and automatic performance of an operation, and the work should be arranged to permit an easy and natural rhythm wherever possible	Partially Applicable
9	Work should be arranged so that eye movements are confined to a comfortable area, without the need for frequent changes of focus	Applicable

B. The arrangement of the workplace		
10	There should be definite and fixed places for all tools and materials	Applicable

11	Tools, materials, and controls should be pre-positioned to reduce searching	Applicable
12	Gravity feed, bins, and containers should be used to deliver the material as close to the point of use as possible	Applicable
13	Tools, materials, and controls should be located within the maximum working area and as close to the worker as possible	Applicable
14	Materials and tools should be located to permit the best sequence of motions	Applicable
15	Drop deliveries or ejectors should be used wherever possible so that the operative does not have to use his or her hands to dispose of the finished work	Applicable
16	Provision should be made for adequate lighting conditions for seeing, and a chair of the type and height to permit good posture should be provided. The height of the workplace and seat should be arranged to allow alternate standing and sitting	Partially Applicable
17	The color of the workplace should contrast with that of the work and thus reduce fatigue	Applicable

C. The arrangement of the workplace		
18	The hands should be relieved of all work of holding that can be done more advantageously by a jig, a fixture, or a foot-operated device	Applicable
19	Two or more tools should be combined wherever possible	Applicable
20	Where each finger performs some specific movement, such as in typewriting, the load should be distributed in accordance with the inherent capacities of the fingers	Partially Applicable
21	Handles such as those used on cranks and large screwdrivers should be designed to permit as much of the surface of the hand to come in contact with the handle as possible. This is particularly true when considerable force is exerted in using the handle. For light assembly work, the screwdriver handle should be so shaped that it is smaller at the bottom than at the top	Applicable

22	Levers, crossbars, and handwheels should be located in such positions that the operator can manipulate them with the least change in body position and with the greatest mechanical advantage	Applicabl e

The first three principles are not applicable because this study does not assume that a user utilizes both hands concurrently, except for the case where Hold therblig is utilized. A user with spinal cord impairment takes the parallel approach when using a home appliance to maximize their arm-reach, as described in the personas developed in Chapter 3. This posture maximizes a reach envelope for one arm with the sacrifice of the other. In the case of visually impaired users, especially blind users, one of their hands (usually left hand) is placed on a certain point of a product while the other navigate and operate as it swipes over the product surface. The hand in a fixed position takes a role as an arbitrary landmark as an orientation reference, while the swiping hand does the rest of the operational tasks such as searching, reading braille, controls, and so on. Despite these users' characteristics, the context of home appliance use also defies the first three principles of motion economy. Most home appliances do not require full-time utilization of bi-manual tasks unlike how material handling does in operations for the manufacturing process where therbligs are first developed for. Surely some tasks within home appliance usage such as allocating heavy items (e.g., a pot filled with foods, large laundry, etc.) may highly benefit from bimanual utilization, however, it is not a mandatory behavior and is seldom performed. Besides, most of the operations can be done by one hand.

Besides, four principles can be applicable with certain modifications: the 4th, 8th, 16th, and 20th principles. First, the fourth principle is a very essential principle related to physical fatigue. Moreover, it provides a general classification of hand motions as shown in Table 4.4, and it is something that beginners can refer to. The reason why this is marked as partially applicable is that the finger motions are no longer the lowest or easiest class of motion anymore when it comes to disabled users, especially the spinal cord impaired users.

Table 4.4. General classification of hand motions

Class	Involved body parts (upper limb)
1	Finger motions
2	Motions involving fingers and wrist
3	Motions involving fingers, wrist, and forearm
4	Motions involving fingers, wrist, forearm, and upper arm
5	Motions involving fingers, wrist, forearm, upper arm, and shoulder.

Barnes (1949) also addressed that the finger motions are more fatiguing and the forearm is the most desirable member to use for light work. In this principle, the lower the class of motion is, the fewer members of body parts are involved in the motion. Consequently, the class can be written in terms of body parts excluded in motion instead of involved. The spinal cord impaired users, also manipulate operable parts mostly by forearm motions because it is challenging for them to manipulate their fingers and wrist. Moreover, for the motions of classes one and two, it requires firm support of the forearm to manipulate only fingers or wrists. Such compartments hardly exist within any home appliances. Therefore, for universality, the first two classes can be ignored, and one can combine finger and wrist into "hand", simply. Then the lowest class will be the third class and it represents the motions involving hands and forearm. With this simplification, this principle of motion economy may be more applicable to meet the purpose of this study.

Secondly, the eighth principle addresses the rhythm of workflow and its importance. However, for home appliance usage, there aren't many repetitive operations and the operations are not performed for such a prolonged period of time to create a rhythm for a user. However, in terms of rhythm referring to smoother workflow, it can be covered by the sixth principle. Therefore, it is marked as partially applicable. Thirdly, the sixteenth principle consists of human factor issues with illumination and postures. In the book of Barnes (1949), this principle was three separate principles. In terms of posture, it is more of height adjustment and resting by the provision of height-adjustable chairs for workers. First of all, there isn't much of sedentary posture used under the context of home appliance usage, other than a spinal cord impaired user in a wheelchair. That too, the wheelchairs are mostly not height-adjustable, thus an appliance must be designed in a size that the spinal cord impaired user can reach effortlessly. Therefore, in the sixteenth principle, only the principle related to illumination is applicable.

Finally, the 20th principle can be ignored or modified because of the same reason the fourth principle is simplified; finger usage is restricted for some user groups. However, this principle is critical considering the user's capability, and no other principles can substitute for this principle. Therefore, it can be modified with a broader statement, "The load should be distributed in accordance with the inherent capacities of the user."

In addition, the 9th, 11th, 16th, and 17th principles only contain the context of eye searching and inspecting, thus it should extend their domain to any sensation a user can use. Moreover, all the terms of workers can be replaced by a more relevant term, “user”.

4.2 Methods

This chapter aims to propose a new methodology to investigate, evaluate, and provide solutions for the accessibility issues under the context of home appliance usage. It is a novel implication of redefined therbligs combined with task analysis. A total of 52 participants (14 visually impaired, 13 hearing impaired, 9 spinal-cord impaired, and 16 elderlies) were asked to freely try out prepared home appliances and observed. As shown in Figure 4.3, based on the observed user behaviors and collected user characteristics from accessibility-related documents, this study 1) redefined therbligs, 2) classified product components of target users, and 3) conducted hierarchical task analysis with therblig notations in order to 4) specify and evaluate the inaccessible tasks for the disabled and elderly users.

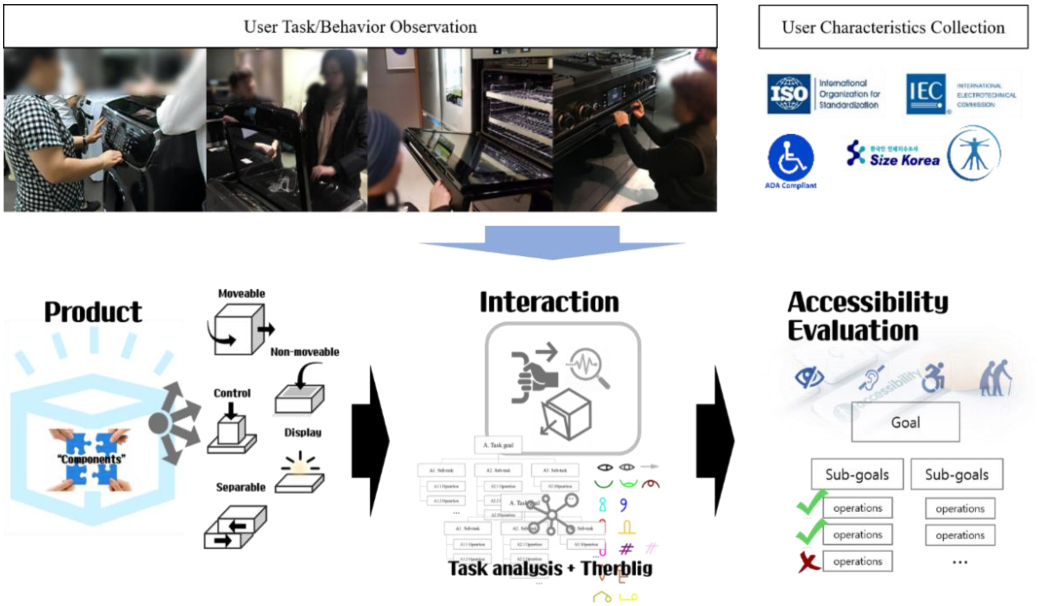


Figure 4.3. Therblig-based task analysis and evaluation process

4.2.1 Therblig-based Task Analysis

Hierarchical Task Analysis (HTA) structuralized the task procedures used by the disabled and elderly users and each detailed task was assigned with a therblig to express the physical or cognitive interaction of the users. Therblig-based task analyses can yield a specific number of steps for a task depending on the movements required (Browder et al., 1993). Each task structure consists of task goals, sub-tasks, and operations, as shown in Figure 4.4. Its goal was to evaluate the accessibility of a product, in other words, it is to identify the problematic task at a micro-level and to come up with an efficient improvement plan that localizes only the necessary tasks (operations). The improvement plan - in other words, solutions - suggested by therbligs are based on the principles of motion economy.

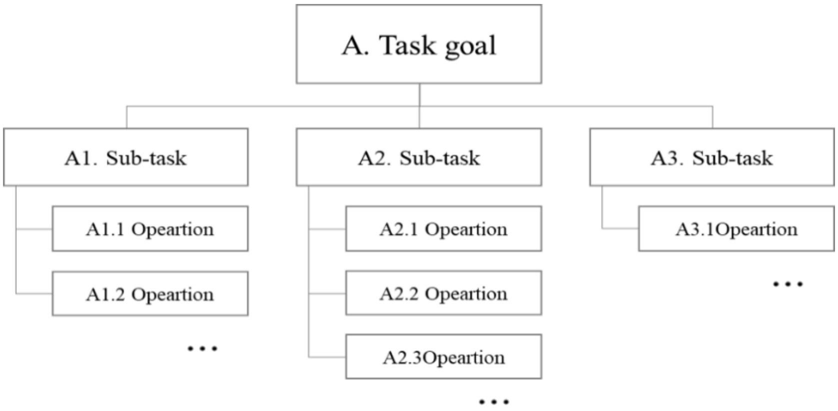


Figure 4.4. Example task structure

Task goals. This study defined the upper-level task goal under the context of use in chronological order as shown in Figure 4.5: 1) pre-usage(preparation), 2) usage(control), 3) mid-usage(monitoring), 4) post-usage(wind-up), and 5) maintenance. So, the whole product usage cycle is covered.

The pre-usage context consists of manipulation of a moveable and positioning a target object on a non-moveable part. Usage context consists of input command and manipulation of controls. Mid-usage context represents notification and error checking situations in the midst of a product running. In the post-usage context, a user unloads an item from a non-moveable before and after manipulating a moveable. Finally, the maintenance context describes the user manipulation of separables to disassemble and reassemble them back.

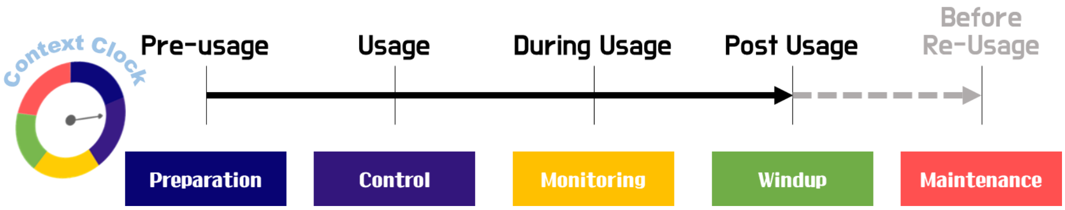


Figure 4.5. Context of use listed in terms of chronological order

Sub-tasks. Sub-tasks are classified based on the task that needs to be done according to the nature of each target home appliance and its compartment behavior. First, in the pre-usage context, the goal was to open the moveables in order to expose the non-moveables, move the related items to the non-moveables, and then close the opened moveable parts. The task structure omitted the tasks related to opening and closing the moveables if there is no moveable part like the cooktops; it only consists of tasks allocating the related items like a pot on the non-moveable part of a cooktop.

Operations. Operations are expressed in terms of therbligs in order to 1) exclude the subjectivity of vocabulary used by researchers expressing each task, and 2) to ensure a sense of unity with other tasks. The task names, a chunk of tasks, task sequence can be differently expressed, combined, split by each analyzer.

Therefore, there must be a standard unit of task that can be universally used. This study utilizes therbligs by assigning them as operations (or a chain of operations) under each sub-task.

General Task Sequence. For each task goal and sub-task, there are established sequential operations concerning the type of compartment a user can interact with. Depending on their product designs, a user can take different actions accordingly, however, the variety of chain of actions shares a common therblig framework by compartment type. For example, a moveable requires the following therblig sequence: search – find – reach – grasp – move - release. However, in between the therbligs, there can be select, position, hold, position, pre-position, and inspect if needed. The overall decision tree, or flow chart, for the operation sequence of all kinds of compartments, is as shown in Figure 4.6.

Every operation starts with search therblig and is followed by find therblig. If there is more than one object to choose, then a user performs select therblig, otherwise, the user will move on to reach therblig. Position therblig can follow if the object requires a precise approach or contact. A grasp occurs when the object requires it, such as a door, door handle, or knob, otherwise skipped. Hold will not occur without the grasp preceding it. Once grasped, a user can either move or operate. If a user moved an object, he or she can release their grip or position the object before releasing it. If a user is to operate, one can either use or disassemble an object. In between, there can be moving and position involved. Finally, just like how every work started by search, it will end with inspect therblig, which checks the final status of user's operation. There were a few therbligs added or switched in orders in between the therblig sequences by different user groups, however, the basic structure remained the same for visually impaired, hearing impaired, spinal-cord impaired, and elderly users.

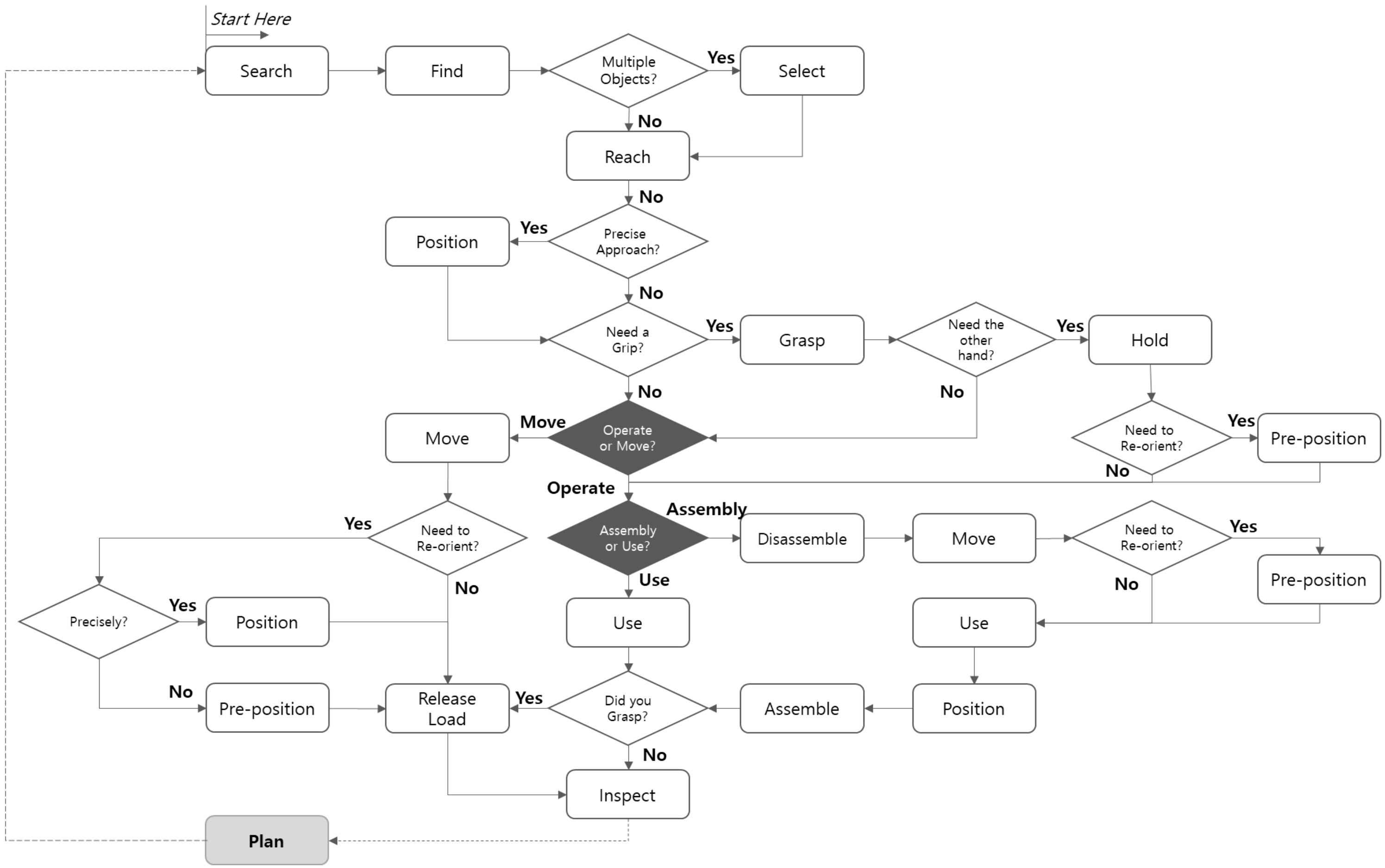


Figure 4.6. Therblig Sequence Flow Chart

4.2.2 Task Evaluation

In this study, the tasks, potential accessibility issues, and the role of motion economy associated with the issues were explored after the general task structure is established for each target appliance and usage phase.

First, each therblig assigned as operations under the sub-tasks were evaluated as either AP (Accessibility Problem) or UP (Usability Problem) if there is a possibility that a user can encounter any accessibility issues. Therbligs evaluated as AP are the processes requiring the user's disabled capability. For example, a search therblig will be evaluated as an AP operation when a visually impaired user cannot perceive task-related information or component because they are provided without any alternative sensory channels other than the visual channel. Searching for a written text without braille nor a voice assistant under a flat surface is surely an accessibility problem for a visually impaired user.

On the other hand, the avoidable delay within the operator's control is now defined as the usability problem (UP) within the user capability. For example, the same search operation is problematic for a non-visually impaired user, the operation is evaluated as UP. It is because the difficulties in perceiving the visual information for the non-visually impaired user is not induced by the visual impairment. Surely, their physical impairment causing less mobility and restricted eye height does lead to the difficulties, however, there is no problem with vision. For example, the adjustment in height can improve the search operation for the non-visually impaired users, while it is no use for the visually impaired users because the information is still given through a visual channel.

Unlike AP, UP does not require the user's impaired capability though it may still interrupt the continuity of product usage. This UP is derived from avoidable delay, nevertheless, UP does not consider the user responsible for the usage discontinuity, unlike Avoidable Delay (AD).

In order to specify which task demanded by an appliance to the user is designed badly, and to provide unified task structure for all user types – comparable to each other, this study implemented the original therbligs with minor changes in definitions to fit better with the context of home appliance.

Secondly, the relevant principles of motion economy for each task and the potential accessibility issues that may occur by each user type under the whole task cycle were scrutinized. Each therblig represents a solution or direction for solutions by motion economy principles and seeks to suggest how the principles can be applied when addressing accessibility for disabled and elderly people. Also, the evaluation result will be compared with the interview result to validate whether this therblig analysis can supplement or replace existing accessibility assessment tools which are time-consuming and costly most of the time. Therefore, this study proposes therbligs as an accessibility assessment tool beyond its original application on manufacturing process evaluation. In addition, this study scrutinizes whether the notation of effective and ineffective for each therblig remains valid under the context of home appliance usage by disabled and elderly users.

4.3 Results

Therbligs structuralizes the chains of behaviors - in other words, task sequences – which allow a behaviorist to analyze the flow of user tasks both in a micro-scale and holistic perspective. The HTA visualizes the whole structure of the tasks and allows a researcher to easily spot and mark the troublesome tasks, unlike the SIMO chart that is commonly used for therblig analysis. There are results of component classification for each target home appliance, task structure from task analysis, and accessibility evaluation.

4.3.1 General Task Structures

The usage behaviors collected from ISO standards and observations were structuralized by hierarchical task analysis on basis of 5 context-of-use: pre-usage, usage, mid-usage, post-usage, and maintenance. The total number of operations is 95. Every task starts with "Approach" which involves the action of a user reaching a product. Especially, for visually impaired users, this operation includes their hands reaching out to the target compartment, thus the reach (Rh) operation in the succeeding subtask is neglectable. Usually, this therblig ends when a user positions oneself in front of a product. However, for visually impaired users, this therblig extends to where a user throws one's hands on top of a product or a certain compartment to start exploring.

Pre-usage context. there are four sub-tasks: approach, opening moveable, loading on non-moveable, and closing moveable. The hierarchy tree of tasks with corresponding therblig notations for the pre-usage context is given in Figure 4.7. In this context, a user starts with move(M) therblig instead of reach (Rh) because usually, a user approaches a product with a relevant object in their hands. The number of maximum operations is 24 in the pre-usage context. However, in the case of cooktop, it has no moveable, thus valid sub-tasks are 1) approach and 2) loading on non-moveable, only. The number of operations required for the pre-usage context of cooktops is 8: move – search – find – reach – grasp – move – position - release. Besides, for washers and dryers, a user can simply toss their laundry instead of positioning them with precision, thus the position (P) operation under the sub-task of loading on non-moveable can be omitted. For ovens, a user may have to hold(H) the door while using it thus pre-position (PP) can be replaced with hold therblig if needed when a door cannot be kept open in the sub-task of opening moveable.

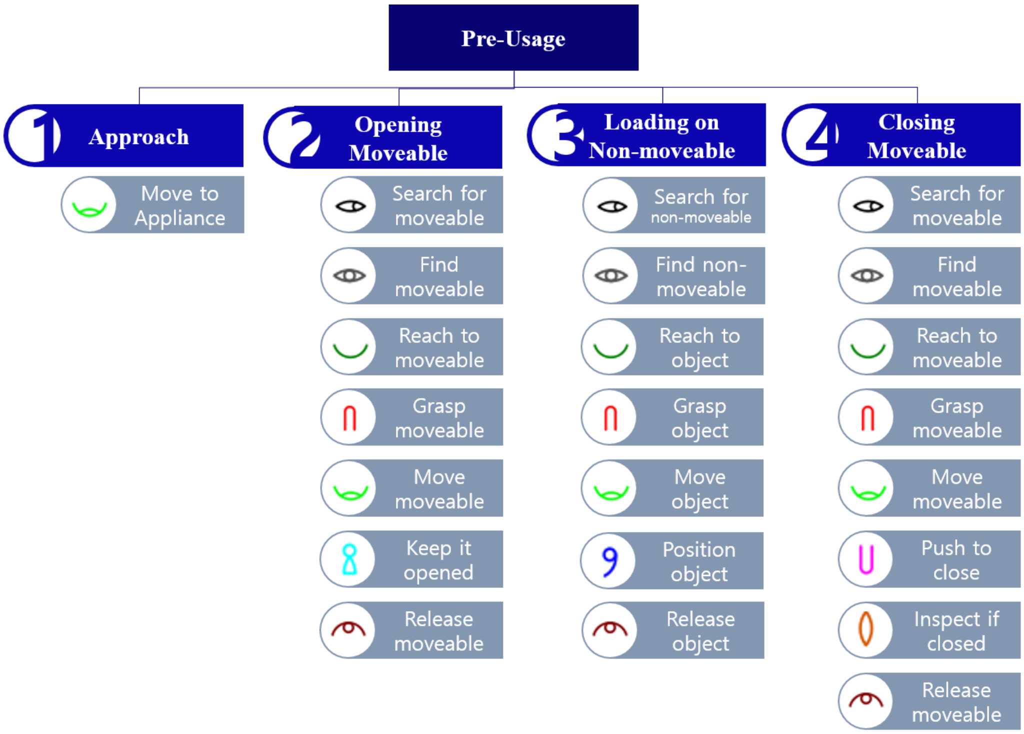


Figure 4.7. Task structure of pre-usage context

Usage context. There are three sub-tasks: approach, navigate, and perform. The hierarchy tree of tasks with corresponding therblig notations for the usage context is given in Figure 4.8. Although the maximum steps to complete the tasks within the usage context are only 11, it can increase as it may require a user to repeat the full cycle to control in detail. At the end of sub-task navigate, a user can either grasp (G) a control or position (P) one's hand or finger on the control, depending on the control type; knob or any graspable controls would correspond to the grasp therblig and a button or touch screen controls would correspond to the position therblig, instead.

