ソフトコンピューティング手法を利用した言語障害者のためのインクルーシブデザインに関する研究

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概要

本研究は、共生社会を実現するために、ソフトコンピューティング手法を活用して、言語障害者のソーシャルインクルージョン（社会的包摂）を達成することを目的とする。失語症のような言語障害者が抱える問題として、障害のために社会への積極的な参加から除外されるソーシャルエクスクルージョン（社会的排除）がある。失語症者はコミュニケーションの障壁のため自宅で家族と過ごす時間が多く、これまでの研究では言語訓練などのリハビリテーションによる臨床的な治療と機能回復に焦点が当てられていた。また失語症者のリハビリテーションを担当する言語療法士も、失語症者の言語能力の回復を支援しているが、共生社会の実現までに解決すべき課題が多い。失語症者のソーシャルインクルージョンを達成するには、繊細な気持ちや感情を他者へ伝えられるよう自身のニーズや要望を適切に表現する必要がある。また他者の気持ちや感情を理解して、コミュニケーションの詳細な内容を把握する必要がある。失語症は他者の話す内容を理解すること、および自身の考えたことを言葉として表現することの障害であるため、繊細な気持ちや感情を他者へ正確に伝えることが困難である。この障害を取り除き、失語症者のソーシャルインクルージョンを目指して、ヒューマンファクタとソフトコンピューティングを活用したインクルーシブデザイン手法を提案した。このデザイン手法は、失語症者一人ひとりが社会に参加するときに対面する困難に基づいて、繊細な感情や感情を伝えて他者とコミュニケーションを取れるようになる手段を提供することに特色がある。インクルーシブデザインの各ステージ「相互作用の問題特定」「再デザイン」「拡張」を、ヒューマンファクタとソフトコンピューティングでサポートする方法を提案した。はじめに、失語症者個人とのアンケートを用いた対面調査により、ソーシャルインクルージョンのための相互作用の問題を特定した。次に、相互作用の問題を特定した失語症者の困難に基づいて、デザインソリューションを再デザインした。失語症者が言葉で表現することが難しい繊細な気持ちや感情をファジィ集合論により定量化した。失語症者へのアンケート調査に基づいて、少し良いなどの繊細な気持ちや感情をファジィメンバーシップ関数で同定した。再デザインしたデザインソリューションにおいて気持ちや感情をスケールとして表現し、そこで失語症者が指定した位置に基づいて、繊細な気持ちや感情、またはその候補を複数表示した。その候補が失語症者の気持ちや感情を適切に表現できていない場合は、ファジィメンバーシップ関数の位

置を制御することで、適切な気持ちや感情を表現する機能を実現した。最後に、ファジィ階層分析法（Fuzzy-AHP）と失語症者による投票を利用して、失語症者個人から他の言語障害者へデザインソリューションを拡張した。失語症の症状や社会的状況は多様であるため、適切なソーシャルインクルージョンを実現するため、言語投票により多数の失語症者の意見を取り込む方法を提案した。また、失語症者のリハビリテーションを担当する言語聴覚士が持つ知識を、ファジィ集合論と階層分析法（AHP）を組み合わせたファジィ階層分析法（Fuzzy-AHP）で定量化した。ファジィ集合論は言語のあいまいさに対処して、階層分析法（AHP）はデザインソリューションに対する機能の重要性を定量化している。多数の失語症者による投票が Fuzzy-AHP に統合され、言語聴覚士の知識だけでなく、失語症者の意見も考慮されるインクルーシブデザインの拡張手法を提案した。言語聴覚士の知識を取り込む Fuzzy-AHP と多数の失語症者の意見を反映する投票の組み合わせの利点は、デザインソリューションを使用するユーザの意見が、その機能の重要性に直接反映されることである。さらに、本研究で提案するデザイン手法の実践として、2 つの事例研究を実施した。はじめの事例研究では、失語症者個人の相互作用の問題を特定し、その失語症者の微妙な気持ちや感情をファジィ集合論で表現できるアプリケーションを再デザインした。再デザイン前後のスマートフォンアプリケーションを利用した実験により、対象となる失語症者個人の社会参加を30%向上できるとの評価が得られた。その向上には、失語症者の繊細な気持ちや感情を、ファジィ集合論により適切に他者へ伝えるデザインが貢献していた。次の事例研究では、Fuzzy-AHP と投票を統合したデザイン拡張手法の有効性を、失語症者 49 人の投票により検証した。提案したデザイン拡張手法による機能の重要性を既存手法による重要性と比較することにより、投票手法の影響について考察した。Fuzzy-AHP と投票を統合したデザイン手法の結果により、失語症を含む言語障害者のユーザの困難を解決するために、絵カードや会話ノートを使用するときに音声をゆっくり再生するなど、どの機能が言語障害者にとって重要であるかが示されており、より多くの障害者の社会参加に必要な要件を明らかにしている。