The sub-task of perform starts with the use (U) therblig, which can require a user a linear motion, rotational motion, or even both. Again, the actual motion that a user may perform can vary depending on the control type, which means an evaluator must know the control type to evaluate the operation as AP, UP, or viable.

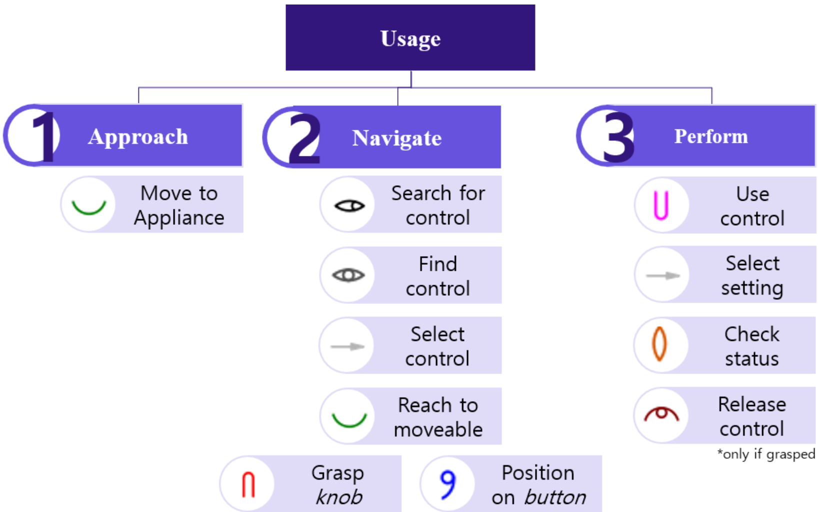


Figure 4.8. Task structure of usage context

Mid-usage context. There are three sub-tasks: approach, status/error check, and reloading/relocation. The hierarchy tree of tasks with corresponding therblig notations for the mid-usage context is given in Figure 4.9. The main task goal assigned to a user during this context are status monitoring and performing corresponding actions. One thing to notice is that the approach can start with the inspect (I) therblig, which indicates that a user received a notice before he or she looked for it; the machine provides information to a user to tell its status. It also means a user may fail to enter this phase and fail to complete it if the information channel and user's impaired sensation used are the same. There are 18 maximum operation steps in the hierarchy tree. However, there can be more operations in reality because it requires a full therblig sequence set in between the tasks. For example, after the plan (Pn) therblig, a user would perform every task in usage or maintenance context to resolve a problem. Moreover, a user may need to perform the therblig sequence set related to opening and closing a moveable before and after the third sub-task(reloading/relocation), though it is omitted in the hierarchical tree. This phase requires a lot of both cognitive and physical loads. This is the phase that a disabled or elderly user confronts despair because it may require a user to respond quickly – otherwise dangerous - and it may be the works requiring the help of someone else. Not to mention, the help is not always acquired.

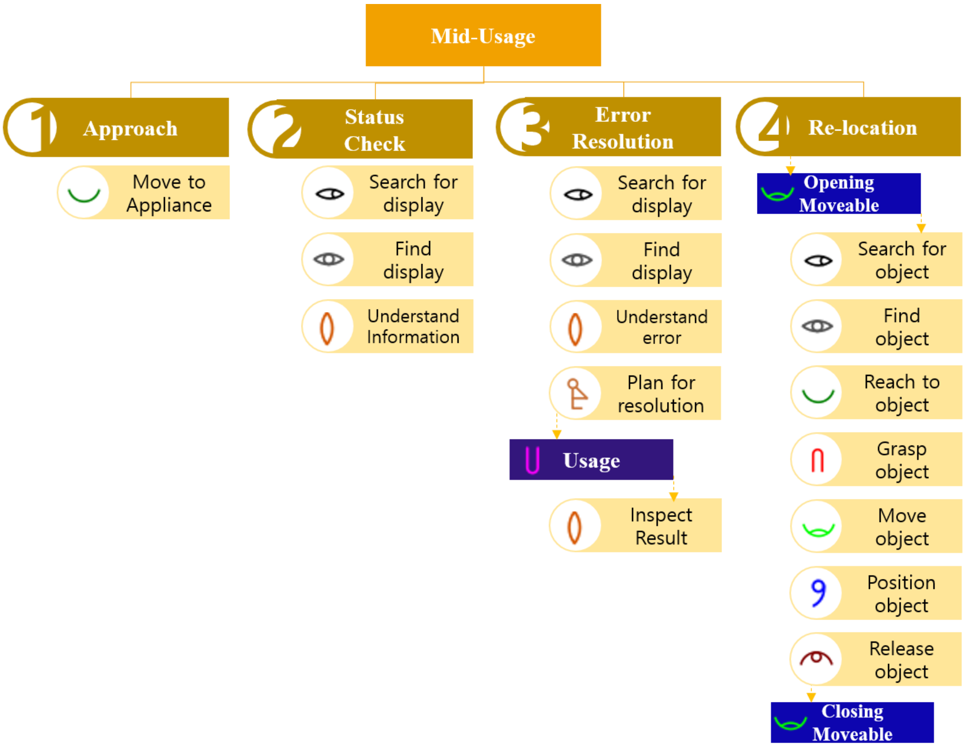


Figure 4.9. Task structure of mid-usage context

Post-usage context. There are four sub-tasks: approach, opening moveable, unloading from non-moveable, and closing moveable. The hierarchy tree of tasks with corresponding therblig notations for the post-usage context is given in Figure 4.10. Most operations in this context are similar to those of the pre-usage context. Its maximum number of operations is 24 and its minimum is 7 (visually impaired user using cooktop). In the third sub-task of unloading, a user holds (H) and inspects (I) the object results unlike how a user positions and inspects the position of the object in pre-usage. There can be several safety issues caused by heat during this context for the kitchen appliances due to hot surfaces and objects.

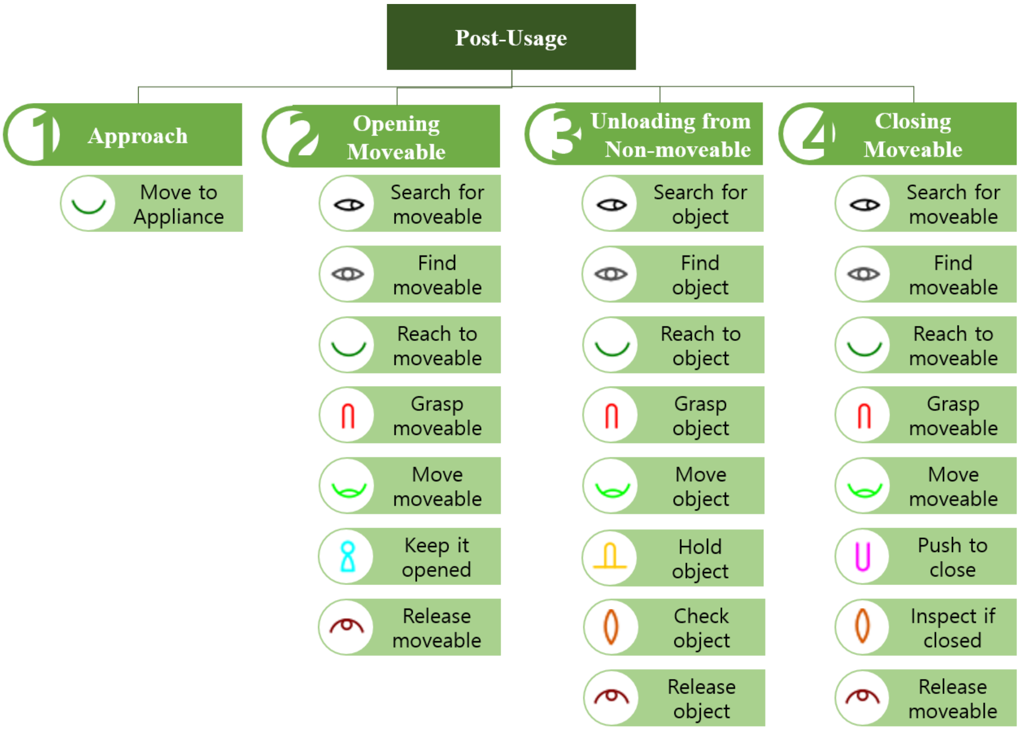


Figure 4.10. Task structure of post-usage context

Maintenance context. There are four sub-tasks: approach, disassemble separable, replace/clean, and assemble separable. There can be opening and closing moveable before and after disassembling and assembling separable if there is a moveable like a door covering the separable. The hierarchy tree of tasks with corresponding therblig notations for the maintenance context is given in Figure 4.11. The number of maximum operations is 19, however, it can increase if it includes opening and closing moveable. This is the only task that involves the interaction with separable. Many users do not even know the existence and the need for the replacement of separable. Due to its unfamiliarity, users often give up on the works included in maintenance with the fear of breaking the appliance.

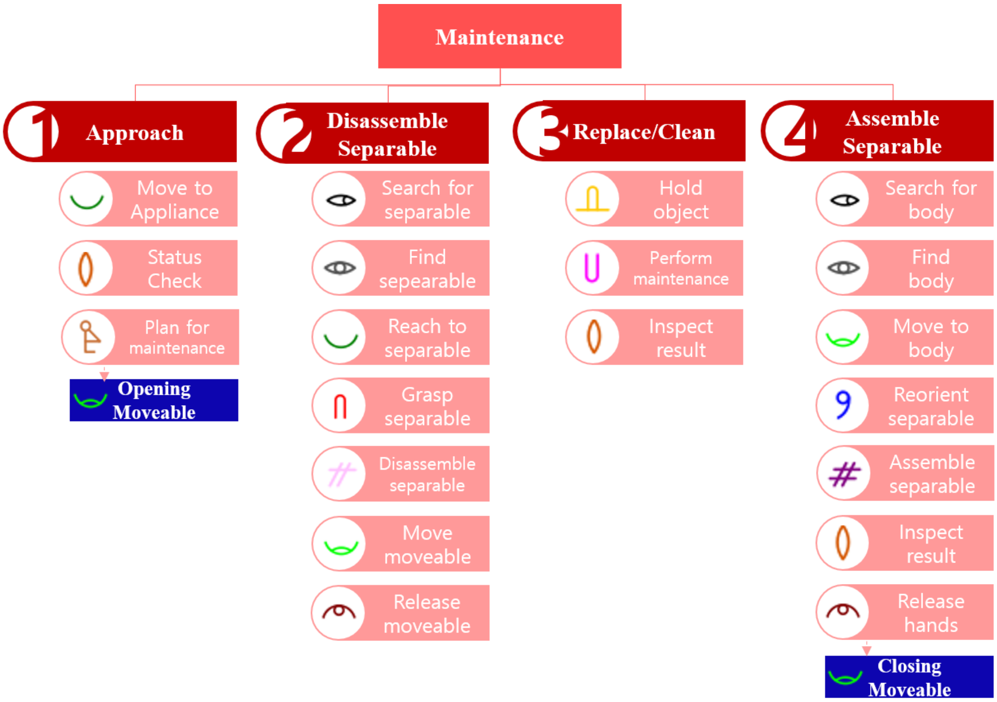


Figure 4.11. Task structure of maintenance context

4.3.2 Accessibility Evaluation Results

This study explored the accessibility issues throughout 95 total operations (58 physical, 37 cognitive therbligs) under 18 sub-tasks and five task goals. All tasks were evaluated based on the pre-defined criteria of accessibility problems (AP) and usability problems (UP). The evaluation result is shown in Table 4.5. The full evaluation chart is given in Appendix 1a-1b.

Washers and dryers required a total of 90 operations. For visually impaired users, they require eight fewer operations. The sum of all problematic operations (both AP and UP) for all four user groups is 123 in total. Spinal cord impaired users showed the highest AP rate of 32.2% followed by visually impaired users with a 31.7% AP rate, hearing-impaired users with 17.8%, and elderly users with 6.7%. In terms of UP rate, elderly users had the highest UP rate with 20% followed by spinal cord users with 13.3%, visually impaired users with 11%, and hearing impaired users with 8.9%. The proportions of viable operations – neither AP nor UP operations - are 57.3%, 73.3%, 54.4%, and 73.3% for visually impaired, hearing impaired, spinal cord impaired, and elderly users, respectively.

Cooktops required 65 operations and visually impaired users perform 62 operations. The sum of all problematic operations for all four user groups is 92 operations. Spinal cord impaired users showed the highest AP rate of 44.6% followed by visually impaired users with 38.7%, hearing impaired users with 23.1%, and elderly users with 4.6%. In terms of UP rate, elderly users showed the highest of 23.1%, followed by visually impaired users with 8.1%, and spinal cord impaired users with 4.6%. Hearing impaired users did not show any UP operation. The proportions of viable operations are 53.2%, 76.9%, 50.8%, and 72.3% for visually impaired, hearing impaired, spinal cord impaired, and elderly users, respectively.

For microwaves, there are complete 95 operations in total, and visually impaired users perform seven fewer operations. The sum of all problematic operations for all four user groups is 99 in total. Spinal cord impaired users had the highest AP rate of 38.9% followed by visually impaired users with 33%, hearing impaired users with 12.6%, and elderly users with 3.2%. Also, elderly users had the highest UP rate of 9.5%, followed by visually impaired users with 8%, and spinal cord impaired users with 2.1%. Hearing impaired users did not show any UP operation. The proportions of viable operations are 59.1%, 87.4%, 58.9%, and 87.4% for visually impaired, hearing impaired, spinal cord impaired, and elderly users, respectively.

Lastly, for the ovens, there are full 95 operations just like the microwaves, while the visually impaired users performed 87 operations. The sum of all problematic operations for all four user groups is 127 in total. Spinal cord impaired users showed the highest AP rate of 43.2% followed by visually impaired users with 33.3%, hearing impaired users with 13.7%, and elderly users with 2.1%. In terms of UP rate, elderly users showed the highest rate of 27.4% followed by visually impaired users with 8%, spinal cord impaired users with 6.3%, and hearing impaired users with 3.2%. The proportions of viable operations are 58.6%, 83.2%, 50.5%, and 70.5% for visually impaired, hearing impaired, spinal cord impaired, and elderly users, respectively.

For every target appliance, spinal cord impaired users had the highest AP rates on average of 39.7%. On average, there were 34.2%, 16.8%, and 4.1% of AP operations for visually impaired, hearing impaired, and elderly users, respectively. In terms of UP rate on average, elderly users showed the highest UP rate of 20% followed by visually impaired users with 8.8%, spinal cord impaired users with 6.6%, and hearing impaired users with 3%.

Table 4.5. Accessibility evaluation result by product

EV Therbligs	Washer & Dryer				Cooktop				Microwave				Oven			
	VI	HI	SpcI	Eld	VI	HI	SpcI	Eld	VI	HI	SpcI	Eld	VI	HI	SpcI	Eld
Total number of operations	82	90	90	90	62	65	65	65	88	95	95	95	87	95	95	95
Accessibility Problems (AP)	26	16	29	6	24	15	29	3	29	12	37	3	29	14	41	2
Usability Problems (UP)	9	8	12	18	5	0	3	15	7	0	2	9	7	2	6	26
Problematic tasks per user group	35	24	41	24	29	15	32	18	36	12	39	12	36	16	47	28
Problematic tasks per product	124				94				99				127			
AP (%)	31.7	17.8	32.2	6.7	38.7	23.1	44.6	4.6	33.0	12.6	38.9	3.2	33.3	14.7	43.2	2.1
UP (%)	11.0	8.9	13.3	20.0	8.1	0.0	4.6	23.1	8.0	0.0	2.1	9.5	8.0	2.1	6.3	27.4
Viable operations (%)	57.3	73.3	54.4	73.3	53.2	76.9	50.8	72.3	59.1	87.4	58.9	87.4	58.6	83.2	50.5	70.5

* VI= Visually Impaired users; HI = Hearing Impaired users; SpcI = Spinal-cord Impaired users; Eld=Elderly users

For visually impaired users, the cooktop was the appliance with the lowest viable operations (53.2%). One thing to notice is that there is no appliance with viable operations over 60% for visually impaired users. By counting only the AP rate, it is still the cooktops that are the least accessible among all target appliances. For hearing impaired users, the washers and dryers were the appliances with the lowest viable operations (73.3%). By considering only the AP rate, cooktops are the least accessible for hearing impaired users (23.1%). For spinal cord impaired users, ovens have the lowest viable operations (50.5%). Just like visually impaired users, there is no appliance with viable operations over 60%. By considering only the AP rate, a cooktop is the least accessible for spinal cord impaired users. For elderly users, ovens showed the lowest viable operations (70.5%). In terms of AP rate only, the washers and dryers were the least accessible appliance.

On the other hand, in terms of context - or usage phase, the operations with accessibility problems and usability problems are shown in Table 4.6. In terms of AP, the mid-usage context possessed the most AP counts of 80 in total, followed by maintenance, usage, post-usage, and pre-usage contexts with 67, 67, 62, and 39, respectively. Both visual and hearing impaired users struggled the most with the highest AP counts during the mid-usage context because it involves many cognitive operations and physical operations related to those cognitive operations. Pre-usage was showed the least counts on AP operations for both visual and hearing impaired users. Spinal cord impaired users showed high AP counts in maintenance (35) and post-usage (34) contexts. Pre-usage, mid-usage, and usage context had 24, 22, and 21 operations evaluated as AP, respectively. For elderly users, the usage scored the highest AP counts of 6, followed by mid-usage (5) and post-usage (2). There were no AP operations found within the pre-usage and maintenance contexts for elderly users. The proportion of AP counts on their full operation sequence, spinal cord impaired users were the most vulnerable user group with 39.4% followed by visually impaired users (33.9%), hearing impaired users (16.5%), and elderly users (4.1%).

In terms of UP operations, the maintenance context scored the highest counts by 46 in total followed by mid-usage, pre-usage, post-usage, and usage with 26, 25, 24, and 8, respectively. Visually impaired users showed the exact same trend of UP counts as the overall counts. The maintenance context scored the highest, followed by mid-usage, pre-usage, and post-usage by 11, 8, 6, and 3, respectively. There was no UP found in the usage context for visually impaired users. On the other hand, hearing impaired users encountered the usability problem the most during the post-usage and maintenance contexts with 4 counts each. The pre-usage context had 2 UP operations, and both usage and mid-usage did not have UP counts. Spinal cord impaired users had the highest UP counts on the pre-usage context by 8 operations in counts, followed by maintenance (5), mid-usage (5), post-usage (4), and usage (1). Finally, the elderly users had higher UP counts (20%) than the AP counts (3.8%) unlike the disabled user groups. Elderly users confronted the highest usability problem during the maintenance context by 26 counts, and both mid-usage and post-usage context scored 13 counts. Pre-usage and usage context scored 9 and 8, respectively.

Spinal cord impaired users seem to have the least proportion (53.9%) of viable operations in the whole operation sets and visually impaired users also showed a similar proportion (57.4%). However, visually impaired users had a higher UP rate than the spinal cord impaired users though their AP rate was lower. Hearing impaired and elderly users had comparably less AP and UP ratings. Hearing impaired users had higher AP ratings than the UPs, while elderly users had the opposite. Hearing impaired users had a higher number of viable operations overall than the elderly users did when considering both AP and UP.

Table 4.6. Counts on the problematic tasks per context

Accessibility Problem (AP)		User Groups			
Contexts	Total	*VI*	*HI*	*SpcI*	*Eld*
Pre-usage	39	13	2	24	0
Usage	67	21	18	21	7
Mid-usage	80	28	25	22	5
Post-usage	62	23	3	34	2
Maintenance	67	23	9	35	0
Total SUM	315 (23.3%)	108 (33.9%)	57 (16.5%)	136 (39.4%)	14 (4.1%)

Usability Problem (UP)		User Groups			
Contexts	Total	*VI*	*HI*	*SpcI*	*Eld*
Pre-usage	25	6	2	8	9
Usage	8	0	0	1	7
Mid-usage	26	8	0	5	13
Post-usage	24	3	4	4	13
Maintenance	46	11	4	5	26
Total SUM	129 (9.5%)	29 (8.8%)	10 (2.9%)	23 (6.7%)	68 (19.7%)

Problematic Tasks (SUM)		User Groups			
Contexts	Total	*VI*	*HI*	*SpcI*	*Eld*
Pre-usage	64	19	4	32	9
Usage	75	21	18	22	14
Mid-usage	106	36	25	27	18
Post-usage	86	26	7	38	15
Maintenance	113	34	13	40	26
Total SUM	444 (32.8%)	136 (42.6%)	67 (19.4 %)	159 (46.1%)	82 (23.8%)

4.4 Discussions

In terms of counts on the accessibility issues reported by chronological context, this study compared the task analysis result with the interview results (from Chapter 3) shown in Table 4.7. The interview result is comparable to those of AP only results from task analysis for the disabled user groups, while it is more comparable with that of UP only result for elderly users. Such results may refer to that elderly users possess the disabilities of other user groups at mild levels, and the most of issues they face will not completely prevent the work procedures, resulting in more usability problems and fewer accessibility problems.

Table 4.7. Interview results (from Chapter 3)

Interview results		User Groups			
Contexts	Total	*VI*	*HI*	*SpcI*	*Eld*
Pre-usage	**70**	14	5	33	18
Usage	**121**	52	23	32	14
Mid-usage	**31**	11	12	3	5
Post-usage	**37**	7	8	17	5
Maintenance	**36**	5	7	7	17
Total SUM	**295**	**89**	**55**	**92**	**59**

The number of issues reported from the interview is biased toward the earlier usage phases like pre-usage and usage because it is challenging to complete the full usage cycle for them. For example, many spinal cord impaired users cannot properly use the oven from the pre-usage phase because their access to the inner tray is prohibited and cannot continue once the oven door is open. Thus, during the interview, all they could report is that the oven is inaccessible, the door blocks their way. The work procedures after the early stage of oven usage may not even be discussed. Also, when an appliance enters into an error or simply malfunctions, most of the target users cannot resolve it alone. Visually impaired users need someone to read out the error message, hearing impaired users need someone else to call customer service, and spinal cord impaired users cannot reach the relevant part though they can know what to do. Moreover, as mentioned earlier, many users did not even recognize the location or needs of separable for maintenance issues. These accessibility issues are the latent needs of disabled and elderly users that they did not experience yet but will experience if the problems at the early usage stage are resolved. It means the accessibility issue of a product may not be fully solved unless a researcher re-recruit the users and investigate these problems from the target users again and again.

Another reason for the difference in the distribution of issue counts could be that the operations at the early stages like pre-usage and usage can require repetitions of the operations. For example, in the pre-usage context of a washing machine, a user may approach, open the door, load laundry, and close the door. Then, instead of jumping into the usage phase, a user can open a detergent drawer, load detergent, and close the detergent – which is the exact same operation cycle of pre-usage context; a user repeats the cycle twice. During the usage context, the same patterns occur because the usage task tree only describes controlling one control per cycle. The deeper the control hierarchy is and the more settings and an appliance requires, the more usage operation steps are required. The probable accessibility or usability issue can occur twice or trice as much, however, the task structure used in this study is the general structure, therefore, it only counted one operation cycle per usage context to prevent duplicate representation.

Therefore, task analysis can evaluate accessibility as effectively as the traditional but time-consuming interview method can. Moreover, it can investigate the latent need that is not discussed during the interview because it scrutinizes the whole usage cycle. Besides, it can distinguish the accessibility and usability issues more clearly, while the users during the interview discuss such issues in similar levels without indicating the difference. The task analysis method will not miss out on the issues and details highly discussed in the interviews as long as the task analysis describes the full operation sequence including repetitions.

The traditional methods like the interview can deeply investigate the problems that the users confront every day, however, task analysis can investigate the latent needs as it analyses through the whole process, holistically. Therefore, the task analysis and interviews can complement each other. It means that a researcher can conduct task analysis in advance of the interview to investigate the latent needs, conversely.

4.4.1 Problematic Therbligs and Related Principles of Motion Economy for Improvements

When the task analysis is to structuralize and visualize the operations, on the other hand, therbligs are the main tool to describe and evaluate user operations at a micro-level. For each user group, some common and different therbligs were causing the inaccessibility, as shown in Figure 4.12. One thing to notice is that the plan therblig does not have any problematic therbligs neither accessibility nor usability. Some might argue that the users who cannot perceive the control layouts or error messages cannot plan what to do. However, the one answered oneself by saying, "who cannot perceive". It means that the users have problems with therbligs related to perception, not the plan. Once perceived well, all users were able to plan further ahead. Each problematic therblig has corresponding principles of motion economy and ECRS to improve the overall task or product design. The counts on problematic therbligs by each user group are given in Figures 4.13 to 4.16. The darker color represents AP while the lighter color represents UP.

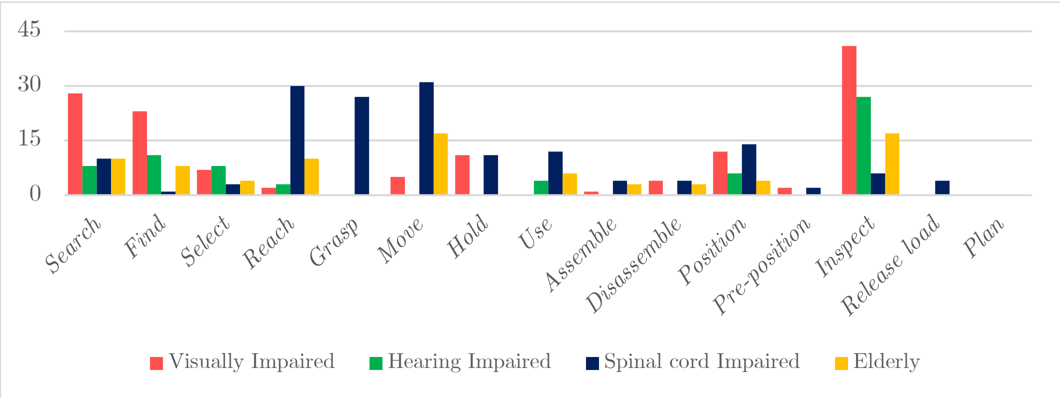


Figure 4.12. Number of Problematic Therbligs by User Groups

First, for visually impaired users, the top 5 problematic therbligs are 'inspect', 'search', 'find', 'position', and 'hold'. The inspect therblig was the most inaccessible operation with a total of 41 counts (37 AP and 4 UP). Inspection required for moveables is to check if the moveable is well shut after closing it. Moveables, especially doors during the pre-usage and post-usage, usually do not provide much feedback when shut other than the sound of the door and the main body contacting each other. For non-moveable, the position of a target object located on the moveable is difficult to investigate during the pre-usage and post-usage. Users may have to solely depend on one's proprioception to estimate the position. Besides, a user may not investigate contamination on non-moveables during the maintenance context. In terms of controls and displays, they provide feedbacks with blinking visual alarms which can hardly or never be seen by visually impaired users. Feedbacks with mere beep sounds are ambiguous to infer its meaning even if given in the auditory form. For separable, it does not provide much feedback when assembled or disassembled, just like the moveables being shut, and it is challenging to recognize the orientation of separable before assembling it back.

Also, the search (22 AP and 6 UP) and find (23 AP) therbligs were the second and third inaccessible operations. It is an indisputable result since these two therbligs are highly corporate with visual sensation. Mostly, it evaluated the search therbligs as AP, however, it is also evaluated as UP if the design of a target component allows a successful task completion but with the prolonged time taken. For example, a door already open of which position is arbitrary and recessed handles which is hidden and less noticeable tactilely.

Finally, there were problematic physical therbligs of position and hold. Position therblig is evaluated as AP twelve times because orienting or allocating an object without seeing it requires high cognitive work – thus, inaccessible. On the other hand, hold therblig is similarly inaccessible because a user must keep the position or orientation of a holding object, however, a user solely depends on one's proprioception.

Even though the position and hold are physical therbligs originally, they require mental work to portrait their orientation and location without visualization. Their cognitive parts caused problems for the visually impaired users. Search, find, select, and inspect therbligs can be improved by the motion principle numbers 9, 11, 16, and 17. Operables or non-operables must be pre-positioned in a certain place and its location must not deviate much so a visually impaired user will not waste their mental load to remember and to find the target (principles 9 & 11). Moreover, adequate salience and contrast in terms of any sensory channels (visual, auditory, or tactile) should be provided for every important component that a user needs to interact with (Principle 16 and 17). The position can be improved by the principle numbers 5, 7, 10, 13, and 18. Finally, the hold therblig can be improved by the 10th and 18th principles. For both physical therbligs, they can benefit the most from principles 10 and 18 as a fixed place, fixture, or a jig can help a user place an object easily with them – for example, magnetic support to induce a position or attachment.

For hearing impaired users, the top 5 problematic therbligs are 'inspect', 'find', 'search', 'select', and 'position'. They struggled the most for the inspect therblig (27 AP) because most of the feedback from home appliances takes the form of auditory feedback. Visual feedbacks are not always perceivable especially when they are small in size and have low contrast. Accordingly, inspect is an ineffective therblig thus it is recommended to remove it from the process. The need for inspection can be removed if the mechanism ensures the end result. For example, a door is always shut correctly by magnetic support, or even a clearer contacting sound of door and body can remove the need for the inspect therblig. However, that is limited to the active inspection task only.

Hearing impaired users also struggle with the find and select therbligs due to their naming mostly. AP counts for select and find are concentrated in the context of usage and mid-usage. During the usage context, the prevalent neologisms throughout the control panels and displays of home appliances make it harder for a sign-language user to comprehend the functions. Therefore, they may not be able to find or select their desired target although they can visually search for targets successfully. They are forced to use a standard function only. During the mid-usage context, the error messages are given with error codes, without explaining their status fully.

Most search, find, select, and inspect therbligs done by the visual task can be improved by the motion principle numbers 9, 11, 16, and 17. However, the problem of miscomprehension on the function names does not have corresponding motion principles. In this case, by applying the ECRS principle, the words written can be simplified so that many users can comprehend without any issues. Additionally, the position can be improved by the principle numbers 5, 7, 10, 13, and 18, accordingly, in the same manner as that of visually impaired users; fixture or fixed location can be beneficial.

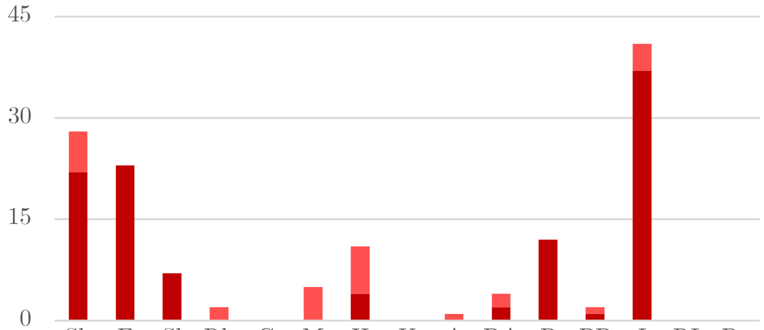
For spinal cord impaired users, the top 5 problematic therbligs are move, reach, grasp, position, and use. Move and reach therbligs both have 27 AP counts and move has 4 UP while reach has 3 UP counts. Both move and reach are effective therbligs, meaning they are essential and required operations to proceed with the work. Move therblig describes a user moving a load. It is challenging for a spinal cord impaired user to move a load especially when the object requires a tight grasp because the grasp is also problematic therblig for this user group. Particularly, the longer they have to move the object, the more challenging the task becomes because they are in a wheelchair. Reach is originally effective but here, it works like an ineffective one because it is more of position than reach; position is ineffective. A user has to orient one's body or body angle to perform the next tasks. A researcher or evaluator may add position therblig (P) before or after every reach therblig (Rh) to annotate this specific ineffective operation to keep reach therblig effective. According to the definitions of effective and ineffective therbligs, this therblig – reach – must remain effective because it is essential to manipulate the operable components like moveable, control, and separable.

The motion economy originated mostly from physical works, thus, it can be applicable for spinal cord impaired users the most in some facets. For therbligs like reach, move, use, and grasp, one can look for improvement direction to reduce the time or route taken to perform the therbligs in accordance with relevant motion economy principles since they are effective therbligs. For reach and move therbligs, the task may support ballistic movements within a working area as close to the user (principle 7 & 13). The operational force and the design of an appliance must be designed based on the user's capability so that a user can take advantage of the momentum and smooth continuous motion without sudden changes in direction of movements (principles 5, 6, and 20). Especially the principles of 12 and 15, related to gravity and droplet, well explain how spinal cord impaired users prefer the top-loading washing machines to the front-loading when loading laundry. Use can be improved with the principle numbers 4, 6, 7, 8, 11, 14, 19, 20, 21, and 22 while grasp can with principle numbers 4, 20, 21, and 22.

On the other hand, hold and position are ineffective therbligs. One can resolve the problems with these therbligs by elimination and combination since they are ineffective. Hold can take benefits from principle numbers 10 and 18, and position can from principle numbers 5, 7, 10, 13, and 18. Again, the fixture or jig can be beneficial

Finally, for elderly users, the top 5 problematic therbligs are move, inspect, search, reach, and find. They are a mixture of top problematic therbligs of other user groups, which infers that the elderly users do share their disability though at a low level. Elderly users had more UP counts (68 counts) than AP counts (14). Move therblig is challenging when an object is heavy or stiff to move due to the diminished strength of elderly users. Also, reach therblig being problematic represents the reduction in their range of motions. The search, find, inspect therbligs indicates that the elderlies share the same issues with visually and hearing impaired users due to their diminished capabilities on perception.

As mentioned earlier, the reach and move therbligs can benefit from the principles number 5, 6, 7, 12, 13, 15, and 20, while the search, find, inspect therbligs can do from the principles number 9, 11, 16, and 17.



	Sh	F	Sl	Rh	G	M	H	U	A	DA	P	PP	I	RL	Pn
Visually Impaired UP	6	0	0	2	0	5	7	0	1	2	0	1	4	0	0
Visually Impaired AP	22	23	7	0	0	0	4	0	0	2	12	1	37	0	0

Figure 4.13. AP and UP counts on Therbligs for Visually Impaired users

	Sh	F	Sl	Rh	G	M	H	U	A	DA	P	PP	I	RL	Pn
Hearing Impaired UP	4	3	0	3	0	0	0	0	0	0	0	0	0	0	0
Hearing Impaired AP	4	8	8	0	0	0	0	4	0	0	6	0	27	0	0

Figure 4.14. AP and UP counts on Therbligs for Hearing Impaired users

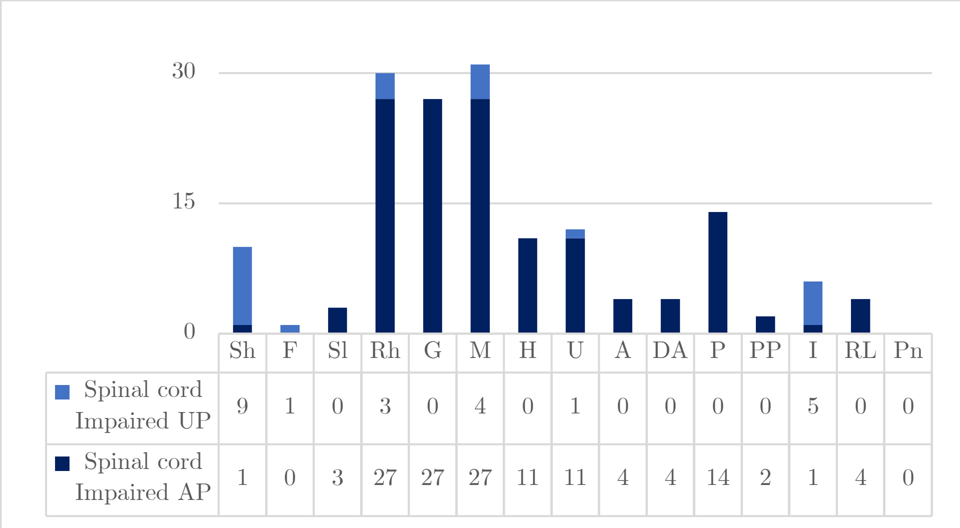


Figure 4.15. AP and UP counts on Therbligs for Spinal-cord Impaired users

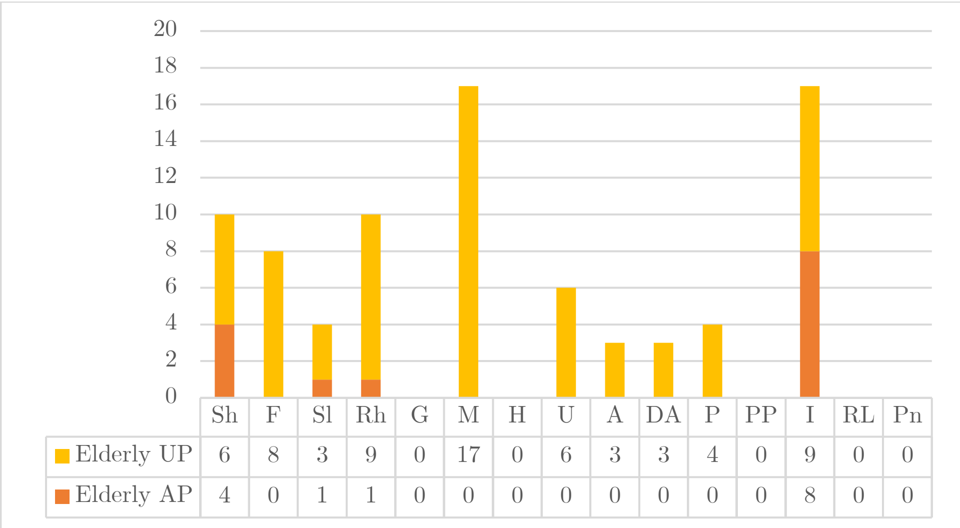


Figure 4.16. AP and UP counts on Therbligs for Elderly users

4.4.2 The Final Set of Therbligs for Accessibility Evaluation

As a result, there were some user interactions the original therbligs and redefined therbligs could not fully encompass. Therefore, this study proposes new therbligs to cope better with the context of home appliance usage when implementing therbligs as an accessibility evaluation tool.

Firstly, a therblig of response toward feedback was required to address the inability of a hearing-impaired user in a better way, instead of describing it either by search or inspect therbligs, unsatisfyingly. There is one AP count of search therblig on each appliance during the mid-usage context (total in 4), where a hearing impaired user must search for the display (auditory display especially, in this case) in accordance with the feedback he or she received. However, it is infeasible for one to search for the part that is beeping or guiding the user in a direction if it utilizes the auditory channel only. This auditory problematic search therblig succeeds the inspect therblig. Besides, this therblig represents the passive search which is performed only if it receives a preceding alert, unlike how regular search via eyes or hands actively looks for a target without preceding alert or information.

Namely, it is more of an inspecting task which compares the mental model of a user with given information, however, the inspect therblig covers a very broad domain already, therefore, it is possible to segregate the inspect therblig into the original inspect that a user inspects the quality of status of the target and the "Heed" therblig which describes a user being aware of surroundings – especially by auditory channel. The search therblig and find therblig are paired to describe user's behavior of exploration and comprehension of what they discovered. Likewise, paired with the 'inspect', this new therblig can address user behavior of receiving feedbacks passively and analyzing the feedback they received – 'heed', and then inspect. As shown in Figure 4.17, the symbol for heed therblig is in the shape of an ear in the color of champagne gold. The color is a mix of orange and grey to represent that this therblig shares the characteristics of search and find (black and grey), and is also paired with 'inspect' (dark orange). Its short abbreviation is "Hd".

Figure 4.17. Newly proposed therblig – Heed (Hd)

Such a therblig was not required in the original therblig because the environment where the original therblig is applied is a factory and it is only considered a user's performance. Besides, there were not many situations or circumstance awareness required because an operator's work was more of a simple assembling and disassembling work on an assembly line. However, under the perspectives of Human-Machine Interface (HMI) for home appliance usage context, there can be a new therblig describing a situation and surrounding awareness. Surely, it will be a cognitive therblig hindering the following processes, thus ineffective.

On the other hand, for spinal cord impaired users, there is a change in effectiveness required for one therblig. It is the therblig of grasp. Grasp is originally effective, but for spinal cord impaired users, it is ineffective because it is more of a positioning task than grasping; position is ineffective – just like the reach therblig. It is challenging for spinal cord impaired users to accomplish a successful grasp due to their hand shapes. they rather place their hand blade or wrist to hook onto the relevant component of the appliance. Thus, one can replace the grasp therblig with a new therblig that reflects their actual behavior. Therefore, this study proposes the "Hook" a new therblig that represents an operation that a user places one's hands or wrist on a component in order to operate or manipulate in rotational (pitch, yaw, roll) directions. As shown in Figure 4.18, the symbol for hook therblig is in the shape of a hook in the color of light amethyst or lavender. The color is a mix of red and blue to represent that this therblig shares the characteristics of grasp (red) and position (blue). Its short abbreviation is "Hk".

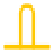
Figure 4.18. Newly proposed therblig - Hook (Hk)

Unlike reach, the grasp therblig may be considered ineffective because there are design variances that do not require grasp to induce the same result or performance from a product. For example, a door that is "push-to-open" or "push-to-unlock" requires the use of therblig (U) instead of grasp, and a user can easily move the slightly opened door with no issue. Surely, a user may perform "Hook" in-between the use therblig and move therblig to successfully move the corresponding component. Therefore, it is possible to segregate the effective grasp into two therbligs: ineffective grasp and effective hook.

Finally, even though this study replaced the delay therbligs (unavoidable delay and avoidable delay) with evaluators (accessibility problem and usability problem), the delays are present, especially within the mid-usage context for cooking appliances. This delay is a type of unavoidable delay because a user can do nothing but waiting for an appliance to finish its current work phase. At the beginning of the study, this delay is considered to be unnecessary and its definition fits more towards the evaluation of the work. However, user behavior – the behavior of users with disabilities in particular – is evident and it contains a problem to address. For example, hearing-impaired users would stand in front of an appliance because they cannot perceive alarms or feedback from a distance. Spinal cord impaired users would also await in front of the appliances because moving back and forth is effort-consuming because they struggle with reach therbligs and staying allows them to react faster to errors if occurred. Therefore, it does not describe the delay itself, however, there must be something that describes a non-efficient but inevitable user behavior of waiting close to an appliance, which is driven by their disabilities. Therefore, this study suggests recycling the "rest" therblig by changing its name into "wait", with the definition of "waiting around/in front of an appliance to respond."

With these two new therbligs and one recycled therblig along with a new definition, it is possible to encompass broader but more detailed user behavior of home appliance usage. The full list of 20 therbligs is given in Table 4.8.

Table 4.8. Final 20 Therbligs for Accessibility Evaluation

No	Therblig	Symbol	Definitions	E/I
1	Search (Sh)		Searching for/Exploring through an object via eyes or hands	I
2	Find (F)		A momentary recognition of what the searched object is, as a result, comprehension on how to (dis)assemble or use it ("Find-out")	I
3	Select (Sl)		Navigating with the purpose of selecting/choosing among several objects in a group	I
4	Grasp (G)		Grasping an object with the active hand/body parts	I
5	Hook (Hk)		Hooking onto an object with the active hand/body parts	E
6	Hold (H)		The retention of an object after it has been grasped by one hand, [with] the other hand to operate on the object	I
7	Reach (Rh)		The motion of approaching/reaching by moving the unloaded hand or body to a certain point to the next function within the sequence	E
8	Move (M)		Moving an object using a hand/body motion to a certain place/position	E
9	Release (Rl)		Releasing whatever that was grasped in advance	E
10	Position (P)		(Precisely) positioning and/or orienting an object in the defined location for the very next task	I

11	Pre-position (PP)		(Approximately) Positioning and/or re-orienting an object for the next operational sequence	E
12	Use (U)		Operating an object/tool for its intended use	E
13	Assemble (A)		Joining two or more parts together	E
14	Disassemble (DA)		Separating multiple components that were joined	E
15	Heed (Hd)		Being aware of surroundings as perceiving feedback, especially via the auditory channel.	I
16	Inspect (I)		The act of comparing received/perceived feedback with a predetermined/intended action performed by employing all human senses	I
17	Plan (Pn)		A mental function that precedes error resolution, deciding which course of action to take	I
18	Accessibility Problem (AP)		Incompletion of work due to factors beyond user's control or capability	I
19	Usability Problem (UP)		Incompletion of work due to cumbersome or counter-intuitive product design	I
20	Wait (W)		Waiting around/in front of an appliance to respond	I

* Hook and Heeds are newly added therbligs highlighted in bright yellow background

** E: Effective, I: Ineffective

4.4.3 New Task Design for Disabled and Elderly Users

The purpose of task analysis and motion study is to derive improvement in task sequence and structure by the removal of unnecessary and bottlenecking tasks(Barnes, 1949; Diaper & Stanton, 2003; Niebel, 1958; Salvendy, 2004; Stanton, 2006). The therblig-based task analysis for accessibility assessment was conducted by using original therbligs with extended definitions. The reason for using the original therbligs is that the home appliances, in general, require such tasks that are not dedicated for disabled or elderly users.

The original therbligs represent the usage requirements to operate in the current design. One may argue that the therbligs and task sequence used in this study is that of users without disabilities, instead of that of disabled and elderly users. It is both true and false at the same time. Specific operations and sub-tasks are required by each home appliance regardless of the user's condition, meaning both users with a disability or no disability are forced to operate the same operations. The sequence and the number of operations may vary in a minor level by user types, however, the overall structure remains the same. Home appliances with physical designs and limited input methods, do not allow much flexibility. This is the reason why home appliances are inaccessible for various users with disabilities, therefore, the original therbligs were used when evaluating the home appliances.

However, the utility of therblig analysis offers more; it provides guidance on improvements. By using the final therblig sets with newly developed therbligs, it is possible to create a task sequence that is suitable for each user type and leads to possible design renewal that is accessible. It is often considered to enable what is disabled when it comes to the accessibility study. However, the effort and time required to create a design that enables a certain user interaction that has been challenging and impossible can be devastating. Instead, a design allowing what users can already do well can benefit both the stakeholders and users. Therefore, redesigning the task sequence and structure shall consider what a user can do well and remove what a user cannot do well.

Visually impaired users would make good use of the voice interface, especially for the usage context. A control panel would require a therblig sequence of reach, search, find, select, position, use, and inspect. The problematic therbligs in this sequence are search, find, select, position, and inspect, simply every task except for reach and use. With the implementation of the voice interface, the sequence changes into plan, use, and inspect. A user will plan what command to give, and use the interface by speaking the command. Consequently, a user will inspect whether the device successfully received his or her command and will operate accordingly. The inspect therblig may be a problem in an ordinary case. However, for the voice interface where the information is given in a dialogue, it is comprehensible for visually impaired users. Therefore, all tasks are essential and efficient.