Soft Computing Methods to Support Inclusive Design for Speech-Language Impaired Individuals

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Abstract

The purpose of this study is to include speech-language impaired individuals like aphasia individuals in society using soft computing methods in inclusive design. They are often excluded from society because they cannot convey their needs or wants exactly with the delicate feelings or emotions to others and they cannot understand the detailed contents of communication from others. Therefore, social inclusion is realized by conveying delicate feelings or emotions based on their difficulties using human factors and soft computing methods. The theoretical contribution of this study is a hybrid method namely, fuzzy analytic hierarchy process (Fuzzy-AHP) with voting during the expansion of Inclusive Design. A linguistic voting was integrated into Fuzzy-AHP to consider not only the speech-language therapist's evaluations, but also the disabled individuals' opinions on the social inclusion attributes. Moreover, the aphasia individuals' insights were included in triangular fuzzy membership functions through a survey questionnaire during the redesign of Inclusive Design. After the redesign, the delicate feelings or emotions were expressed as a scale and candidate(s) of them were shown based on their specified position. If the candidate(s) cannot properly convey their delicate feelings or emotions, then the corresponding function can be realized by controlling the position of the fuzzy membership function. The practical contributions of this study were two case studies in the design of communication support applications for aphasia individuals. The first case study was conducted to include an aphasia individual in society who identified the interaction problems and gave insights for the redesign. Experimental result shows that the social participation of the aphasia individual could be improved by 30% after the redesign. The second case study was conducted to demonstrate the effectiveness of the hybrid method. In this case study, 49 individuals with aphasia participated in the voting process. The results of hybrid method show which functions are important to solve the difficulties of speech impaired users including aphasia, and clarify the necessary requirements for social participation of more disabled people.

Keywords: Human factors, Social inclusion, Inclusive design, User expectation, User opinions, Soft computing Methods

Doctoral Dissertation

Soft Computing Methods to Support Inclusive Design for Speech-Language Impaired Individuals

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Table of Contents

List of Tables

List of Figures

1 Introduction

There are many people living in our society with speech-language impairment. Aphasia also affects the speech-language of individuals. According to the 2009 survey, about 500,000 individuals in Japan have aphasia with some level of speech-language disability [1]. Recently, about 200,000 individuals in the United States and 250,000 individuals in the United Kingdom live with aphasia [2]. People with aphasia cannot communicate properly with others in society. Their poor participation in society gradually decreased their relationship with others. They lose their job, and their contact with other people are decreased. Thus, they are gradually disconnected from society due to their communication difficulties. However, they want to include themselves in society with their limited capabilities. In this connection,they can be included in society by conveying their wants or needs in detail with their feelings or emotions to others, and by understanding the detailed contents of communications from other people. This study presents a new method for including speech-language impaired individuals in society. Social inclusion is realized by introducing a new concept using human factor knowledge and soft computing methods to convey delicate feelings or emotions based on the difficulties of speech-language impaired individuals.

The theoretical contribution of this study is the development of a hybrid method namely, fuzzy analytic hierarchy process (Fuzzy-AHP) with voting during the expansion of Inclusive Design. A linguistic voting technique was integrated into Fuzzy-AHP to consider not only the speech-language therapist evaluations, but also the disabled individuals' opinions on the requirements. Moreover, this is the first study to include the insights of aphasia individuals in triangular fuzzy membership functions during the redesign of Inclusive Design.

The practical contributions of this study are two case studies in the design of communication support applications for aphasia individuals. The first case study was conducted to include the aphasia individual in society who identified the interaction problems for social inclusion and gave insights for the redesign. The second case study was conducted to demonstrate the effectiveness of the proposed hybrid method. In this case study, 49 individuals with aphasia participated in the voting process. This is the first study to analyze the opinion data of such a large number of individuals with aphasia in the design of communication support application to include more people in society.

The Inclusive Design is selected to include speech-language impaired individuals for some reasons. Speech-language impaired person can include his/her insights through Inclusive Design. The inclusion of his/her insights is important because it finds different ways to include impaired person in society. Since speech-language impaired persons face communication difficulties, Inclusive Design needs support of soft computing methods to include their insights for social inclusion. Furthermore, soft computing methods also assist Inclusive Design to include more people based on their difficulties. In this study, Inclusive Design is applied to the social inclusion of aphasia individuals, and find different ways to include more aphasia individuals as well as other people in society through the incorporation of human factors and soft computing methods.

In this chapter, the possible causes and diverse symptoms of aphasia are mentioned first. Then, how communication difficulties affect the social inclusion of aphasia individuals are explored. Next, the contexts of communication for social inclusion of aphasia individuals are presented. After presenting contexts of communication, the inefficiencies of existing design approaches for social inclusion of speech-language impaired individuals are discussed. Then, the issues of interaction problems, redesign and expansion process of Inclusive Design to include aphasia individuals in society are described. Finally, this study addressed how the Inclusive Design include aphasia individuals in society.

1.1 Background

This section presents the background about aphasia individuals as speech-language impaired individuals, key concepts of Inclusive Design to include aphasia individuals in society and the research direction of this study.

1.1.1 Speech-language Impairments as Aphasia

Aphasia is a speech and language impairment, caused by acquired brain damage [3]. A stroke is the most common cause of aphasia, but other types of acquired brain injuries such as traumatic brain injuries, brain tumors and anoxia can also cause aphasia. The incidence of aphasia after stroke is about 20% to 38% in the acute phase [4–6]. In addition, brain damage often causes hemiparesis, which is weakness or the inability to move on one side of the body. In this connection, right-sided hemiparesis involves injury to the left side of the brain, which controls language and speaking. The language organization of left hemisphere of the brain is shown in Figure 1.1. People who have this type of hemiparesis may also have problems with talking and/or understanding what people say.

Depending on the specific locations of brain damage, the severity and pattern of aphasic symptoms vary from person to person. Clinical researchers categorize patterns of aphasia individual's symptoms as either non-fluent aphasia (Broca's, Transcortical Motor, Global) or fluent aphasia (Wernicke, Transcortical Sensory, Conduction, Anomic) [7]. Figure 1.2 illustrates the specific aphasia condition that results from damage in certain areas of the brain. The categories of aphasia and their diverse symptoms are shown in Table 1.1. Particularly, Broca's and Wernicke are the most common types of aphasia in Japanese society. It is noted that most of the existing research focused on issues of treatment and functional recovery of aphasia individuals through clinical interventions to resolve the deficiency areas of the patient with aphasia [8]. However, this study mainly works on aphasia individuals after they leave the hospital.

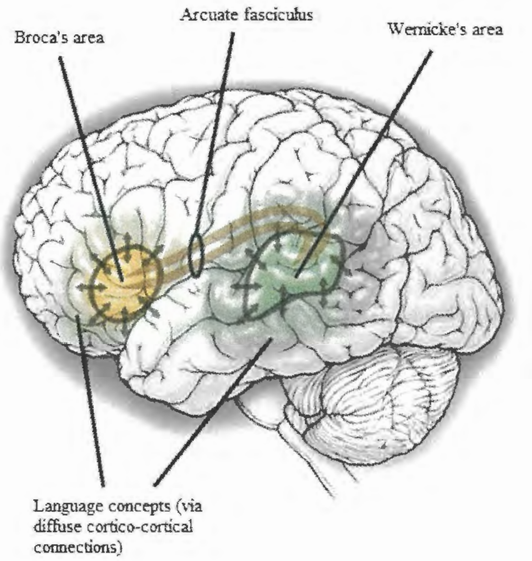


Figure 1.1: Specific aphasia conditions that result from brain damage [9]