Likewise, a spinal cord impaired user accessing a moveable like a door would require a therblig sequence of Reach, Search, Find, Reach, Grasp, Move, Pre-position, and Release. To resolve problematic "Reach" and "Grasp", the height, depth, and clearance of a door must be redesigned along with its size and overall dimensions; it can be disastrous for a complex product. Moreover, the problematic therbligs are still remaining within the task structure; they need to be removed.

However, concerning that the spinal cord impaired user can utilize their vocals well, one can implement a voice assistant feature for a spinal cord impaired user to simply speak, "open" to unlock a door lock. A user needs to operate "Plan", and "Use" therbligs to think which command to give and speak (Use). Once a door is unlocked, the door will slide toward a user and a user needs to perform only the following therblig sequence: Hook, Move, Pre-position, and Release. The problematic "Reach" is removed from the task structure, and "Grasp" can be easily replaced with "Hook" because a user no longer needs to grasp a handle, but simply place his or her hand on a loose door to open it.

On the other hand, it is no use for a hearing impaired user to interact with the voice interface. Just like the visually impaired users, hearing impaired users will be frustrated by a task that is difficult to inspect the result. For example, when they assemble a piece and it can look fine although it is not assembled correctly. A hearing-impaired user can utilize their vision well, however, the information given through visual channels may not provide adequate information sometimes. In such cases, a magnetic design inducing a part to automatically position itself in the right position will reduce the need for the inspection task.

Such improvements in the task also deliver insights to developers into which design factors need to be focused on and changed. Integrating a microphone, speaker, magnet, and a spring and lock mechanism for a door hinge, control interface, and separable parts can be less effort-consuming than redesigning a whole appliance structure from a scratch.

4.5 Conclusion

In this study, the main aim was to introduce therblig-based task analysis as a new accessibility evaluation tool because it is less effort and time-consuming. It is fairly easy to learn and perform and it does not require any special tools. Moreover, it comes with the principles of motion economy as if they are sold as a package. This allows the researcher to set the direction for the solution.

Structuralizing the task hierarchy does not require expertise, especially when given the therblig sequence flow chart in Figure 4.6 along with the task goals sets based on chronological usage phases, it is no longer challenging. In this study, there were general task structures given for all appliances and all user groups. There were a few therbligs added or switched in orders in between the therblig sequences by different user groups, however, the basic structure remained the same for visually impaired, hearing impaired, spinal-cord impaired, and elderly users. It is because the home appliances can be manipulated in a certain way so that users are restricted to perform a certain chain of operations and the variation cannot fluctuate much. What a user can cope with the moveables, non-moveables, controls, displays, and separables are almost pre-determined. Such low flexibility may be the cause of low accessibility within present home appliances.

On the other hand, evaluation on each therblig based on the user characteristics may require some expertise. ISO standards like ISO TR 22411 (2008) and ISO TR 29138-1 (2008) well summarized the user needs by user group, yet, it may be insufficient when it comes to the specific product evaluation. However, such a problem can be minimal as long as an evaluator conducts a good observation session. Nonetheless, it is much easier and quicker to learn than the interview skills for users with various disabilities.

The therblig, a unit of micromotion, allows the researcher to investigate problems on a micro-scale, resulting in efficient solution outcomes. One can localize a specific task or component to be modified instead of modifying the parts that do not require changes. Performance-wise, therblig based task analysis evaluated the accessibility issues of home appliances for the target user groups (visually impaired, hearing impaired, spinal-cord impaired, and elderly users) with the fairly equivalent result compared to one of the traditional methods, interview. Besides, they could be used together to complement each other.

To be a more practical evaluation tool, this study redefined therbligs, redefined some motion economy principles, and suggested new therbligs. The newly added therbligs were heed and hook. One probable shortcoming of this therblig-based task analysis was that there were not many therbligs that can describe the accessibility issues of hearing impaired users unlike how well it could describe the issues of visually impaired and spinal-cord impaired users. The 'heed' and 'wait' therbligs best describe their problems and behaviors, therefore, the inclusion of those therbligs contributes to the better performance of this evaluation tool. Furthermore, there are many home appliances or devices that are equipped with more flexible input mechanisms, such as voice commands and gestures. Therblig can describe such operations as one unified therblig, Use. However, it could be possible to create new therbligs like "talk", "rotate", and "press" to subdivide the use therblig into more specific usage behavior so that an evaluator can specify the issues more precisely.

Such needs for new therbligs substituting the use therblig indicates that the way to control an appliance has gotten more complex these days. Nevertheless, such statements do not imply that the progress in technology must stop and remain analogous. Instead, they promote inclusive progress rather than exclusive one. The consideration of including broader user groups when developing a product or service can achieve both the advancement and accessibility for the users in the needs. Unfortunately, in this chapter, there was no prototype built based on the directions for probable solutions provided by therbligs and relevant principles of motion economy. However, in the next chapter, there are prototypes made to resolve the accessibility issues based on the needs of the target user groups.

Chapter 5

Accessible Home Appliance Designs : Prototyping and Design Guidelines

5.1 Overview

It is undeniable that there is no such single product that everyone can use (Vanderheiden, 1991). In return, there have been specialized products developed for disabled users under the name of whatsoever "special-" something. However, disabled users do not want to be "special" users. It breeds another discrimination perpetuating the segregation between the disabled and non-disabled users because the disabled users are bounded to use the specialized product only, apart from the conventional products for non-disabled users (Story, 1998). It is ironic that such assistive technologies to haze the border between the disabled and non-disabled actually make a clearer border. Then is it a wrong approach to build special products?

Vanderheiden (1991) provided and discussed four different ways to develop more accessible products. The four approaches are not exclusive to one another but a product can utilize one or a combination of these approaches. The four approaches, in order of desirability, are:

1) Direct accessibility

2) Accessibility via standard options or accessories (from manufacturer)
3) Compatibility with third-party assistive devices
4) Facilitation of custom modifications

Among these four, the first type, direct accessibility is the best and most desirable approach since a product is accessible "out of the box." Vanderheiden (1991) also stated that it can also remove the stigma of "special" aids or modifications through this direct access approach. On the other hand, the "special products" are nowhere near the direct access, but rather fall into the fourth approach. It is still accessible for a user, but not universal since the product is accustomed to a single user with a specific need.

In contrast to the specialized products, the design methods like accessible design, barrier-free, design for all, inclusive design, and universal design - though different in names - all aim to accommodate as many users as possible in their designs (Persson et al., 2015). This chapter, under the perspective of universal design (UD), aims to provide a solution that is directly accessible, in other words, accessible out of the box. However, it may not be possible to build a directly accessible solution due to various reasons: mutually exclusive alternatives, too costly, un-ready technologies, etc. In this case, the second aim is to provide a solution in a form of an accessory that is either pre-installed or easily installable.

Along with the UD perspective, this chapter adopted the Design Thinking process. Design thinking is a needs-driven, novel problem-solving approach for designers to come up with creative and innovative ideas. One of the fundamental characteristics of design thinking is its human-centered perspective led by collaborative and participatory methods of co-creation (Tschimmel, 2012); it builds for users and with users.

The design thinking process consists of five stages (Henriksen et al., 2017;

Wolniak, 2017): 1) empathize, 2) define, 3) ideate, 4) prototype and 5) test. Previous chapters fall into the early phases of the design thinking process: empathize and define. Personas were created to empathize with the target users so that the designers can have a better understanding of the problems the users encounter. Task analysis defined the problems in terms of therbligs, thus the problems are no longer vague and addressed in both verbalized and schematized structure. Therefore, hereupon, this chapter conducted ideation, prototyping, and evaluation - the remaining phases of design thinking. First, it collected ideas to improve accessibility for home appliances through an ideation workshop. Out of collected ideas, several final ideas were selected as the seed ideas. Prototypes were built based on four principles developed based on the accessibility issues mentioned in the previous chapters. Finally, the prototypes were tested by users with disabilities on whether they improved the existing accessibility issues of home appliances.

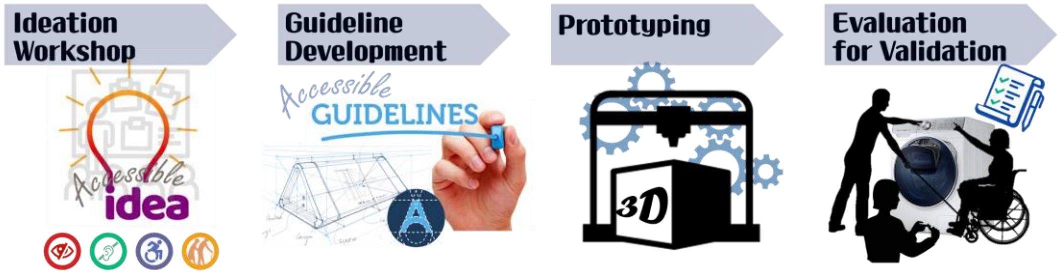


Figure 5.1. Research procedure

5.2 Ideation for accessible home appliances

This chapter aims to complete the rest of the design thinking process: ideate, prototype, and evaluate. It eventually aims to deliver accessible design solutions of home appliances to the target users. It collected and selected novel ideas under both human factors and universal design perspectives.

5.2.1 Ideation Workshop

To develop accessible product designs, this study conducted an ideation workshop. A total of 5 Ph.D. students and 4 master's students majoring in Human Factors participated in the workshop to provide ergonomic solutions. One of the Ph.D. students was a spinal-cord impaired user himself.

Given the eight personas created from Chapter 3 in the form of scenarios, participants ideated for probable solutions under the perspectives of Universal Design and Human Factors. Inevitably, many ideas will accompany the automation of appliances. However, the higher the automation level an appliance provides, the lower the autonomy of users can be. Besides, some ideas may not be applicable in a near future due to financial or technological issues. Therefore, the participants were given the level of design application and pre-defined level of automation as shown in Table 5.1 and Table 5.2. The classification and definition of automation levels were borrowed from those of automated vehicles from SAE International (2014). The automation levels of self-driving car increase as the system, in this case, a car, intervene more operations to control instead of a human driver. Likewise, the level of automation for home appliances also increases as the intervention of an appliance increases.

In zero automation, a user performs every task. Designs at this level may seem dull and not accessible much. However, it can indicate that a product is well-made if a product is accessible at this level. The next level is called “hands-on.” A user would still perform the most of operations, however, an appliance can decrease the effort put by the user as it supports minimal movements of moveables and some feedback for notice. Any design structure that assists the user’s operation at its minimal level so that a user can operate with less physical and cognitive effort would fall into this category. They are rather some features than automation.

For level 2 automation, it is called “hands-off” in SAE’s self-driving car automation level because the system takes the wheel so that a user can take their hands off. However, for home appliances, it is named “fingers-on”, instead. Such a name indicates that a user does not have to operate any large components like moveables but small parts like controls operated by fingers still need to be operated by a user. In terms of therblig, one can say reach (Rh) and move(M) may be eliminated but use(U) is still valid; the moveables may be automated, the controls are still on the user’s responsibility to operate. Feedback-wise, the feedback is more detailed than it is in level 1, where the purpose is to deliver notice only.

From level 0 to 2, the intervention of the appliance does not include the monitoring, however, from level 3, the appliance will monitor the status of both the appliance and the relevant object. In level 3 (Eyes-off), a user may perform the minimal operation but is left with error resolution. A product with level 4 automation will diagnose errors and resolve them by itself, thus it is called mind-off. All that a user needs to do shall be switching on and off for the appliance. Finally, the level 5 automation is full automation like a maid bot.

All participants were asked to provide ideas based on the following three criteria.

1. Design accessible/usable by as many user groups as possible
2. Unbounded, free from present design form factors
3. Clarify the target appliance, automation level, design application-level per idea

Each ideation session took approximately 90 minutes.

Table 5.1. Classification of Idea Application Levels

Level	Idea Applications
A	Idea demanding changes and automation of overall structures
B	Partial alteration(automation) of large parts such as moveable, non-moveables, and, separables (e.g., non-moveables redesigned into moveables)
C	Localized modifications on a component. Use of accessories or assistive device
D	Software-wise modification accompanying none or minimal modification on hardware
E	Basic principles to promote accessibility for the disabled and elderly users

Table 5.2 Definition of Home Appliance Automation

Automation Level	Definitions	Intervention by		Beneficial Operations (Therbligs)	Examples
		Appliance	User		
Lvl 0 No Automation	The full-time performance by the user for all aspects of the home appliance usage task, without additional assistive devices.	None	Every task	None	1) Operables and non-operables within user's reach 2) Perceivable and recognizable operables and non-operables
Lvl 1 Hands-on: Usage Assistance	The context-specific performance by an appliance equipped with low-level assistances (either hardware or software) to reduce either physical or cognitive effort. A user performs all the remaining home appliance usage task	The partial motion of components Software feedback for notice	Most operations	Grasp, Hold, Release, Position, Pre-position, Inspect (Heed)	1) Easy opening door with semi-auto door hinge 2) Magnetic or physical latch/guide/slide to direct objects to the correct position 3) Easier to perceive alarms, controls by multi-channel sensation
Lvl 2 Fingers-on (Hands-off): Partial Automation	The context-specific performance by an appliance equipped with one or more components (either hardware or software) to highly reduce either physical and cognitive effort A user performs all the remaining home appliance usage task	Full motion of components Software feedback in detail	Some operations and Error resolution	All above + Reach, Move, Use Search, Find, Select, Inspect	1) A component moving to where it is within the user's reach and sight 2) Voice assistance

※ From the level 0 to 2, a user monitors the status of appliance and objects

Automation Level	Definitions	Intervention by		Beneficial Operations (Therbligs)	Examples
		Appliance	User		
Lvl 3 Eyes-off: Conditional Automation	The context-specific performance by automated components of all aspects of the home appliance task User will respond appropriately to a request to intervene	Level 2 + Status diagnosis	Minimal operations and Error resolution	All above + Plan, Inspect	1) Voice command 2) Customized(pre-planned) settings to minimize process 3) Auto-detecting self-status (contamination, error, etc.) to request appropriate intervene of user
Lvl 4 Mind-off: High Automation	The context-specific performance by automated components of all aspects of the home appliance usage task, even if a user does not respond appropriately to a request to intervene	Level 3 + Error resolution	Power on/off	All above + Assemble, Disassemble	1) Robot vacuum cleaner auto-detecting its battery level and coming back to its charging position 2) Vacuum dumping trash automatically when the capacity is full
Lvl 5 Full Automation	the full-time execution by an automated appliance of all aspects of the home appliance usage task under all circumstances	Every Task	None	All above + Delays	A maid bot

※ From the level 3 to 5, automated appliance monitors the status of appliance and objects

5.2.2 Ideation Result

The number of all ideas shared by participants was 102. After the screening procedure, the number of ideas went down to 60, as shown in Figure 5.2. Also, the list of ideas is given in Table 5.3. There were 2 ideas classified as A level which is costly, thus less practical. Disregarding them, the number can be 58, instead. The automation level of 4 and 5 are also undesirable. These sections are colored in grey in the table.

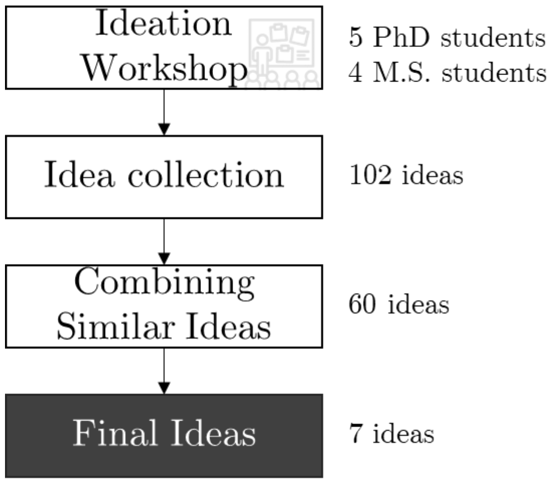


Figure 5.2. Ideation Screening Procedure

The most frequent automation level was level 1, the usage assistance, followed by level 2, 0, 3, and 4. Their counts are 19, 16, 13, 11, and 1, respectively. The most frequent design application level was C, followed by B, E, D, and A. The counts were 31, 10, 10, 7, and 2, respectively. Level C outnumbered the others as it contains localized modification and the use of additional assistive devices. The advantage level C can bring is scarce but the cost can be less, at the same time.

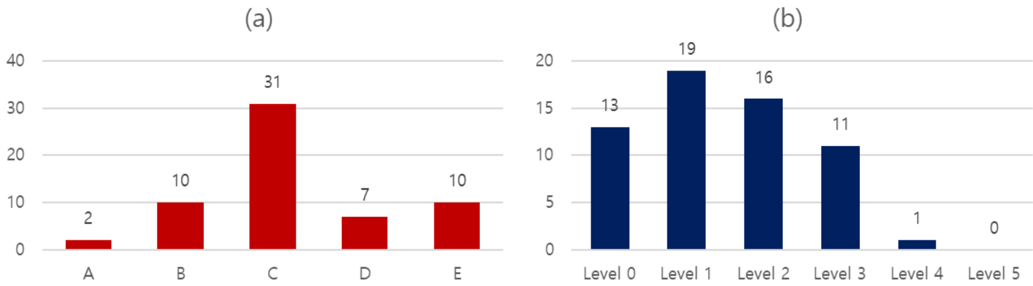


Figure 5.3. Idea counts - a) design application level and b) automation level

Although there were impressive ideas throughout all levels of design applications and automation, for the practical matters with given time and budget, the prototypes targeted for the ideas at automation level at 0 and 1, and ideas at the design application-level among C, D, and E. Seven ideas were selected for their practicality, which is marked bold in Table 5.3. The selected ideas are: 1) height risen by a pedestal, 2) adequate handle clearance, 3) protruding button, 4) protruding surface, 5) multi-frequency auditory feedback, 6) different tone/pitch/light by selecting levels, and 7) operable by fist and elbow. Based on these 7 ideas as the seed ideas, 6 different prototypes were developed in detail by combining the ideas. As mentioned earlier, the ideas were developed in a way that they can either be directly accessible or provide some easily installable accessories. Consequently, the design guidelines to substantialize the ideas were developed.

Table 5.3 Classified and screened ideas

Level	0: No Automation	1: Usage Assistance	2: Partial Automation	3: Conditional Automation	4: High Automation	5: Full Automation
A		• 45° Reclined Washer			• Conveyors for Stoves	
B	• Spinning door for front loading washer • Muti-directional magnetron without the spinning plate	• Sideway opening door • Specialized section that swallows up with respect to the heat level	• Height adjustable stove • Dispenser like a vending machine • Auto-coming out tray • Smooth and soft door opening/closing • Moving non-moveables, controls to user's reach	• Fire-eye hiding after cooking is done until it cools down for safety		
C	• Drawer type battery holder at front • Mirror at the upper tub of top-loading to monitor inside • Braille at packaging explaining the compartments • **Height risen up by pedestal** • Gravity-assisted assembly of spinning plate • **Adequate handle clearance**	• Button to unlock a door • Magnetic guides to help positioning • **More protruding button with haptic feedback** • Wearable/TV/Smartphone to receive alarms • Grasp-assist device to grasp • Hydraulic door hinge to assist door opening and closing • **Protruding/indented surfaces** • Build handle at the back of the oven door	• Button-operated automatic door • Gesture/motion recognition for moveables to open/close • Built-in camera to see inside • Both button and touch input • Slanted controls or remote controls • Large display for video calls with family, customer center • Fire level alerted auditorily/voice • Detachable charging cable for stove • Sending error log to the customer center through QR code	• Voice interaction • Alarm if there is something left inside • Door opened as the operation is over • Sensor detecting hand/human approaching (for safety alert) • Providing information related to situation awareness • Integrated timer to control operation • Miniature of a product explaining compartments as a manual • Filter popping out as it needs to be replaced		
D	• Referring to actual parts with error instead of error codes	• **Multi-frequency auditory feedback** • **Different tone/pitch/light by selected levels**	• Minimize the menu structure and display the selected one on one side • Status bar for battery or progress given in visual display and voice	• Customized command settings • Providing recipes/guide step by step to follow through		
E	• High contrast target (fire eye, text. Etc.) • Simple vocabulary • Sign-language compatible customer center • Tagged figures in the manual	• **Operable by fist or elbow** • Blinking lights as an Indicator • Multi-modal feedback • Redundant information delivery (iconic & text) • Continuous notifications to alert the surface is hot • Provide enough lights for inner side				

5.3 Development of Design Guidelines and Prototypes

This study created prototypes according to the developed design guidelines and evaluated their improvement. The design guidelines collected relevant principles from the ADA, ISO, IEC standards, and military standards related to accessibility and ergonomics. Also, the Korean anthropometric dimension of the disabled population from Size Korea and hand dimensions are also considered when developing the guideline.

Figure 5.4. Standards, guidelines, and anthropometric data used to develop the design guidelines

The design guidelines concentrated on the common problematic therbligs across the target user groups from Chapter 4 as the target problems. They are 'search', 'find', 'inspect', 'position', 'reach', and 'move' therbligs. The four criteria of design guidelines are: 1) a user must be able to locate and comprehend the product components by using their abled senses, 2) major components should be located within the user's reach envelope, 3) there should be adequate clearance for the user and user's body to move and pass through, freely, and 4) users with different physical or sensory capabilities should be able to perceive.

The first criterion corresponds to the therblig of search and find. To begin with, an appliance and its components must be within a user's perception. It should be within non-visually impaired user's visual angles, and it should provide distinguishable tactile figures and landmarks for visually impaired users. Also, those perceived targets should be in a comprehensible form. Therefore, the first criterion of this guideline is, "user must be able to locate and comprehend the product components by using their abled senses."

The second criterion corresponds to the therblig of reach and move. A user must be able to reach a target. A designer must consider not only the standing posture but the posture of a spinal cord impaired user in a wheelchair. One must keep in mind that the spinal cord impaired user takes a parallel approach, and the arm reaches such a position. Thus, the second criterion of this guideline is, "any major components should be located within the user's reach envelope."

The third criterion corresponds to the therblig of hook and position. There must be an adequate space or clearance allowing a user or user's body to pass through so that a user can land their hands on a target object in order to manipulate it. The clearance not only works as physical spacings but more as error tolerance. Thereupon, the third criterion of this guideline is, "there should be adequate error tolerance for the user and user's body to pass through or be positioned, freely and correctly."

Finally, the fourth criterion corresponds to the therblig of heed and inspect. It can be similar to the first criterion, but its target task is monitoring and feedback. It is more of a subsequent perception whereas the first criterion is oriented to the preemptive and initiative perception. Therefore, the last criterion of this guideline is, “users with different physical or sensory capabilities should be able to receive feedback through their capable sensation.”

Accordingly, seven prototypes were built based on the guidelines. For the fast validation, the chosen ideas were at a lower design application level, meaning the ideas do not accompany the change in platform or form factors. First, all prototypes underwent through Lo-Fi prototype phase to actual Hi-Fi prototype. Also, there was the software used to build the Lo-Fi prototype if it is difficult to physicalize it.

For a washing machine, this study designed an additional layer of transparent acryl to assist control and navigation and they were made by clay and multiple layers of transparent films with holes cut as shown in Figure 5.5a. The pedestal is very large in real size thus, simulated through a CAD system instead, as shown in Figure 5.5b. For a cooktop, especially the induction stove, a transparent protruding surface was designed to assist control and navigation. It was simulated by a wood glue drawn on a surface of an induction stove as shown in Figure 5.6. It provided guidelines indicating the fire eyes and the controls.

For a microwave, we designed an additional block to leverage a user’s force exertion to open a door. As shown in Figure 5.7, it was made out of foamboard in a swingable shape. For an oven, a plastic handle in “L” shape was made and attached to a large foam board to mimic the oven door as shown in Figure 5.8.