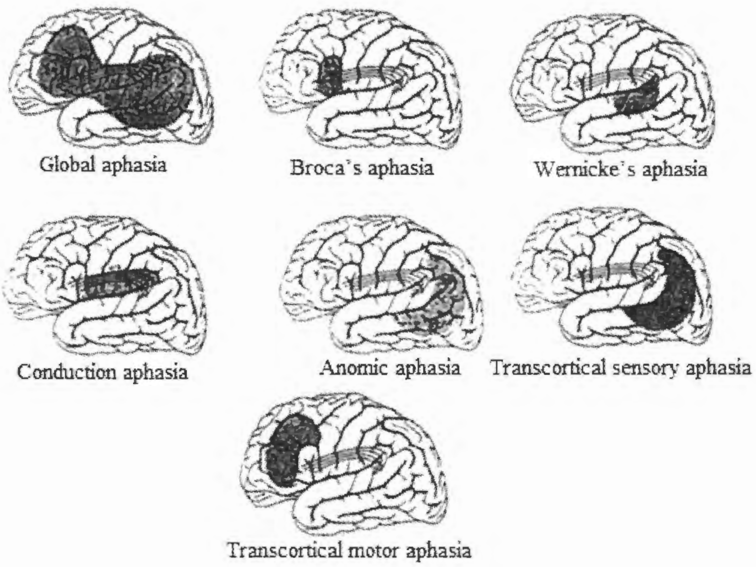


Figure 1.2: The language organizations of left hemisphere of the brain [10]

Table 1.1: Different types of aphasia and their symptoms

Category	Type	Symptoms
Non-fluent	Broca's aphasia	People with Broca's aphasia can say only a few words at a time. They cannot express themselves properly because they face the trouble to find the appropriate words they want to say. However, they can understand speech.
Non-fluent	Transcortical motor aphasia	People with this aphasia can understand language but cannot communicate fluently. They can use short phrases and frequently repeat phrases. Their response is also delayed.
Non-fluent	Global aphasia	The person with global aphasia has almost no communication abilities and faced major problems in comprehension. Global aphasia is likely to occur immediately after a stroke or brain injury, and then it moves into another type of aphasia as the health of their brain begins to improve.
Fluent	Wernicke's aphasia	People with Wernicke's aphasia cannot form coherent words. Thus, they say many meaningless words that sound like a sentence but do not make sense. They also have trouble with understanding language and repeating phrases.
Fluent	Transcortical sensory aphasia	Individuals with this aphasia have trouble comprehending language. Although they can communicate fluently, their speech is likely to lack meaning due to word errors and invented words.
Fluent	Conduction aphasia	They have trouble with inability to repeat words and finding words.
Fluent	Anomic aphasia	A person with anomic aphasia has trouble retrieving specific words, especially nouns and verbs. They will typically speak incomplete, grammatically correct sentences but they use vague words.

1.1.2 Exclusion of Aphasia Individuals from Society

Aphasia individuals cannot be included easily in society because they have problems with communication. Aphasia affects individuals' ability to speak, to understand speech, to read and to write. These language difficulties seriously hamper their daily communications [11]. It is noted that other disabilities caused by brain damage such as motor speech disorder (e.g., dysarthria, dysphonia, or apraxia of speech) affect intellectual capabilities but have no difficulty in finding the words they wish to say and report no difficulties with reading, writing, or auditory comprehension. On the other hand, aphasia individuals cannot communicate properly by their own words because their brain areas are restricted to process primarily speech and language, but their intelligence is intact. Thus, communication barriers often stigmatized disabled people and can further exacerbate the difficulties in quality of life (QOL) [3, 4]. Aphasia individuals face difficulties in communication even with their family members after they leave the hospital. Consequently, aphasia individuals live at home with their families. They are confronted with an enormous challenge to fulfill his or her roles, for example as a partner, parent, friend, or employer. Their contact is gradually withdrawn from society and their participation in society is reduced [12–14].

Aphasia individuals are excluded from society because of the poor social participation which leads them to social isolation and thus decreased QOL. As a result, aphasia individuals cannot live independently in society without the support of others [15–17]. In this connection, speech-language therapists (SLTs) support people with aphasia in recovery the speech-language ability to include them in society [18]. SLT supports aphasia individuals based on the diverse symptoms such as non-fluent, fluent, mild, moderate, severe, unable to read, unable to write or unable to understand. SLT supports them in various ways of communication such as memo writing, using picture boards, picture cards or gestures. These type of support of SLT through rehabilitation enhance a little social participation of aphasia individuals. Thus, aphasia individuals can be partially included in society to perform their daily activities and rebuild their relationships within society which can increase QOL. However, their communication capabilities for daily activities are not recovered easily only by rehabilitation with SLT once or twice a week. Although they improve gradually with the support of SLT, the recovery rate of communication difficulties depends on individuals. As a result, they cannot be included in society.

1.1.3 Factors to Include Diverse Aphasia Individuals in Society

Delicate feelings or emotions, and contexts of communication are considered as important factors to include diverse aphasia individuals in society. The aphasia persons who recover a certain level must be engaged in society for daily living regardless of their communication difficulties. They need to perform their daily activities in various places such as hospitals, restaurants, shopping centers, pharmacies or banks. The inclusion of aphasia individuals in society would increase their QOL. They are included in society when they can perform their activities without the support of others. However, after a certain level of recovery, a few aphasia individuals can participate in society or join their work, but their communication difficulties remain present. According to the recovery rate in the life-stage of aphasia individuals, their opinions become different. Thus, in addition to language recovery, their different opinions are important to meet their life-stage, environments of use, and daily needs of aphasia individuals. These factors are related to context of communication and vary from aphasic person to person. Furthermore, social inclusion of aphasia individuals will be successful when aphasia individuals can express their delicate feelings or emotions to convey their exact situation to others. As a result, interaction will be improved among aphasia individuals and other people in society.

1.1.4 Issues of Existing Communication Support Devices or Applications

A few digital communication support devices or applications are found for aphasia individuals, however they cannot be included in society using these existing applications. The reason is that these are designed by considering the common wants or needs of aphasia individuals. In addition, these applications were not matched to the difficulties of aphasia individuals. Mahmud et al. implemented an email tool for language impairments using user-centered design approach that did not focus on the difficulties of aphasia individuals [19]. Their tool was developed for sending email where other tasks cannot be performed. Thus, this tool is insufficient to support social inclusion of aphasia individuals. Allen et al. developed an application using Participatory Design approach to manage digital image to support face-to-face communication where a few disabled users were involved in only evaluation phase [20]. In the previous works, either SLT played the roles of the aphasic participant or the caregivers of aphasic participants provided feedback to the designers. In that case, the real voices of aphasia individuals are not included in design. As a result, the aphasia individuals need to compromise to use the application because application was not designed according to their difficulties. Therefore, the aphasia individuals cannot be included in society with the above-mentioned applications.

1.1.5 Issues of Existing Design Approaches

The existing design approaches are not enough to include aphasia individuals in society. The popular design approaches to design products or environments for disabled people are Barrier-free Design, Universal Design, Design for All or Inclusive Design. Barrier-free Design is specially introduced to remove architectural obstacles for disabled people [21–23]. On the other hand, Universal Design and Design for All are looking for a design solution that can support everyone including people with disabilities [24–27]. However, Universal Design is insufficient to cover everyone's needs. First, designers acquire needs of product or environment from different user groups including those with disabilities. Then designers identify common needs that can support all user groups. Designers think that design solutions are enough to fulfill these common needs. Finally, designers complete a design with these common needs. However, disabled users' needs are partially included in the common needs of Universal Design solutions. Nevertheless, these common needs are not sufficient to fulfill disabled users' needs. Thus, disabled users are excluded from design solutions. It is noted that these disabled users are extreme users because they represent the extreme end of the usability spectrum and are most affected by poor design solutions as shown in Figure 1.3. Extreme users may have exaggerated needs, thought or behavior compared to the typical users. In addition, extreme users can offer unique insights about the products and inspire a different way of thinking about current and future users. For this reason, Universal Design seems impractical and no longer effective for extreme users with common views of the design [28].