For auditory signals, we downloaded sound files by relevant frequencies and recorded them together. Moreover, for a melody, the Guitar Pro program was used to composite and record the melody. Additionally, a blinking light to draw the user’s attention was implemented on a refrigerator. The refrigerator was not included in the target appliance, but the idea was easier to implement, thus implemented in a refrigerator just for the idea test purpose.

(a) (b)

Figure 5.5. Lo-Fi prototypes for a washing machine: a) acrylic panel, b) pedestal

Figure 5.6. Lo-Fi protruding surface of induction stove

Figure 5.7. Lo-Fi assist block to open a microwave door

Figure 5.8. Lo-Fi oven handle with adequate clearance

5.3.1 Design Guideline Principles

The design guidelines provide quantitative values along with important ergonomic principles to direct product designers toward more accessible home appliances. Important design properties such as size, height, width, length, and depth are the major attributes provided in this guideline. The guideline not only possesses the design specifications related to prototyping but also the general specifications for overall product design within the home appliance design realm.

Principle I: User must be able to locate and comprehend the product components by using their abled senses

A. The location of visual information

To begin with, the term visual information not only represents information displayed on a graphic display like an LCD screen but any type of product part providing information to a user visually. This can be applied to any part that requires the user's vision. The information should be located within the viewing angle of both the standing user and the user sitting in a wheelchair. The viewing distance is set in accordance with the distance where the user-product interaction occurs. The distance to receive visual information while in a wheelchair shall be based on the arm reach extended to manipulate the control as shown in Figure 5.9. The user-product distance considered the user's reach as well because there is no use if a user cannot control or physically interact with the appliance in accordance with what is displayed unless the interacting component is an actual display. Both postures of frontal and parallel approaches share the same maximum distance of 510mm (20 inches). However, the parallel approach is the main posture to be considered most of the time.

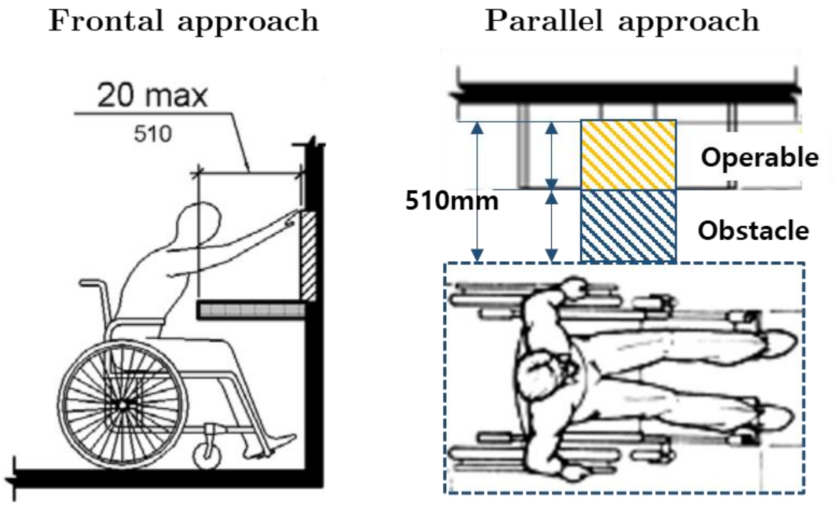


Figure 5.9. Maximum User-Product distance borrowed from ADA standard

On the other hand, ADA standards suggest visual characters be located 1015 mm above the floor (US Department of Justice, 2010) however, it is when the viewing distance is around 1830mm, which is quite far for home appliance usage. The visual angle shall be calculated based on the viewing distance given above (510mm). By utilizing Korean Anthropometric data of the disabled population (KATS, 2006), the eye heights in a wheelchair of both the 5th percentile female and 95th percentile male are 942.5 mm and 1274.7 mm, respectively (see Table 5.4.).

Table 5.4. Eye height of wheelchair users in Korea

The eye height (in a wheelchair) (mm)		
Gender	*5th percentile*	*95th percentile*
Male	1030.5	1274.5
Female	942.5	1176

The viewing angle considered the eye movement. The normal line of sight (S_N) is considered to be 15° below the horizontal line. The vertical visual angle varies by the context of whether it is a detection task or a monitoring task. The visual angle of the monitoring task is wider but lower, while that of the detection task provides ± 30° based on a horizontal line (S) (ISO 9355-2, 1999), as shown in Figure 5.10. The A zone represents a recommendable and optimal range. The B zone represents an acceptable range. Any range beyond the B zone, in other words, the C zone, represents an unacceptable range.

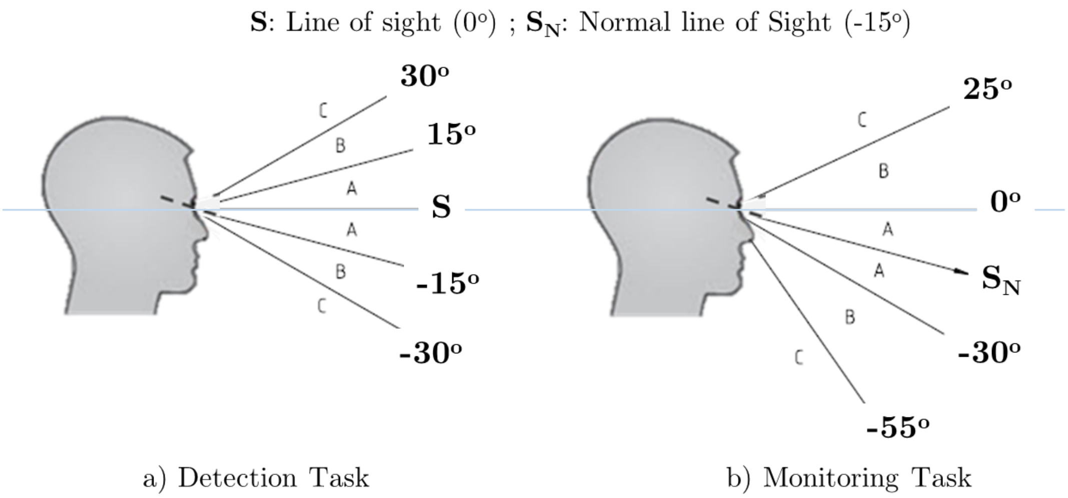


Figure 5.10. The vertical visual field for a) detection and b) monitoring task from ISO 9355-2

The lower and upper vertical height limits can be calculated based on the visual angle and the viewing distance. The upper limit is based on the 5th percentile female's eye height, while the lower limit is based on the 95th percentile male's eye height. The equations are given in Eq.1 and Eq.2

$$Upper\ visual\ field\ height$$
$$= eye\ height\ of\ 5th\%ile\ female \qquad \text{Eq.1}$$
$$+ viewing\ distance \times \tan(upper\ visual\ angle)$$

$$Lower\ visual\ field\ height$$
$$= eye\ height\ of\ 95th\%ile\ male \qquad \text{Eq.2}$$
$$- viewing\ distance \times \tan(lower\ visual\ angle)$$

Accordingly, the calculated values of both lower and upper bound, and both contexts of detection and monitoring tasks are as shown in Table 5.5. For the detection task, the range is from 980.05mm to 1236.95mm. For the monitoring task, the range is from 546.14mm to 1180.32mm. The intersection would be from 980.05mm to 1180.32mm. This range is the most recommendable because a user can perform both detection and monitoring tasks, however, it may be too tight to place everything in this range. Therefore, along with the display height suggested by ADA standard (1015mm), an appropriate allocation of components based on their task characteristics is required. The approximate height range is schematized in Figure 5.11.

Table 5.5. The vertical height of visual fields for users in a wheelchair

Visual Field (in a wheelchair) (mm)		
Context	*Lower Bound*	*Upper Bound*
Detection Task	980.05	1236.95
Monitoring Task	546.14	1180.32

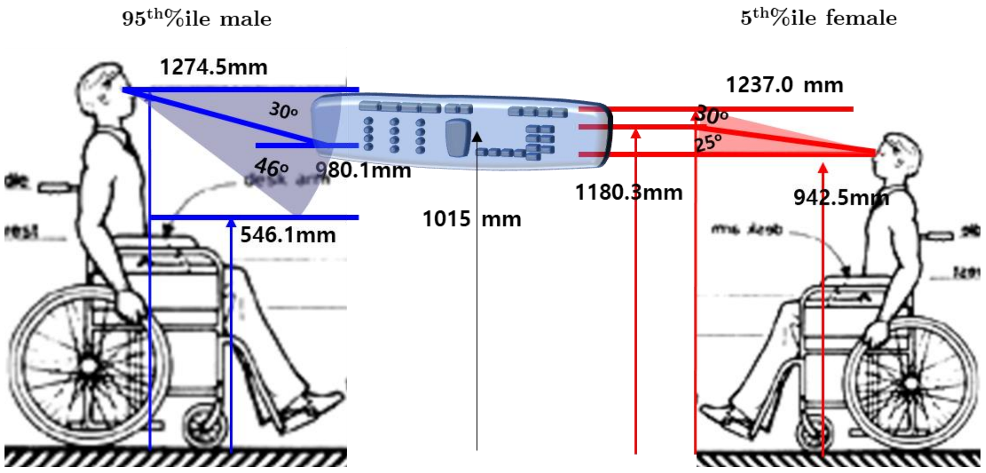
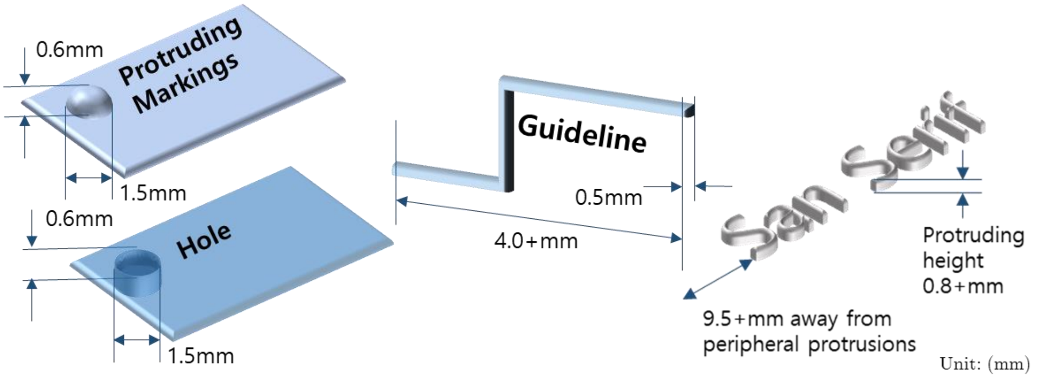


Figure 5.11. Schematized range of vertical visual field for users in wheelchairs

B. Design of tactile information

There are situations where a user solely depends on their fingertip sensation to explore a product when a target part is out of the visual field, or a user cannot utilize their vision. To indicate tactile information, there can be protruding lines, markings, dots, texts, and braille. Also, conversely, there can be groove, hole, and cavity as well. The height, depth, and size of tactile projections and braille shall differ from its surroundings so that a user can distinguish them easily. The design specification is shown in Figure 5.12. These dimensions of tactile markings, text, and braille are directly borrowed from that of ISO TR 22411 (2008). Both the protruding markings and holes share the same specification of minimum height and depth of 0.6 ± 0.2 mm and diameter of 1.5 mm to be tactilely distinguishable. Protruding lines shall be given a minimum length of 4 mm and a height of 0.5 mm. The raised text shall be written in San serif, not in irregular font, with a height of 0.8mm. Finally, the markings, lines, and raised text shall be 9.5mm away from other peripheral protrusions to be distinctively recognizable.



Dimensions	Tactile Markings		Text		Braille
Protrusion height	Dot	0.6±0.2	Minimum 0.8 mm		0.4±0.1 or 0.7~1.3
	Bar	0.5±0.1			
	Symbols	0.25~0.5			
Size	Dot (diameter)	1.5±0.2	Height	16 ~ 51	-
	Bar (length)	4.0±1.0	Width (Stroke Thickness)	15% of height	
	Symbols (size)	9±1 or 18±2	Spacing	T2T(V): 135~170% of text T2T(H): 3.2mm~400% of text T2P: minimum 9.5mm away	

* T2T: Text-to-Text; V:vertical; H:Horizontal; T2P:Text-to-Peripherals

Figure 5.12. Dimensions of tactile markings used in applications (fingers) (ISO 22411, 2008)

Therefore, for Principle I, 1) visual display and information shall be located within 980.05 mm and 1236.95 mm above from the floor for detection task, and 546.14 mm to 1180.32 mm above the floor for monitoring task. 2) tactile display and information shall be designed with specific dimensions so that they are distinguishable even if unseen.

Principle II: Major compartments should be located within the user's reach envelope

The height design should consider the user's reach in terms of the upper reach and lower reach in a wheelchair. A spinal-cord impaired user – a user in a wheelchair – take a parallel approach if there is insufficient space for their knees. There are three parallel approaches (side reach) types according to ADA Standard (US Department of Justice, 2010) as shown in Figure 5.13. The unobstructed side reach is applicable for front-loading washer and dryer, and oven. In this case, the lower reach should be a minimum of 380 mm and the upper reach should not exceed 1220 mm from the floor. On the other hand, obstructed side reach has two different cases: a) with a taller obstacle, b) with a taller and wider obstacle. The first case (a) may be suitable for cooktop and microwave usage. The upper reach height remains the same, 1220 mm from the floor. The second case (b) may be applicable for cooktops with rear-mounted controls and refrigerator usage. In this case, the maximum upper reach height decreases to 1170 mm instead of 1220 mm due to thicker and taller obstruction beside the user.

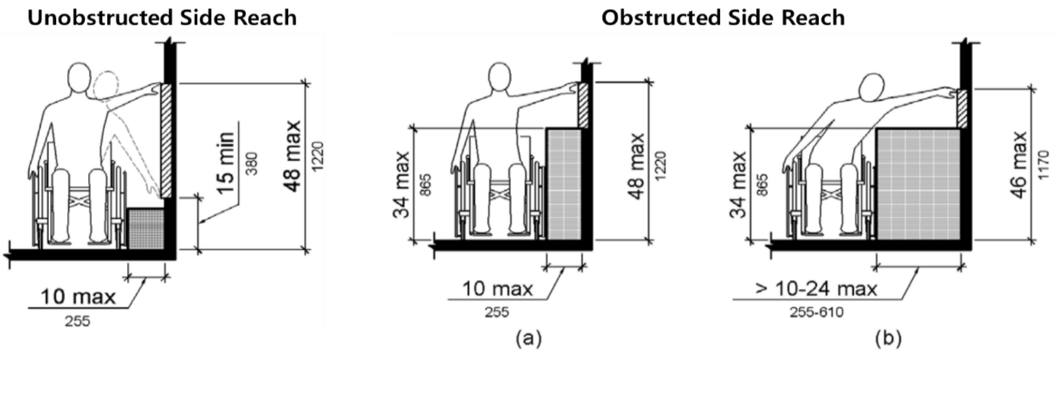


Figure 5.13. Types of parallel approach (side reach)

However, for stricter design specifications to accommodate more people, the upper and lower reach in a wheelchair for the Korean disabled population is considered because the ADA standard considered only the American disabled population who are relatively larger than that of Korean. Especially, in terms of reach, there can be a left-out population if an appliance is designed only in accordance with the ADA standard specification. There was upper and lower side reach with unobstructed side reach posture measured in 2008 (KATS, 2008). Accordingly, the dimensions are shown in Table 5.6. The smallest value for the upper side reach height was that of the 5th percentile male (996 mm) and the highest value for the lower side reach height was that of the 95th percentile male (515.5 mm). For the lower side reach, although the higher number is assigned with a higher percentile value, the higher values represent lower capability. Therefore, for a stricter design specification with larger accommodation, any operable in unobstructed condition (obstacle width less than 250 mm) shall be located within 515.5 mm to 996 mm range from the floor.

Table 5.6. Side reach dimension of Korean disabled population

Unit: (mm)

Side reach (Unobstructed)	Gender	5th percentile	95th percentile
Upper side-reach	Male	996	1733
	Female	1008	1603
Lower side-reach	Male	36	515.5
	Female	69.5	502

Principle III: There should be adequate error tolerance for the user and user's body to pass through or be positioned, freely and correctly.

Not only the reach but the clearance is a major specification to consider for home appliance design. The clearance not only refers to the clearance of the upper or lower limb, but it also means a passthrough hole for small parts like fingers and hands. In principle I-b, the tactile guideline suggests that a hole should have a minimum depth of 0.6 ± 0.2 mm and a diameter of 1.5 mm. However, for a finger to pass through, the diameter should be larger than that of the finger radius (thickness). Apparently, Korean 95th percentile male has the largest index finger thickness thus this value (22 mm) is utilized as a minimum clearance required for a hole above a touch interface device to allow a finger operation.

Table 5.7. Hand dimension of index finger thickness

Unit: (mm)

Index finger thickness	Gender	5th percentile	95th percentile
British (Pheasant & Haslegrave, 2018)	Male	17	21
	Female	14	18
Korean (KATS, 2008)	Male	19	22
	Female	17	20

However, not all users can utilize their fingers freely. Namely, many spinal cord impaired users utilize their hand blade or other parts of their hands to activate touch buttons. In this case, we refer to the hand thickness at the metacarpal, representing the thickness of the hand blade. The 95th percentile British male had the largest hand thickness at metacarpal (38 mm) as shown in Table 5.8.

Table 5.8. Hand dimension of hand thickness (metacarpal)

Unit: (mm)

Hand thickness (metacarpal)	Gender	5^{th} percentile	95^{th} percentile
British (Pheasant & Haslegrave, 2018)	Male	27	38
	Female	24	33
Korean (KATS, 2008)	Male	25	31
	Female	22	28

Therefore, a diameter of a hole shall be a minimum of 38 mm wide, so that any spinal cord impaired user who may not be capable of using his or her fingers can operate with their hand blade instead. Moreover, a chamfered design of a hole can derive both fingertip and hand blade operation, and also design aesthetics. A touch interface can be activated as long as a proportional area of a hand or fingers contact the interface surface, meaning not the whole 38 mm of hand blade needs to be in contact. The examples of chamfered hole design for both finger and hand blade (fist) operations are given in Figure 5.14.

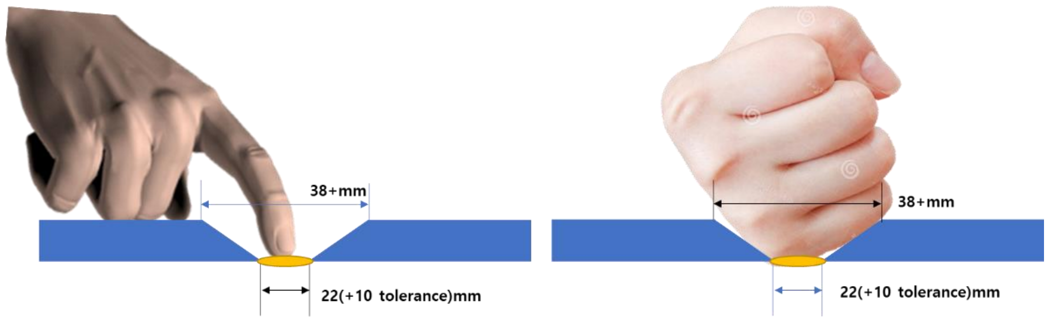


Figure 5.14. Examples chamfered holes for both fingertip and fist operation

Principle IV: Users with different physical or sensory capabilities should be able to receive feedback through their capable sensation.

An appliance may fall into an erroneous situation and it needs to draw the user's attention. From a distance, an appliance can utilize its visual alarm and auditory alarm to do so.

A. Dynamic (blinking) visual display

According to ISO TR 22411 (2008), a flashing, blinking, and/or flickering light is effective in drawing attention and can be used for conveying task-relevant information to be discerned. However, a sequence of flashes with more than three flashes within any 1 second period can cause undesirable biological effects such as seizures.

B. Auditory display

Human hearing sensitivity is usually within the range of 20 Hz to 20kHz, however, the cochlear implants are optimized for the human speech spectrum, which is mostly measured between 125Hz to 8kHz (ISO 9921, 2003), thus a hearing-impaired user with a cochlear implant has much narrower frequency domain that he or she is capable of hearing. According to ISO 24500 (2010), the fundamental frequency of auditory signals should not be higher than 2.5kHz. At the same time, according to the ISO TS 16071 (2003), the fundamental frequency of task-relevant non-speech audio should occur in a range between 500 Hz and 3,000 Hz – or be easily adjustable by the user in that range. Also, alerts and other auditory warnings should include at least two strong mid-frequency to low-frequency components, with recommended ranges of 300 Hz to 750 Hz for one component, and 500 Hz to 3,000

Hz for the other. Therefore, as shown in Table 5.9, an auditory signal should be designed within the range of 300 to 2,500 Hz and there should be two components of frequencies from the two recommended frequency ranges (300 to 750 Hz, and 500 to 2500 Hz).

Table 5.9. Frequency bands and corresponding musical notes by octaves

Unit: Hz

Musical Note	Octaves								
	0	1	2	3	4	5	6	7	8
C	16	33	65	131	262	523	1047	2093	4186
C#	17	35	69	139	278	554	1109	2218	4435
D	18	37	73	147	294	587	1175	2349	4699
D#	20	39	78	156	311	622	1245	2489	4978
E	21	41	82	165	330	659	1319	2637	5274
F	22	44	87	175	349	699	1397	2794	5588
F#	23	46	93	185	370	740	1475	2960	5920
G	25	49	98	196	392	784	1568	3136	6272
G#	26	52	104	208	415	831	1661	3322	6645
A	28	55	110	220	440	880	1760	3520	7040
A#	29	58	117	233	466	932	1865	3729	7459
B	31	62	124	247	494	988	1976	3951	7902

■: Speech spectrum (125 ~ 8,000 Hz)

■: Recommended frequency band 1 (300 ~ 750 Hz)

■: Recommended frequency band 2 (500 ~ 2,500 Hz)

■: Common frequency band (500 ~ 750 Hz)

5.3.2 Prototyping

Based on the ideas established upon the seed ideas and the ergonomic design guidelines, seven prototypes were developed. Most of the prototypes were built by CAD and 3D printers.

Prototype I: Intaglio. The first prototype is a transparent acrylic panel with holes drilled in indicating an activation spot for touch buttons, especially on the washing machines and dryers. The word "intaglio" refers to a design incised or engraved into a surface in Italian. As the name refers, this prototype tries to promote accessibility by creating grooves on a surface of an appliance. The target problem to resolve was the prevention of unintentional or accidental touch activation on touch interfaces. Visually impaired users can accidentally and unintentionally touch undesired touch buttons as they swipe through the touch interface. Also, spinal cord impaired users can unintentionally activate peripheral buttons due to difficulties in precise touch control. Therefore, its aim is to 1) assist product exploration and navigation, and 2) prevention of unnecessary activation.
At the same time, such an additional layer can hinder the reception of visual information, which hearing-impaired users highly depend on. Thereupon, the material must be a transparent one, as the acrylic panel. On the surface of "Intaglio", there were raised lines and dots - including braille – to provide a tactile indication for visually impaired users. First, there are raised lines indicating the segregation of upper control and lower control parts; this specific model of the washing machine had two different controls. Also, around the parting lines and important controls, there are braille telling which section they are. The braille says, as shown in Figure 5.15, course selection, detailed settings, S S P P, upper controls, lower controls, power, and controls. S and P stand for "Start" and "Pause".

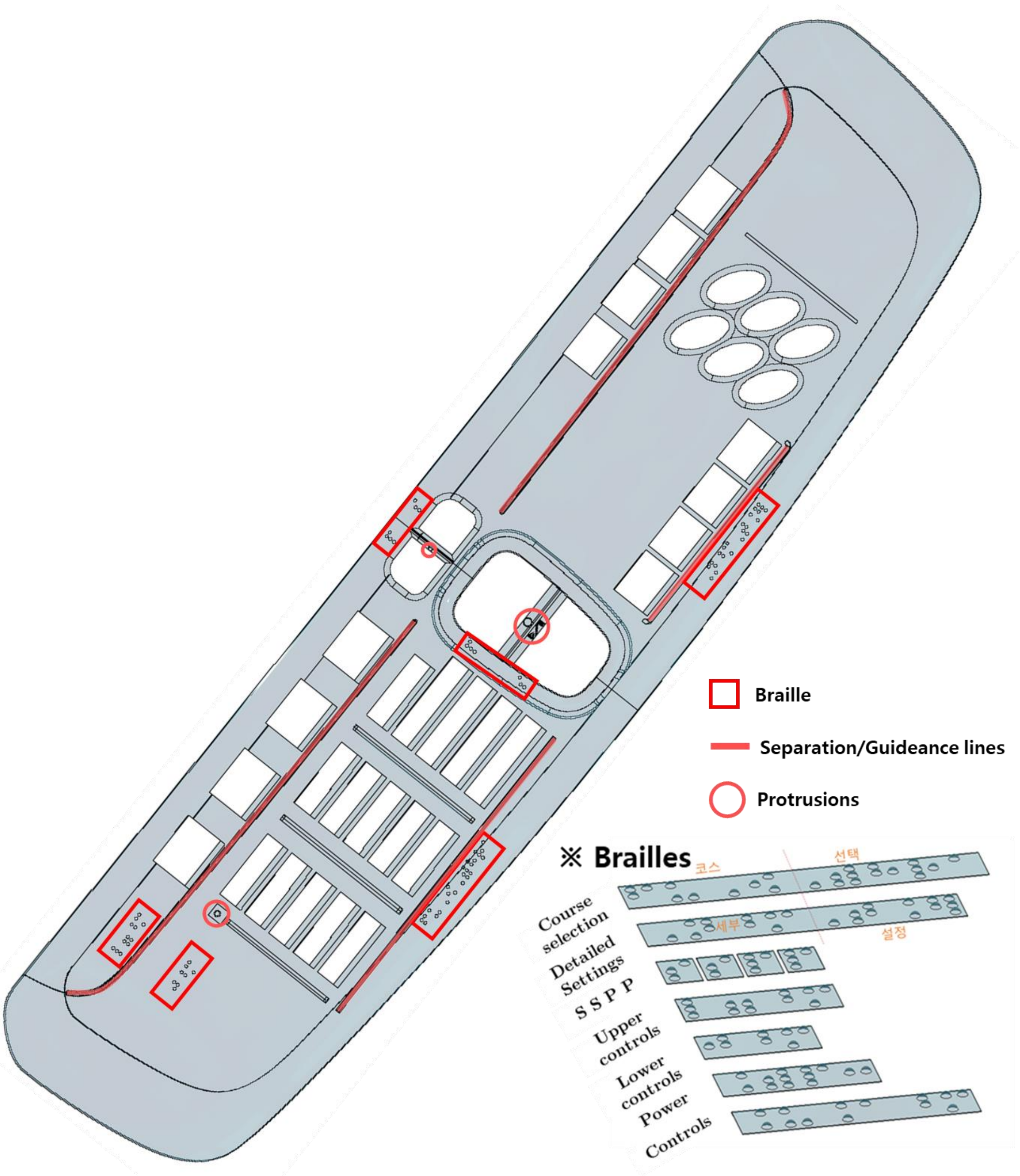


Figure 5.15. Prototype I: Intaglio - transparent acrylic panel for touch buttons on washers and dryers

Secondly, the groove or cavity can be as small as a circular fingertip, if only visually impaired users are considered. However, it is required to provide larger clearance to accommodate spinal cord users, who may struggle to control with their fingertips. As shown in Figure 5.16, all cavities attempted to meet the dimension of 38mm in any direction possible so that a spinal cord impaired user with a large hand can also use it without any problems. The dimension is symbolic than a practical one because the 38mm size is a dimension taken from 95th percentile male. Many spinal-cord impaired users who lost control of their hands have relatively smaller hands. That 38 mm is still more than an adequate number even if their hands were as large as 95th percentile male. Moreover, when activating a touch control device, only part of the fingertip or thumb will be utilized resulting in a proportion of length and width of finger and thumb (Wang & Ren, 2009). The same will be applicable for the hand blade as well.

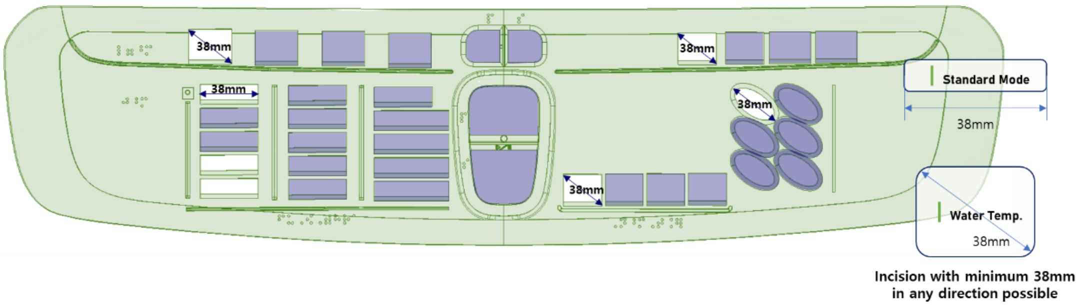


Figure 5.16. Cavity spacing dimension of 38 mm

Prototype II: Cameo. The second prototype is also a transparent acrylic panel but with protruding indicators on the surface of an induction stove. The word "cameo" refers to a design protruding or raised on a surface in Italian. As the name refers, this prototype tries to promote accessibility by creating protrusion on a surface of an appliance. The target problem to resolve was the inability to explore and discover the fire eye, center of fire eye, and control part on a touch interface of induction stoves. It is challenging for visually impaired users to successfully find the middle of fire eye to locate pots. It becomes more challenging when the surface is hot when it is already difficult in its normal state. Therefore, the fire eyes are surrounded by raised circular line, and each line continues in a single line connected to each corresponding control so that a user can easily distinguish not only the fire eye location but also its corresponding control. Besides, triangular arrows are pointing at the center of each fire eye on the metal rim around the stove so that a user can estimate the center by using their fingers only even if the stove is hot.

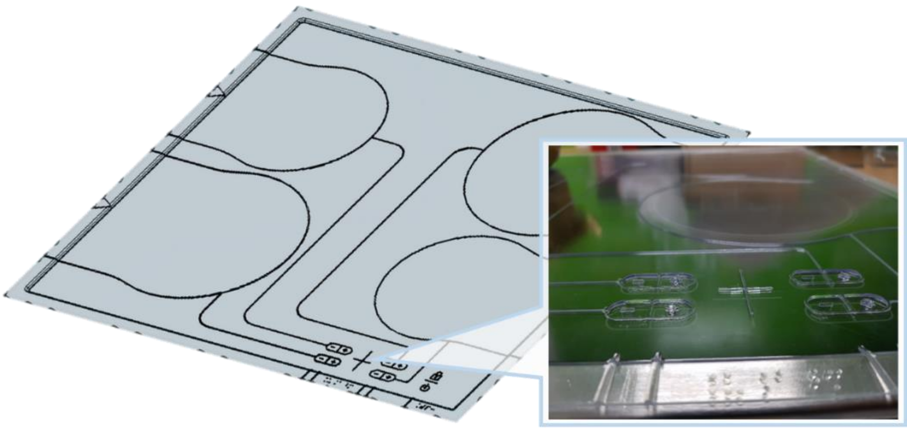


Figure 5.17. Prototype II: Cameo - transparent acrylic panel for the guideline on induction stove eyes and controls

In the middle of the controls, there is cross-shape raised lines so that a user can understand which plane each control corresponds to. Also, there are raised lines and braille on top of the metal rims so that a user can distinguish the level controls, power button, and lock button. Each circular guideline is 11 mm away from the fire eye, which is half of the finger thickness. Such a gap will allow a user from being burnt even if the user's finger reaches closer to the fire eye during the operation. The height and sizes of the raised line and braille followed the design specification described in Figure 5.17 above.

At the same time, such an additional layer can hinder the reception of visual information, which hearing-impaired users highly depend on. Thereupon, the material must be a transparent one, as the acrylic panel. Instead, hearing impaired users and elderly users can be assisted with such visually salient lines as well.

Prototype III: Dondolo. This prototype is an assistive button pusher for a microwave button that is flushed to the surface. This prototype is a simple-to-install-and-use assistive product in a swing-like shape. The word "dondolo" means swing in Italian. The target problem to resolve was that a spinal cord impaired user with opened palm or closed fist cannot fully push in the flushed-to-the-surface microwave door button.

In accordance with two principles of motion economy, "dondolo" leads to a better motion. The first relevant principle is "Ballistic movements are faster, easier, and more accurate than restricted (fixation) or controlled movements." Unlike how a spinal cord impaired user had to precisely position their hands or fingers on a button and press it, the user can take a ballistic motion of hammering down the Swing to open the microwave door. Moreover, this circular or rotational motion from top to bottom does not sacrifices the reach of a spinal cord impaired user whereas a linear pushing motion may push back the microwave and possibly require a longer reach. Therefore, a change in the direction of the force exerted is appropriate. As shown in Figure 5.18, before being pushed, the dondolo provides enough space for a user to place their hand. After being pushed, the back wing of the dondolo pushes the flushed button inward so that it can activate the mechanism to open the door.

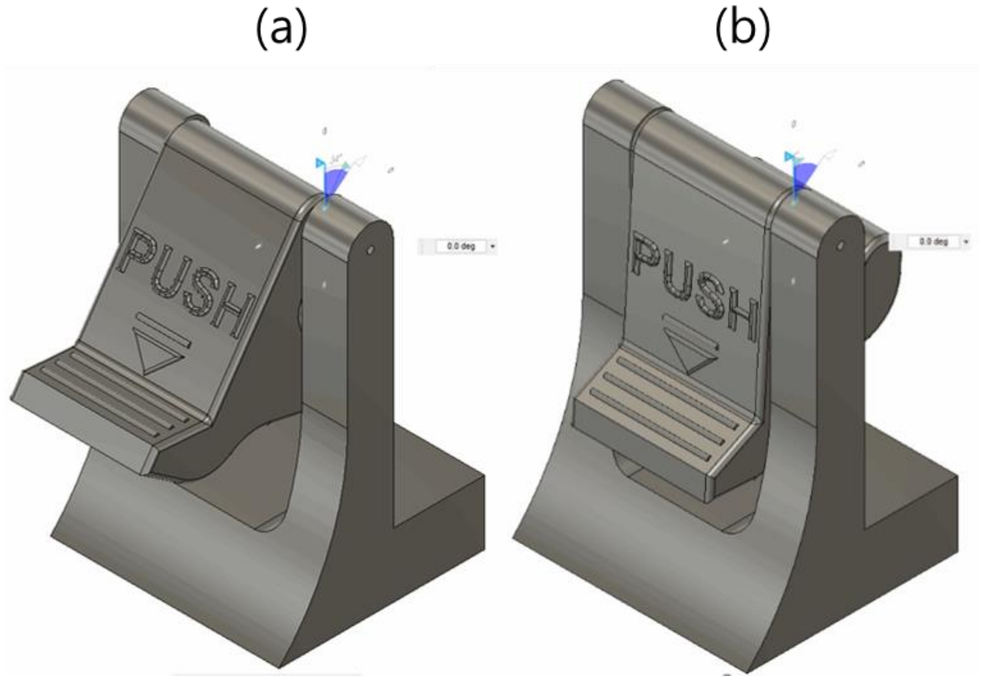


Figure 5.18. Prototype III: Dondolo – a) before being pushed, b) after being pushed

Dondolo will rest itself at 45 degrees as shown in Figure 5.19 when it is installed because of the back wing. The distance from the very back of the wing to the point where the user's force will be applied is 40.14mm, which is longer than that of the 95th percentile male's hand thickness at metacarpal. Therefore, a user with a large hand can place their hand and hit dondolo with no issue delivering the force to the microwave. Also, the support part of the dondolo is gently curved toward the bottom, resulting in a smooth sliding motion of the user's hand after a user hits the dondolo. It prevents any damages for a user which would have occurred if the bottom part was in a sharp square shape.

One may argue that this is useful for the spinal cord impaired user only, however, visually impaired users, whose task of searching the flushed button is challenging, can benefit from this tactilely salient surrogate button. Also, hearing impaired users and elderly users can benefit from such visually salient lines too.

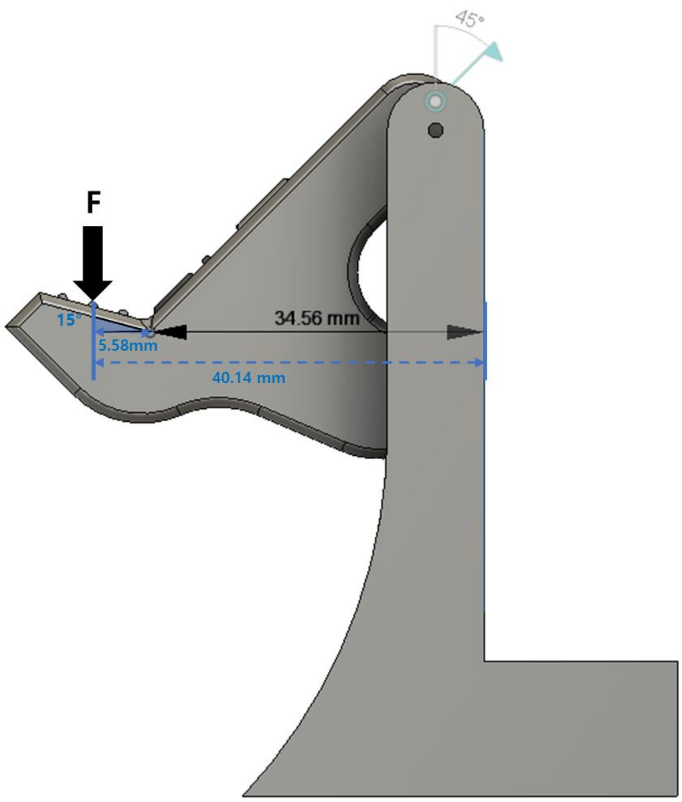


Figure 5.19. Dondolo - Sideview

Prototype IV: Arrivo. A pedestal was implemented to lift up the lower height of the washer's tub in order to comply with the ADA standard. The ADA standard, suggests that a front-loading washing machine shall have the bottom of the opening to the laundry compartment located 380 mm minimum and 915 mm maximum above the finished floor. The minimum value of 380 mm is equivalent to the lower side reach height of a disabled user in a wheelchair, meaning that a user should be able to reach for the laundry in a parallel approach position.

The bottom of the opening to the laundry compartment of the target washing machines in this study (Samsung WF23R9600KP) was 260 mm from the floor originally; it could not satisfy the ADA standard. Fortunately, there was a pedestal made for this model with a height of 160 mm, as shown in Figure 5.20.

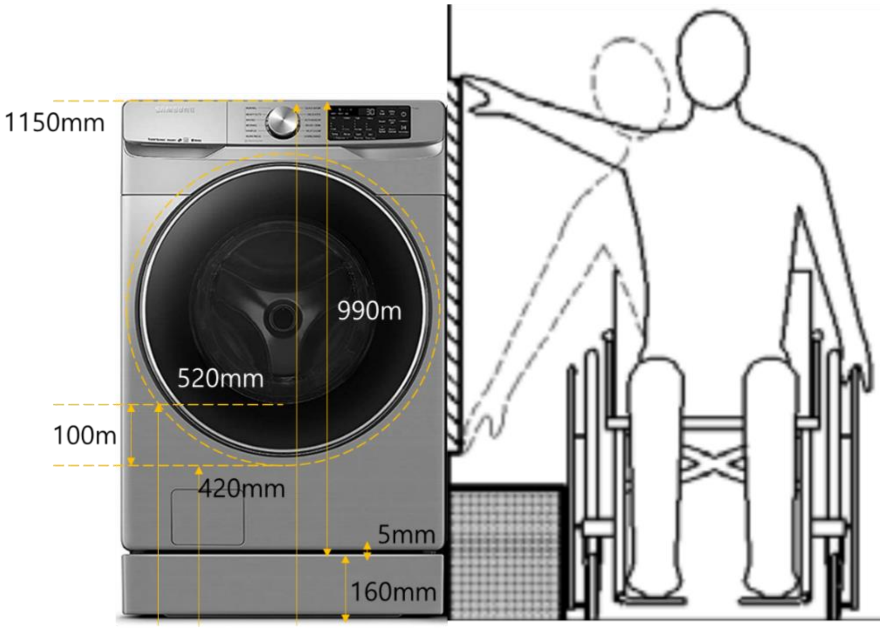


Figure 5.20. Prototype IV: Arrivo - estimated washing machine with a pedestal usage by a spinal cord impaired user and their side reach

The tub radius is 100 mm larger than that of the opening. Accordingly, the bottom of the opening could be raised up to 520mm, as the bottom of the tub was raised up to 420 mm. Therefore, both the tub and bottom of opening heights comply with the ADA standard.

Although this prototype mainly targets spinal cord impaired users, however, the other user groups can also benefit from the raised height of the washing machine because they do not have to bend their upper limb as much as they had to.

Prototype V: Libero. This prototype is a handle with adequate clearance considering the closed-fist operation. The word "libero" refers to freedom in Italian. This handle has openings on each side so that a user may not only grasp the handle but also hook their hand or wrist on the side of the handle to open a door. There were various types of handles considered in the beginning, as shown in Figure 5.21. However, for more versatility, the L-shape design with two openings on both sides is selected.

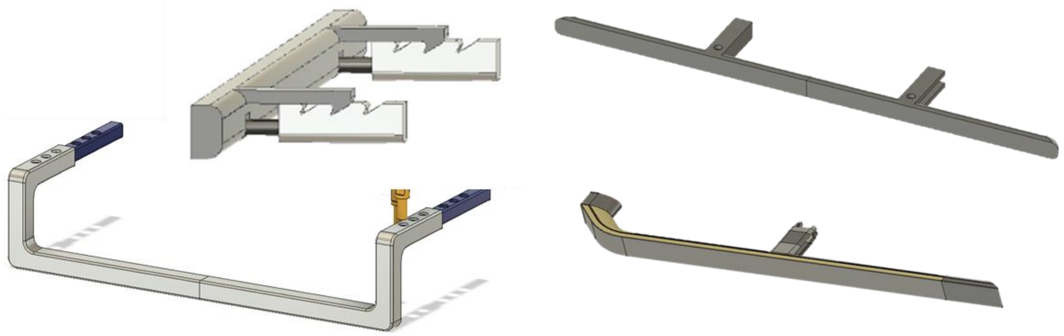


Figure 5.21. Various early prototypes of Libero

The T-shape handle was the most versatile candidate and had many variances. However, the advantage of the L-shape design, that it can lower the hinge (handle arm) height without sacrificing the height of the graspable handle part, led itself to be the final design.

Handle arms that provide the clearance length is 68mm. The hand thickness including thumb of 95th percentile male is 58 mm (Pheasant & Haslegrave, 2018). For this clearance, a 10 mm width allowance is given for movement (ISO 15534-2, 2000). Therefore, the handle arm length is 68 mm considering the width allowance. The prototype and relevant hand dimensions are shown in Figure 5.22.

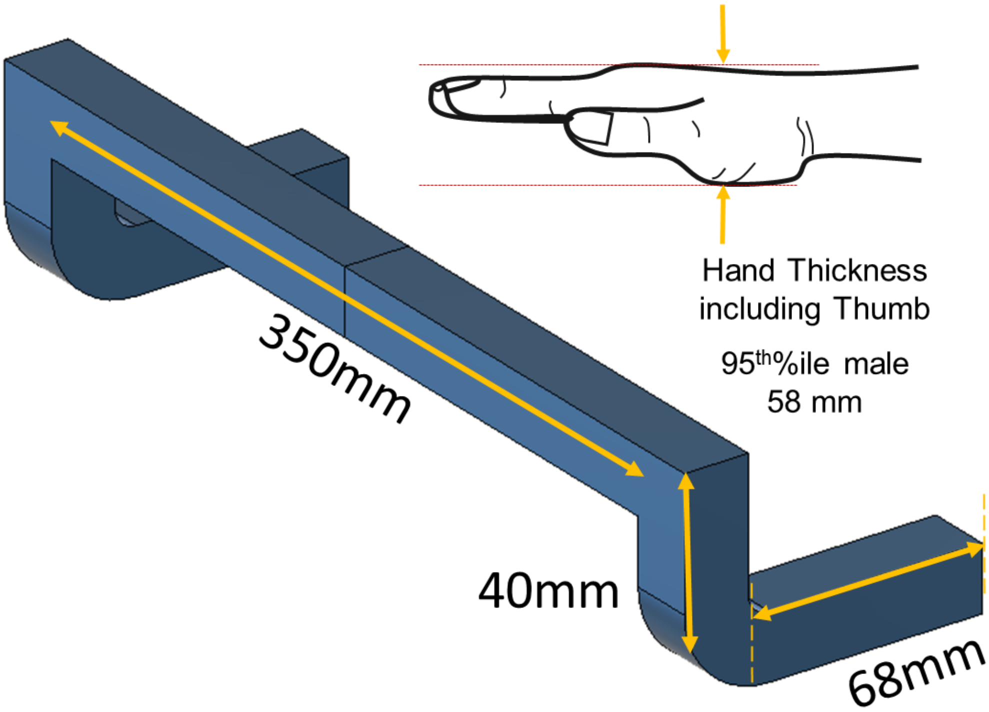


Figure 5.22. Prototype V: Libero – a handle with related hand dimensions

Prototype VI: Concordia. This prototype consists of three different beep sounds and two melodies. The word "Concordia" means harmony in Italian. All the beep sounds and melodies are made using the notes within the recommended frequency ranges given in Table 5.9, only. The frequency bands between 300 Hz to 500 Hz are low frequency, the bands between 500 Hz and 750 Hz are middle frequency, and the frequency between 500 Hz and 3000 Hz is high frequency. The beeps, as shown in Figure 5.23, are 1) low-frequency dominant, 2) balanced, and 3) high-frequency dominant beeps, and they are all in a major key. The low-frequency dominant beep sound is E major, and it consists of three low-frequency notes (330 Hz, 415 Hz, and 494 Hz) and one of each frequency note from the middle (659 Hz) and high frequency (988 Hz) note. The balanced beep is in D# major, and it has two low frequencies (311 Hz and 466 Hz) and high frequencies (784 Hz and 932 Hz) with one middle frequency (622 Hz) note. Finally, the high-frequency beep is in G major key and it consists of three high frequency (784 Hz, 988 Hz, and 1175 Hz) notes and one of each middle (622 Hz) and low frequency (392 Hz) note.

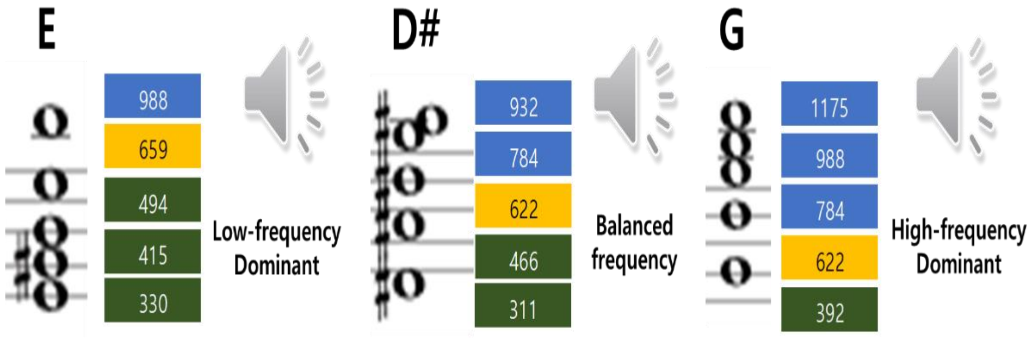


Figure 5.23. Prototype VI: Concordia 1 - Beep sounds

On the other hand, there are two melodies played in harmony. The base melody was the introduction of a song named “over the horizon”, which is Samsung’s representative song. There was no single note played alone. Every note was played along with another note with a different frequency no matter if they are in the same frequency band or not. The low-frequency version of over the horizon mostly contains low-frequency notes and middle-frequency notes. There are only two notes in high-frequency bands. In contrast, the high-frequency version contains more notes in high-frequency bands and there were only two notes in the low frequencies. The musical sheets of each version are given in Figure 5.24.

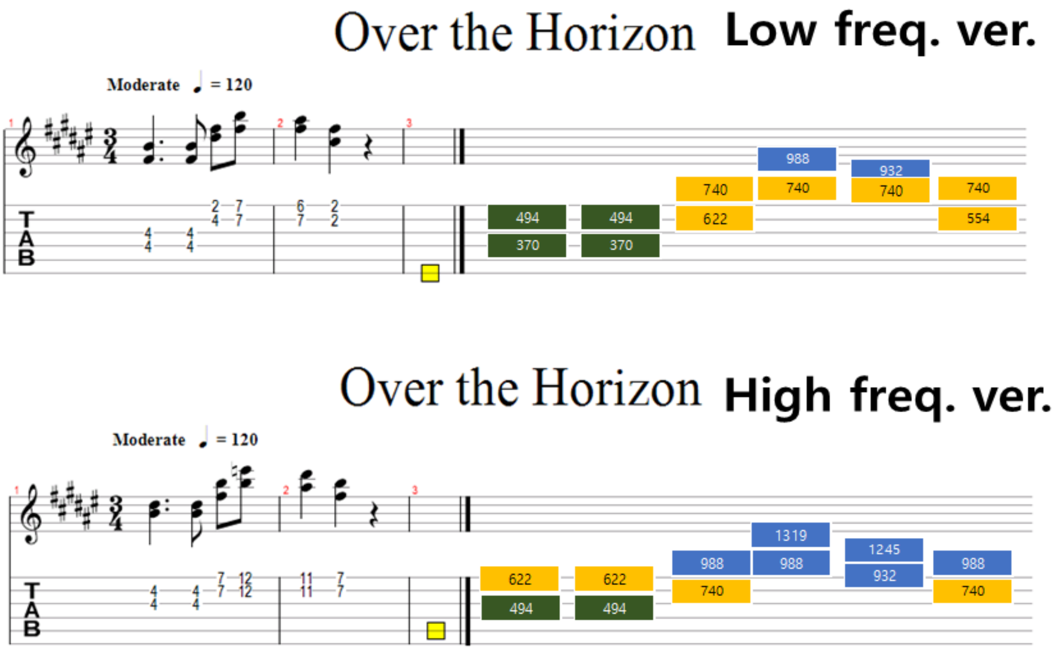


Figure 5.24. Prototype VI: Concordia 2 – Melody, musical sheets

Prototype VII: Lucciola. Finally, the last prototype is a blinking LED light to draw the user's attention. The word "Lucciola" refers to a firefly, thus this prototype was named after it to represent its light blinking behavior. Installing an additional LED with software to control the blinking rate seamlessly on an existing product was a challenging task. Therefore, instead of the target home appliances, this idea was implemented into a refrigerator for this evaluation only. During the interview and observation, many visually impaired, hearing impaired, and elderly users referred to the refrigerators with inadequate feedback of whether their doors are securely shut or not, as they spoke of home appliance accessibility. Therefore, this idea was implemented in a refrigerator in accordance with the design guideline's 4^{th} principle. The blinking rate was two blinks per second (2 Hz). The refrigerator's inner LED started to blink if the door was left open for more than 20 seconds.

(a) (b)

Figure 5.25. Prototype VII: Lucciola - a) light on, b) light off

5.4 Experiment for validation

We re-recruited a total of 14 participants (5 visually impaired, 5 hearing impaired, and 4 spinal cord impaired users). All participants already participated in the interview and observation held earlier from Chapters 3 and 4 because they have experience of using the stock appliances before the changes so that they can analyze whether the prototypes actually resolved some problems they shared earlier or not. There were seven prototypes prepared in the experiment site and each user group tried out every prototype as shown in Figure 5.26, and evaluated as shown in Figure 5.27. The evaluating moment was not taken for prototype 6, Concordia, because it was a simple listening session.

Figure 5.26. Experiment environment

All participants answered survey questionnaires after each trial. The questionnaires mainly asked four points: 1) this prototype will make it easier to use the appliance, 2) my disability can benefit from this prototype, 3) this prototype rather hinders my use of the appliance, and 4) please share your opinion on this prototype (thoughts, improvement, etc.). The first three questions are given on a 7-point Likert scale and the fourth question was open-ended. For the auditory prototypes, it asked about perceivability and affective ratings. The deaf participants were exempted from answering the auditory questions. Finally, the questionnaires on the refrigerator asked for perceivability, brightness, and blinking rate. The blind users were exempted from answering these questions. The evaluation result will also approve the validity of the design guidelines established.

Figure 5.27. Prototype Evaluation

5.4.1 Evaluation Results

Participants evaluated every prototype to validate if the prototypes designed based on the design guideline can improve accessibility without hindering the smooth usage flow. As a result, the prototypes mostly provide enhanced accessibility, yet, there can be minor improvements for a better universal solution.

Prototype I: Intaglio. All user groups answered that this prototype makes it easier to use the washing machine, and helps overcome their disability without hindering a smooth usage flow, as shown in Figure 5.28. Most visually impaired users – who are one of the main target user groups of this prototype - agreed that it is now easier to find where the control panels are, and they can successfully perform the standard operation as long as this prototype is installed. However, in terms of shortcomings of this product, there lacks consistency and explanation on the control menus though there are so many menus they can choose. They can count how many menus are there, but there is no speech guidance or braille for every menu button telling which menus they are. Moreover, it is difficult to count the oval-shaped cavity, unlike the square grooves.

Spinal cord impaired users, who are another target of this prototype, answered positively because the groove certainly prevented unintentional mis-activation when they operate the washing machine. Besides, the grooves help them visually distinguish the control sections. There was an unexpected benefit of the prototype found for spinal cord impaired users. Most washing machine's touch panels are slanted toward the eyes of a standing user, and the reflected glare is seen at the seated height in a wheelchair. This additional layer of less glossy panel prevented glares for the spinal cord impaired users.

Hearing impaired users also answered positively because the additional layer of intaglio was not opaque but adequately transparent, and the grooves were large enough so that they could operate the washing machine without any hindrance. However, they mentioned that the visual feedback from the control panel became less bright due to the panel, and this can be improved by material changes.

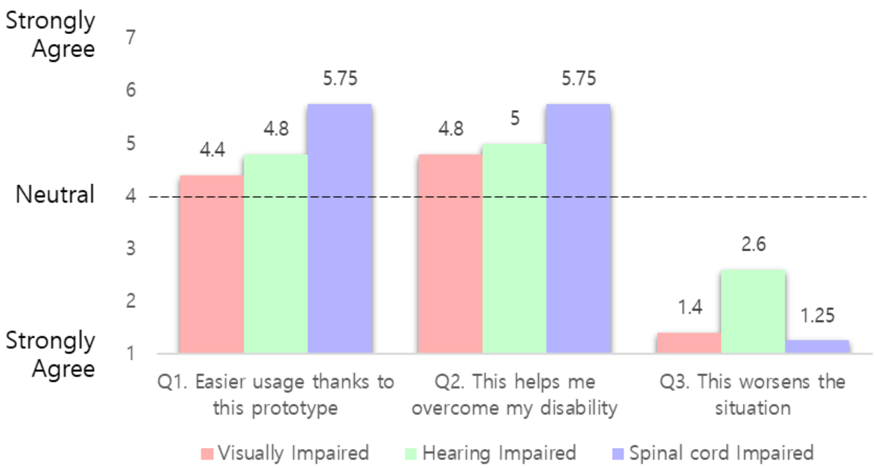


Figure 5.28. Evaluation result on Prototype I: Intaglio

Prototype II: Cameo. All participants answered that this prototype makes it easier to use the induction stove, and helps overcome their disability without hindering a smooth usage flow. The concept of the cameo is similar to that of the intaglio because both add a transparent layer on top of an appliance. Visually impaired users were the main target user group for Cameo, and they could successfully find the center of fire eye and corresponding controls. Visually impaired users highly appreciated the triangular protrusion and braille on the metal rim because they could explore and comprehend the appliance structure without risking their hands getting burnt since the metal rim is away from the fire eye. However, the protruding lines connecting the fire eye and the controls were not much appreciated because they prefer to have the controls near each fire eye so that the need for guidelines is nonsignificant. They also showed higher satisfaction overall for cameo than the intaglio, it is because there was adequate braille matching each control, and the control types do not require spoken instruction for induction stove, unlike the washing machine.

Hearing impaired users appreciated the salient borderlines indicating which part is the fire eye and control. They stated the protruding line could be colored to be more salient. However, they were not satisfied that there was no written text around the controls and fire eyes though there was braille. Spinal cord impaired users were less impressed with Cameo than they were with intaglio. Mostly because they were worried about the maintenance issue. The protruding lines and dots seemed to be difficult to keep clean with their paralyzed hands when they spill foods on a surface, which occasionally happens when cooking on an induction stove.

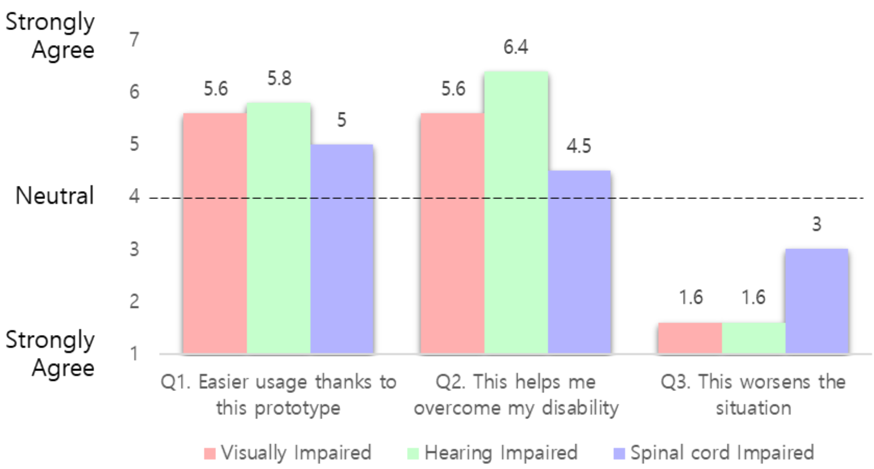


Figure 5.29. Evaluation result on Prototype II: Cameo

Prototype III: Dondolo. For the third prototype, not everyone agreed that the prototype improved accessibility. Spinal cord impaired users evaluated Dondolo positively. They could successfully open the microwave door without exerting much force. However, the door and the button were close to each other so that their hand could be jammed as the door pops.

Visually impaired users, unlike the expectation that it would assist their usage, showed that the prototype does not make the usage easier and help, but rather hinders their smooth usage. The hindrance was because of the protruding letter, "PUSH" on the surface of the swinging part of the prototype. This protrusion can be misread into some other words that mean something else, according to some of the visually impaired participants. They also mentioned that protrusion can interfere with their movement and cause possible damages.

Hearing impaired users were worried that the additional structure in front of a microwave will take some space in the kitchen. One other participant stated that it would be better if the letter, "PUSH" was written more clearly or lit instead.

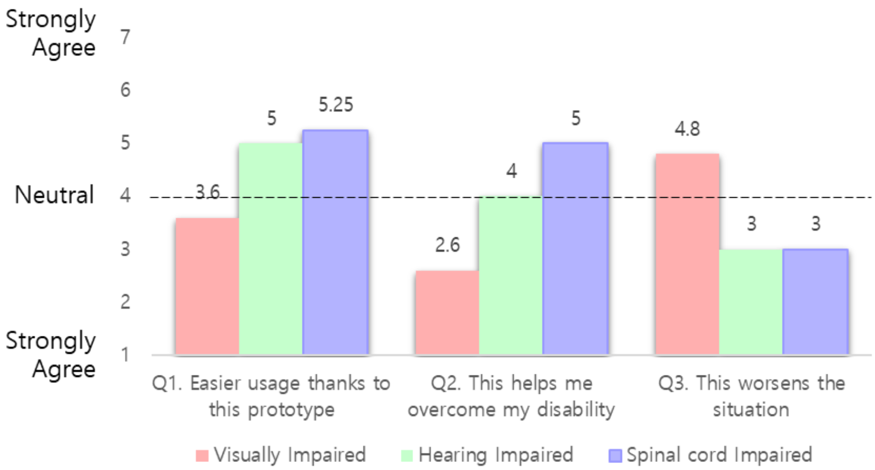


Figure 5.30. Evaluation result on Prototype III: Dondolo

Prototype IV: Arrivo. This prototype received an unexpectedly low score, especially by its target users - namely, spinal cord impaired users. Spinal cord impaired users all agreed that the access to the bottom of the tubs was made accessible through the pedestal. However, it is accompanied by a severe drawback. The rise of the height in a whole appliance increased the height of the control panel and detergent drawer, which used to be accessible. The top of the washing machine is measured at 1150 mm and it was beyond the Korean upper side reach limit (996 mm). To use the detergent drawer, it should not only be in the user's reach but also a user should be able to see the level of detergent being poured. It means that the height of the detergent drawer should be below the user's eye height, and the 5th percentile female user in a wheelchair has an eye height of 942.5 mm. The ADA standard limits the upper height of washing machines to be below 914.4 mm (36 inches). The raised washing machine certainly did not comply with the ADA standard, yet the ADA standard could have ensured the accessible use of the detergent drawer.

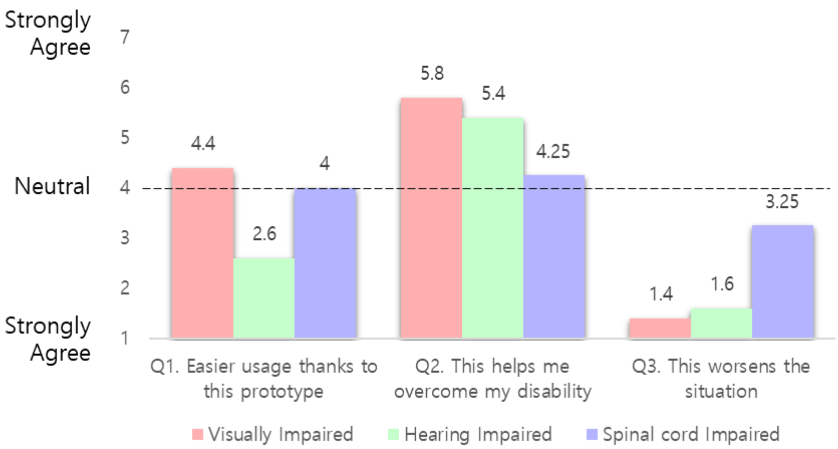


Figure 5.31. Evaluation result on Prototype IV: Arrivo

Hearing impaired users liked the fact that they do not have to bend over as much as they had to, thanks to the raised height. Visually impaired users, especially the low-visioned participants appreciated the raised height since they can bend less.

Prototype V: Libero. Spinal cord impaired users appreciated the wide clearance on both sides so that they can easily hook their hands and wrists into the handle. They can access the handle from any side. The L-shape of Libero allowed horizontal access whereas the T-shape handle forced a user to shove down their hands vertically. It means that the user can lift their arm higher for the T-shape handle. Also, the handle's graspable part remained at its position, while the handle arm is 40 mm lower, thus the spinal cord impaired users could have easier access.

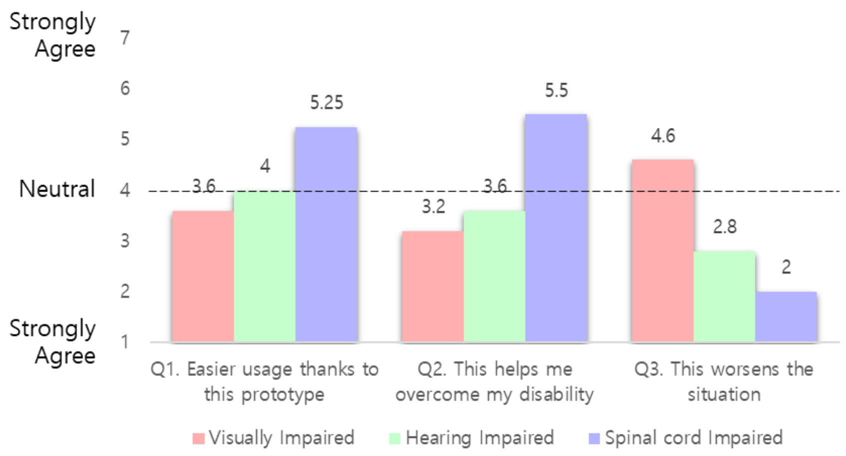


Figure 5.32. Evaluation result on Prototype V: Libero

A visually impaired user appreciated its rounded edges and easily discoverable handle. However, such a long protruding part can be a potential hazard of bumping and jamming. Also, when the handle is far from the door surface, visually impaired users may not be able to estimate the door status (position, orientation, etc.). Such problems led them to give low scores on this prototype.

Hearing impaired users also showed their worries about its long protruding length. One of the hearing impaired participants suggested a foldable handle as a solution. Overall, such a problem can be resolved by implementing springs for adjustable length of handle arms.

Prototype VI: Concordia. This prototype was highly appreciated by hearing impaired users with cochlear implants. The perceivability was all high enough for every participant – except for the deaf participants – could perceive the beep sounds and melodies, as shown in Figure 5.33.

However, in terms of affective ratings, there was a distinct difference found between the hearing impaired participants and the other user group, as shown in Figure 5.34. Both visually impaired and spinal cord impaired users showed strong negative ratings toward the beep sounds whereas hearing impaired users showed very high positive ratings. The beep sounds were produced without a proper sound engineering technique thus the sound was very raw. This is probably the reason why the other two user groups rated the affective scores so negatively. However, hearing impaired users rated it positively. It may lead to the wrong conclusion that hearing-impaired users with cochlear implants do not have an affective preference for sounds as long as they are heard. Such thought is misled because the ratings on the high-frequency beep sound were also low for hearing impaired users, thus they do have an affective preference though they may not be as sensitive as the other users. Moreover, some spinal cord impaired users stated that the affective attribute is not significant for the beeps since such alarms mostly indicate an emergent situation.

The affective ratings on melody were positive for both hearing impaired and spinal cord impaired users. However, visually impaired users showed neutral ratings. It is probably because they are more sensitive to auditory signals since they highly depend on auditory information.

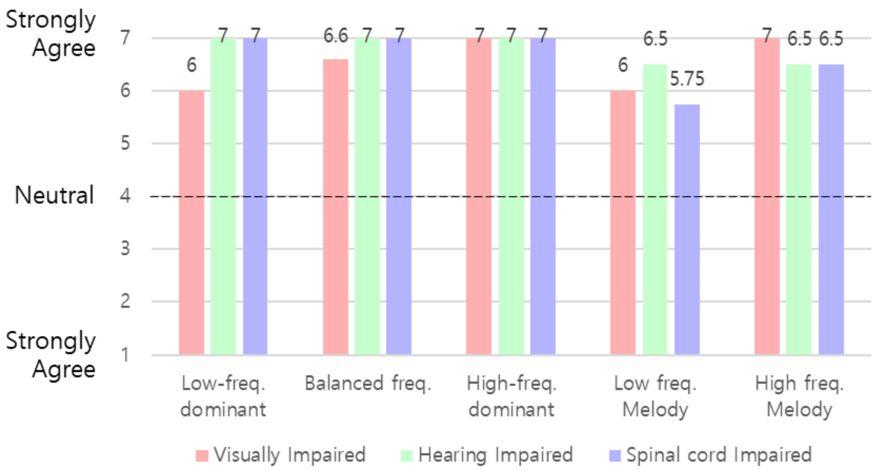


Figure 5.33. Evaluation result of perceivability on Prototype VI: Concordia

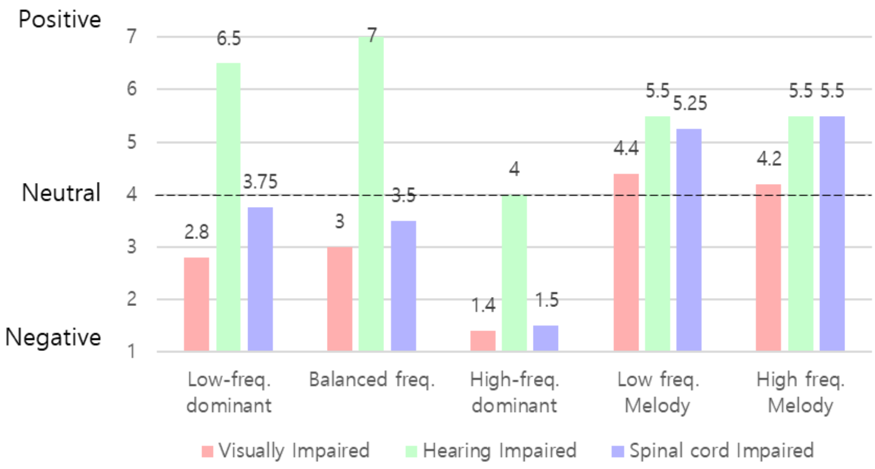


Figure 5.34. Evaluation result of affective rating on Prototype VI: Concordia

Prototype VII: Lucciola. This prototype was highly appreciated by the hearing impaired users since they highly depend on visual information. They rated the best they can for their perceivability, brightness, blinking rate, and helpfulness, as shown in Figure 5.35. However, they were disappointed that the blinking led was installed inside the refrigerator instead of the exterior.

Visually impaired users who are low-visioned rated Lucciola to be less perceivable and too bright. For low-visioned users, such a sudden change in illumination is too intensive. To resolve this, the blink can follow a gradual sinusoidal wave instead of the current on-and-off gaussian type.

Also, all user groups stated that the blinking LED is not easily perceivable when the door is almost shut because the light leaking through the gap is inadequate.

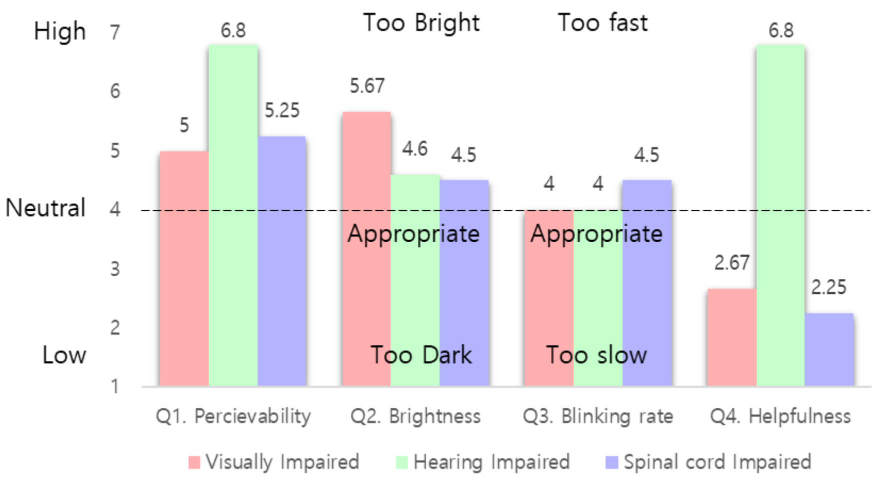


Figure 5.35. Evaluation result on Prototype VII: Lucciola

5.5 Discussion

In this study, the chosen ideas for prototypes were toward faster implementation and easy manufacturing, sacrificing the build quality and high technologies with higher potential to solve deeper accessibility problems. Nevertheless, most of the prototypes delivered enhanced accessibility to many users without leaving out a certain user group and approved the validity of design guidelines. However, there need many improvements by prototypes.

First, Intaglio could not guarantee the accessible use for visually impaired users because there were too many controls to interact with, and it cannot be solved by tactile solution only – it requires the involvement of a voice assistant. Secondly, the third prototype, Dondolo, needs to remove the protruding letters "PUSH" and have it written on a flat surface instead so that the blind users won't be confused and the low-visioned user and hearing impaired users can see it better.

Arrivo itself does not require many changes, however, there need big changes in the structure of the washing machine to compensate for the raised height by lowering the control panel and detergent drawers. Some of the ideas screened suggested touch controls on the surface of the door. Such design can allow a designer to lower the upper part of washing machines. The detergent drawer may be left unused if the washing machine is compatible with a detergent pod, which a user can simply throw into a tub along with their laundry. Moreover, the values of lower openings and tub bottom heights comply with the ADA standard, however, as mentioned earlier, there can be a stricter side reach range calculated from Korean anthropometric data (515.5 mm to 996 mm). With this stricter range of side reach, the bottom of the washer needs to be raised higher.

The result also indicates that the design guideline needs to add the following statement, "the height of a compartment, where a user keeps monitoring a level of some object or material, should be below user's eye height (942.5mm; eye height of 5th percentile female user in a wheelchair)" in the principle I-A. the location of visual information

Concordia, the beeps and melodies, require more refined processing in terms of sound engineering to be implemented in a real product. The last prototype – Lucciola – is implemented in a refrigerator, not the target appliances. Therefore, the direct application may not be appropriate, however, important principles, that can be applied in any appliances, were discovered from this evaluation. The blinking shall follow a sinusoidal curve rather than gaussian to prevent excessive stimulation for low-visioned users, and the blinking lights should be implemented on the outer surface where a user can see from a distance.

As a limitation of this study, there were no elderly users re-recruited for the evaluation for prototype validation. It could have been worthy to receive valuable opinions from the elderly user groups, however, the previous studies indicated that they share common issues with the other three disabled user groups. Therefore, this chapter assumed that the prototype targeting the other three user groups can also resolve the accessibility issues that elderly users possess. Moreover, the prototype was developed under the Universal Design perspective, which aims to accommodate as many users as possible, thus it is possible to assume that the problems of the elderly users are well covered by targeting the other three user groups with disabilities.

Moreover, this validation evaluation did not accompany any statistical analysis due to a low number of participants, however, it has drawn adequate enhancement of targeted accessibility and possible improvements by prototypes. It could have been more evident if there were original products and newly improved products with prototypes next to each other for the participants to evaluate. However, there were too many appliances already. The lack of budget, space, time and the recruitable number of disabled users led to a simpler experiment. However, as mentioned earlier, all the participants in this validation evaluation have experience of trying the original appliances because they participated in the interview and observation sessions conducted in Chapters 3 and 4. Therefore the participants were appropriate subjects to evaluate whether the accessibility of each target appliance has improved or not.

The prototypes used in this study advocate largely two approaches: 1) direct access, and 2) assistive access. Prototypes such as Arrivo, Libero, Concordia, and Lucciola are the example of direct access. Prototypes like Intaglio, Cameo, and Dondolo shall be categorized as assistive access. Intaglio and Cameo can be categorized as direct access if a manufacturer merges the clear panels and their product in one.

5.6 Conclusion

In this study, the ideas to improve accessibility was collected and screened, selected base idea, developed design guidelines, built prototypes, and evaluated the prototypes. A total of 7 prototypes were developed and participants with visual impairment, hearing impairment, and spinal cord impairment evaluated whether the prototypes built based on the design guideline validly enhanced the accessibility or not. Most prototypes approved the validity of the design guideline that a product designed based on this guidance can assure a certain level of accessibility enhancements. However, in case of little to no improvement found, the possible improvement on prototype design and design principles were appended.

The development of design guidelines is critical when developing an accessible product, however, there is a lack of adequate design guidelines to follow for physical products (Law et al., 2007). WAI guideline (World Wide Web Consortium, 2008) is a great example of a successful design guideline. The web page is controlled by keyboard and mouse – a fairly simple and universally definite source of control, whereas the control types vary very much among home appliances. Not only the controls, but designers have also unleashed various ideas and implemented them to the other components like moveables and separables with numerous form factors. The user behaviors and input method can be much more complex, meaning the establishment of the design guideline may be harder. Nevertheless, such statements do not imply that the progress in technology must stop and remain less complex and analogous. Instead, they promote inclusive progress rather than exclusive one with appropriate ergonomic principles to grant better interaction.

Unlike the standards which are permanent, it is possible to update the guidelines and enhance them based on the newly discovered knowledge or barriers;

this is the dynamics of guidelines (Abascal & Nicolle, 2005). Accordingly, the design guidelines made in this study can also be updated and applied for other types of home appliances and newly updated appliances of the same product groups.

For future studies and prototype development, where higher automation and design application levels are available, one may take design improvement criteria as follows. First, most of the studies for accessibility focuses on overcoming the disabled or impaired capabilities of the users. However, it is easier to enhance what the user can do well, than to promoting a user to overcome challenges. For example, instead of creating a door that has an easy-unlock button with less strength required to open, a spinal cord impaired user should simply tell the appliance, “Open the door” via voice interaction because they have no problem talking already. Besides, the door does not have to be fully automated, it just needs to unlock the hinge with just enough clearance for the spinal cord impaired user to “hook” into the gap.

Moreover, unlike a smartphone or any other smart device, most home appliances are not equipped with accessibility features. Even if they are, such accessibility supports may be limited to its software domain of interaction. Of course, it is possible to implement such features in the household product like a refrigerator. Besides, many manufacturers, nowadays, feature some of the accessibility functions into their products as their products become smart products. However, one must recognize that there is a financial accessibility issue as well when developing an accessible product; such products may not be affordable for most of the target users. Therefore, it is essential to investigate the accessible needs and frustration of disabled users so that the designers and manufacturers can produce corresponding products, which are accessible without additional or unnecessary features.

Chapter 6

Conclusion

Recently, researches on user experience have been actively conducted on various products, nevertheless, the disabled and elderly users encounter discrimination because most researches focused solely on non-disabled users. The development of new products and advances in technologies has not influenced or stimulated the studies on accessible products yet. Therefore, this study aimed to provide a method to breakthrough accessibility barriers within home appliances in a holistic manner, for visually impaired, hearing impaired, spinal cord impaired, and elderly users.

Disabled users and elderly users are comparably difficult to recruit when concerning the need for research on them. However, this study overcame such issues through new approaches like persona creation and therblig-based task analysis, which can be done with a fairly smaller number of recruited target users. It is important to note that efforts on user recruitment and investigation can be reduced and further activate more researches on the vulnerable user population.

Chapter 2 clarified the definition of accessibility as the threshold that a user must overcome in order to accurately and completely achieve the desired goal. In Chapter 3, the target users were classified into a total of 8 personas: blind, low-visioned, deaf, cochlear implemented, opened palm, closed fist, grandma, and grandpa personas. Given the persona cards with scenario-like explanations, one can better empathize with the users instead of cold-written principles found in standards and books.

In Chapter 4, task analysis was conducted based on re-defined therbligs, and a general task structure was established. A researcher can refer to the general task structure and relevant product compartment to create a new task structure of future evaluation target at ease. Besides, there were two new therbligs created to better evaluate the behaviors and barriers of the target users based on the principle of motion economy. The application of motion economy principles can highly reduce the burden of analysis to convert a task-oriented problem into a design-oriented solution.

Chapter 5 conducted an ideation workshop with ergonomic majors for accessible solutions and developed prototypes based on a design guideline built together. The prototypes showed accessibility enhancement and approved the validity of the design guideline. Significantly, the designer can understand and directly implement how to utilize the principles found in existing standards and guidelines when developing their product designs.

Overall, even in the early 20 century, Gilbreth and Gilbreth (1920) stated that disabled people have become a different sort of member of the society, to be shielded and pitied perhaps, but scarcely to be welcomed into the society. This shameful neglect of society did not seem to change much. Gilbreth also pointed out that these emotional attitudes of mind toward the disabled must be changed. There has been an emotional approach to the disabled user groups, however, it requires a scientific approach to their behaviors and emotions to truly welcome them into our lives. Simply, it requires a scientific approach such as motion study and prototyping to define the problems and resolve them as the process is combined with empathy, not sympathy. This whole procedure from user empathy, problem definition, ideate, prototyping, and evaluation is a full-product development cycle shall be called accessibility-breakthrough, a dedicated holistic approach to resolve accessibility issues.

Furthermore, existing studies confirmed that there is a large population to interest investment from stakeholders. The lack of accessible products for disabled users provides an opportunity for stakeholders like manufacturers and designers to seize a large number of customers whom their competitors missed out, leading to profitable ventures. The disabled population will be loyal to products of which design considers their needs and frustration, especially when they can reclaim and appreciate the benefits they have been missing. Hence, it will be a blue ocean for stakeholders to expand their market shares (Kleinke, 2013). Stakeholders can benefit from studying disabled users to obtain latent user needs and product innovation when they consider the disabled users as lead users (Conradie et al., 2014; Hannukainen, 2005; Hannukainen & Ho¨ ltta¨-Otto, 2006). Overall, there are adequate reasons for stakeholders to study disabled users.

Finally, accessible design, universal design, and barrier-free designs have been recognized as “considerate designs.” It delivers a nuance as if the company or designers is giving benevolence to the disabled and elderly users, although it has actually been the opposite. The disabled and elderly users have sacrificed their easy use of products, services, and environments by considering that their non-disabled, young family and friends would face any inconvenience. Therefore, one must realize that developing an accessible product does not demonstrate the consideration of non-disabled designers and stakeholders, but rather is the right design to restore the natural rights of the disabled and elderly users.

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국문 초록

가전제품을 포함한 현대 기술은 사용자의 삶에 혜택을 제공하지만 제조업체와 설계자의 접근성 지원 부족으로 인해 장애인 및 고령 사용자는 그 혜택으로부터 소외되었다. 여러 신 기능의 개발 및 발전은 비장애인 사용자의 삶의 질을 풍요롭게 한 것과는 반대로 이러한 기능들은 복잡도가 상향되어 장애인 및 고령 사용자의 접근성과 독립적 사용을 저해하고 이내 사용자 경험을 저하시켰을 뿐이다.

이와 같이 접근성 지원이 필요한 상용자의 사용자 경험을 수집하는 것은 생각보다 번거로운 일이다. 대상 사용자들은 민감한 개인정보상의 이유로 사용자 경험 제공을 꺼릴 수도 있고, 인터뷰나 설문조사를 수행하기에 적합한 조건이 아닐 수도 있으며, 더 나아가 소통에 어려움이 있을 수도 있다. 이와 같은 문제는 제조업체나 설계자와 같은 이해당사자와 대상 사용자 간에 장벽을 만들고, 이러한 장벽은 사용자들이 일상 제품을 사용하며 겪게 되는 문제를 온전히 이해하고 정의하는 것을 어렵게 만들어 공감의 형성이 불가능해진다.

이해당사자들은 장애가 있다는 것, 고령이 된다는 것을 경험해 보지 못 했기 때문에 그들의 사용자 경험을 잘못 해석할 수 있고, 이러한 공감의 부족은 장애인 및 고령 사용자에 대한 편견과 오해로 이어진다. 결국, 접근 가능한 제품 개발을 목표로 하는 제조사나 설계자가 이들의 불편사항 및 요구를 인지한다 해도 대상 사용자의 이러한 문제를 해결하기는 어렵거나 심지어 불가능하기도 하다.

이러한 문제로, 본 연구의 3장에서는 인터뷰와 관찰 데이터를 기반으로 가전제품 사용 맥락에 따른 네 가지 사용자 유형에 대한 여덟 종류의 퍼소나를 개발하였다. 시각장애(전맹, 저시력), 청각장애(농아, 인공

와우), 척수장애(주먹 쥔 손, 펴진 손), 고령자(할머니, 할아버지) 퍼소나는 각각 퍼소나 카드의 시나리오와 같은 형식으로 접근성 이슈를 제공하여 실 사용자와 면대면으로 만나기 어려운 이해당사자로 하여금 대상 사용자의 접근성 이슈를 파악하고 공감할 수 있도록 하는 것을 목표로 한다.

또한, 이해당사자들은 사용자 인터랙션 관점에서 장애인 및 고령 사용자의 다른 행태를 파악하고 이해할 도구가 필요하다. 본 연구의 4장에서는 위계적 작업분석(Hierarchical Task Analysis; HTA)을 수행하여 가전제품 사용 시 시간 순서에 따른 일반적 작업 구조를 제시하여 사용자의 작업 행태를 시각화 하였다. 이 구조와 함께 서블릭(Therblig)을 통해 사용자의 작업을 미시적으로 표현하였다. 서블릭은 가전제품 맥락에 맞도록 재정의하고 사용자군 별로 문제가 있는 서블릭이 파악된 경우 동작경제 원칙에 의한 설계 가이드에 따라 개선안을 제시하도록 하였다. 동작경제원칙은 사용자의 작업측면에서의 문제점과 설계측면에서의 해결안을 연관 지어 해석하는 짐을 덜어주는 역할을 해, 제안하는 접근성 도구는 접근성 평가 도구로서 큰 가치를 가진다.

마지막으로 본 연구의 5장에서는 기존 표준과 가이드라인을 수집해 설계 가이드라인을 개발하였다. 기존 표준 및 가이드라인은 여러 수치를 제공하고는 있지만 장애인 및 고령 사용자의 사용 맥락을 충분히 반영하지 못하고 사용자의 신체 능력, 환경, 제품의 형태에 따라 적용이 어려워 실제적 활용도가 낮은 문제가 있다. 또한 접근성과 인간공학적 전문성이 부족할수록 실 적용이 어려워져 이러한 문서의 가치는 더욱 낮아질 수밖에 없다. 이에 장애인과 고령자의 사용 맥락을 반영해 가이드라인을 재정립하고 이를 기반으로 총 일곱가지의 프로토타입을 개발하였다. 총 14명의 참가자가 프로토타입을 평가하여 대상 가전제품의 접근성 향상 여부를 평가하였다. 대부분의 프로토타입은 성공적으로 접근성에 향상을 보여 설계 가이드라인의 유효성 또한 반증하였다. 또한, 본 논문에서 사용된 절차를 따라 접근성 보장

제품 설계 시 각 가이드라인의 수치를 어떤 식으로 설계에 적용하는지를 참고할 수도 있다.

본 논문의 의의는 다음과 같다. 첫 째, 본 논문은 시각장애, 청각장애, 척수장애인을 대상으로 사용자 조사를 진행하고 이를 기반으로 사용자들의 접근성 이슈를 퍼소나 형식으로 구체화하여 이해당사자가 대상 사용자와 보다 쉽게 공감할 수 있도록 하였다. 둘째, 본 논문은 접근성 연구분야에서 부족한 접근성 평가 도구를 제안하여 접근성 연구의 연구장벽을 낮추는데 기여하였다. 마지막으로 실제 접근성 향상 제품을 개발을 위한 가이드라인과 이를 기반으로 제작된 프로토타입을 실제 사용자들이 평가하도록 해 가이드라인의 실효성을 검증하였다.

전반적으로, 본 연구는 접근성 문제의 장벽을 돌파하기 위해 전반적인 제품 개발 프로세스를 적용하였으며 유니버설 디자인 관점에서 접근성 문제 해결을 위한 일련의 새로운 접근 방식으로 제안하여 사용자가 본인의 장애나 연령과 상관없이 제품 - 특히 가전제품 - 을 자유롭고 안전하게 사용하도록 하였다.

주요어: 접근성, 유니버설디자인, 가전제품, 페르소나, 작업분석, 서블릭
학번: 2014-22647

감사의 글

어느덧 7년이라는 시간이 지나 박사 학위 논문을 제출하게 되었습니다. 인간공학이라는 분야에 대한 관심과 꿈이 헛되이 사라지지 않도록 기회를 주신 윤명환 교수님께 항상 감사드리며, 끝없이 믿고 지원해주신 부모님과 누나, 할아버지, 할머니를 포함한 가족들 모두에게 감사의 마음을 전합니다.

길었던 연구실 생활에 힘이 되어준 동기인 지원 누나, 동건 형, 용민이와 우리 휴먼 인터페이스 시스템 연구실의 선·후배님들에게 즐겁고 행복한, 잊을 수 없는 연구실 생활을 만들어주어 고맙다는 말을 전합니다. 연구실 일이 바쁘다는 핑계로 소홀히 했던 친구관계에도 기다려준 친구들에게도 고마움을 표합니다. 본 논문 작성 시 바쁜 와중에도 내용 교정을 위해 확인해 준 친구 Vishwaman Raj에게 특별한 감사를 보냅니다.

본 연구의 시작에 있어 본인들의 사용자 경험을 흔쾌히 공유해 주신 시각장애인 협회, 청각장애인 협회, 척수장애인 협회 분들과 관악구의 할아버지 할머님들 한 분 한 분께 모두 감사드리고, 필요한 접근성 연구에 관심을 갖고 지원 해준 삼성전자에도 감사의 마음을 표합니다.

마지막으로, 항상 많은 도움을 준 같은 인간공학 연구실인 삶 향상 기술 연구실의 박우진 교수님과 학생들, 그리고 산업공학과 모든 식구들에게 감사드립니다.

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APPENDICES

Appendix 1a. Accessibility Evaluation on Washer Dryer and Cooktop

Products			Washer & Dryer				Cooktop			
User Groups			*VI*	*HI*	*SpcI*	*Eld*	*VI*	*HI*	*SpcI*	*Eld*
pre-Usage	Approach	M			AP				AP	
	Opening moveable	Sh	UP	UP	UP	UP				
		F	AP	UP		UP				
		Rh			UP					
		G			AP					
		M			UP	UP				
		PP								
		RL								
	Loading	Sh					AP			
		F					AP			
		Rh								
		G								
		M							AP	UP
		P					AP		AP	
		RL								
	Closing moveable	Sh	UP		UP					
		F	AP							
		Rh			UP	UP				
		G								
		M			UP					
		U								
		I	AP	AP	UP					
		RL								
Usa	Approach	Rh			AP				AP	

	Navigate	Sh	AP			AP	AP		UP	AP
		F	AP	AP		UP	AP	AP		
		SL	AP	AP			AP	AP		
		Rh			AP				AP	
		P	AP	AP	AP			AP	AP	
		G			AP				AP	
	Perform	U			AP				AP	
		SL	AP	AP		AP		AP	AP	
		I	AP	AP		AP	AP	AP		
		RL								
Mid-Usage	Approach	I	UP	AP		AP	UP	AP		AP
		Rh								
	Status/Error check	Sh	AP	AP	UP		AP	AP	UP	UP
		F	AP	AP			AP	AP	UP	UP
		I	AP	AP		UP	AP	AP		AP
		Pn								
		U		AP	AP	UP		AP	AP	UP
		I	AP	AP			AP	AP		
	Reloading/ Relocation	Sh	AP				AP			
		F					AP			
		Rh			AP				AP	
		G			AP				AP	
		H					UP		AP	
		I					AP			
		U								
		M			AP		UP		AP	UP
		P					AP	AP	AP	
		RL								
Post-Usag	Approach	Rh								
		Sh	UP	UP	UP	UP				

	Opening moveable	F	AP	UP		UP				
		Rh			AP					
		G			AP					
		M			UP	UP				
		PP								
		RL(H)								
	Unloading	Sh	AP			AP	AP			
		F					AP			
		Rh			AP	AP			AP	UP
		G			AP				AP	
		M							AP	UP
		I	AP		AP		AP		AP	
		RL	AP		AP		AP			
	Closing moveable	Sh								
		F	UP	UP	UP	UP				
		Rh		UP		UP				
		G			AP					
		M			AP					
		H			UP					
		U								
		I	AP	AP						
		RL								
Maintenance	Approach	Rh	UP	UP	AP				AP	
		I	AP	AP			AP	AP		UP
		Pn								
	Disassemble	Sh	AP	UP	AP	UP				
		F	AP			UP				
		Rh			AP				AP	UP
		G			AP				AP	
		DA	UP		AP	UP	AP		AP	UP

		M	UP				UP		AP	UP
	Replace /Clean	H	UP		AP		UP		AP	
		U			AP				AP	
		I	AP				AP			
	Assemble	Sh								
		F								
		M			AP				AP	UP
		P	AP	AP	AP	UP	AP	AP	AP	UP
		A			AP	UP			AP	UP
		I	AP	AP		UP	AP	AP		UP
		RL								

Appendix 2b. Accessibility Evaluation on Microwave and Oven

Products			Microwave				Oven			
User Groups			*VI*	*HI*	*SpcI*	*Eld*	*VI*	*HI*	*SpcI*	*Eld*
pre-Usage	Approach	Move			AP				AP	
	Opening moveable	Sh	UP							
		F	AP							
		Rh			AP					
		G			AP				AP	
		M	UP		AP	UP			AP	UP
		PP					UP		AP	
		RL			AP				AP	
	Loading	Sh								
		F								
		Rh								
		G								
		M			AP				AP	
		P	AP		AP		AP		AP	
		RL								
	Closing moveable	Sh	AP				UP			
		F	AP							
		Rh			AP				UP	UP
		G			AP				AP	
		M			AP				AP	UP
		U								
		I	AP				AP	AP		
		RL								
Usage	Approach	Rh								
	Navigate	Sh	AP			AP	AP			
		F	AP	AP		UP	AP	AP		UP
		SL	AP	AP			AP	AP	AP	UP

		Rh			AP				AP	
		P	AP		AP				AP	
		G			AP				AP	
	Perform	U			AP				AP	UP
		SL	AP	AP	AP	UP	AP	AP		UP
		I	AP	AP		AP	AP	AP		AP
		RL								
Mid-Usage	Approach	I	UP	AP		AP	UP	AP		AP
		Rh								
	Status/Error check	Sh	AP	AP			AP	AP	UP	UP
		F	AP	AP			AP	AP		
		I	AP	AP		UP	AP	AP	UP	UP
		Pn								
		U		AP	AP	UP		AP	AP	UP
		I	AP	AP			AP	AP		
	Reloading/ Relocation	Sh	AP				AP			
		F					AP			
		Rh			AP				AP	UP
		G			AP				AP	
		H	UP		AP		UP		AP	
		I	AP				AP			
		U								
		M			AP				AP	UP
		P	AP		AP		AP		AP	
		RL								
Post-Usage	Approach	Rh								
	Opening moveable	Sh	AP				AP			
		F	AP							
		Rh			AP					
		G			AP				AP	

		M	UP		AP	UP			AP	UP
		PP					AP		AP	
		RL(H)							AP	
	Unloading	Sh					AP			
		F					AP			
		Rh			AP				AP	UP
		G			AP				AP	
		M			AP				AP	
		I	AP		AP		AP		AP	
		RL	AP				AP			
	Closing moveable	Sh								
		F					AP			
		Rh								
		G			AP				AP	UP
		M			AP				AP	
		H			AP	UP			AP	UP
		U								
		I	AP	AP			AP	AP		
		RL							AP	
Maintenance	Approach	Rh					UP	UP	AP	UP
		I	AP				AP		UP	UP
		Pn								
	Disassemble	Sh			UP		AP			
		F	AP				AP			
		Rh						UP	AP	UP
		G			AP				AP	
		DA	AP		AP		UP		AP	UP
		M							AP	UP
	Replace /Clean	H	UP		AP		UP		AP	
		U			AP				UP	UP

		I	AP				AP			
	Assemble	Sh								
		F								
		M							AP	UP
		P	AP		AP	UP	AP	AP	AP	UP
		A	UP		AP				AP	UP
		I	AP	AP	UP	UP	AP	AP	UP	UP
		RL								