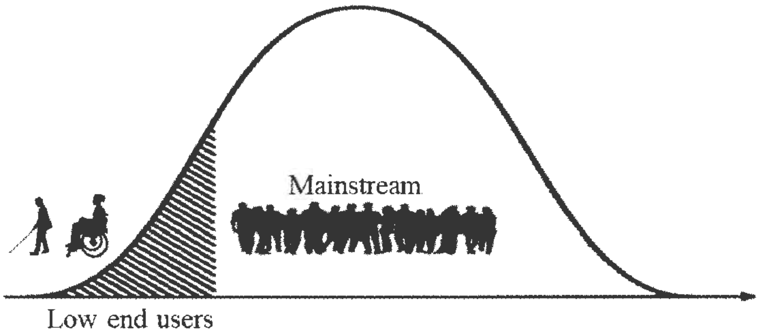


Figure 1.3: Usability spectrum of product or environments (adopted from [29])

In this study, the Inclusive Design approach is focused to ensure that extreme users (e.g. disabled people) are included in society like other healthy people. Inclusive Design is an approach of designing with extreme users to find different ways for the access of products and environments. Most importantly, Inclusive Design requires active participation of extreme users with a variety of viewpoints in the entire design process from beginning to end. Extreme users contribute to Inclusive Design in several ways. First, extreme users recognize interaction problems between their changed capabilities and the existing or expected design solution. Second, extreme users identify needs from their experience. Third, extreme users give insight into different ways of participation through redesign to access the products or environments. Then, extreme users discover a new design solution through expansion process so that many other people can access the products or environments. Regarding this, OXO good grip utensils can be illustrated as an example of an Inclusive Design product [30]. Here, extreme users (arthritis users) face interaction problems with existing kitchen utensils (e.g. potato peeler). Extreme users cannot peel potatoes because they cannot grip the peeler handle for three interaction problems. First, the swollen thumb of the arthritis user is hurt by sharp edges of the handle. Second, finger heads of arthritis users slip on metal handles. Third, finger heads of arthritis users release the narrow handle. Finally, the contributions of extreme users improve the existing peeler handle with the features of edgeless rounded shape, anti-slip rubber surface, and the fins on the wide handle for easy finger positioning. These handle features also expand to other people to use the peeler. The process of Inclusive Design for improving the old peeler design is shown in Figure 1.4. In the same way, aphasia users become extreme users because they have communication disabilities, and they can use their experience to find different views to join in the society.

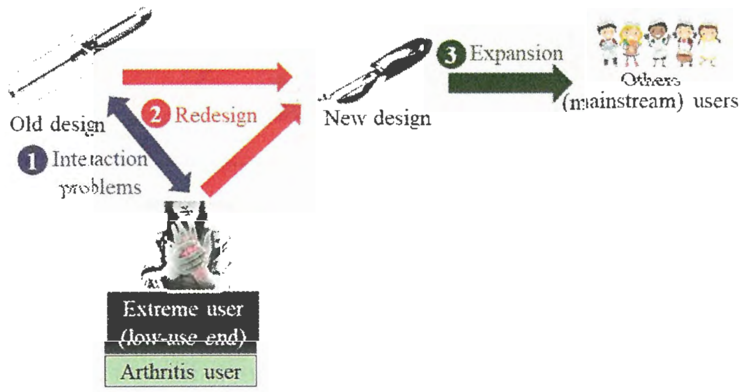


Figure 1.4: Inclusive Design process to design potato peeler

1.2 Issues of Aphasia Individuals in Inclusive Design

This section presents the difficulties of identification of interaction problems, difficulties of redesigning the solutions, and difficulties of expanding the design solution when the Inclusive Design is used to include aphasia individuals in society.

1.2.1 Difficulties to Identify Interaction Problems in Aphasia Individuals

The first issue is the identification of interaction problems in Inclusive Design for social inclusion of aphasia individuals regardless of their limited capabilities. The Inclusive Design is not enough to include sufficient aphasia individuals in society. The reason is that the aphasia individuals cannot convey their wants or needs in detail and their feelings or emotions to others. Second, they cannot understand the detailed contents of communications from other people. An aphasia individual recognizes interaction problems as an extreme user, but they cannot convey their needs and wants exactly with their delicate feelings or emotions to others. In addition, other people cannot understand them precisely for social inclusion. Thus, interaction problems cannot be identified easily in Inclusive Design due to communication difficulties.

1.2.2 Difficulties to Include Insights of Aphasia Individuals

The second issue is that insights of an aphasia individual are not included properly in redesign of Inclusive Design. An aphasia individual can identify wants and needs from their live experience, but they are not met by Inclusive Design. He or she gives insights into different ways of participation to access the products or environments, but other people cannot include his or her insights in the society. Consequently, redesign cannot cover the expectation of more aphasia individuals to include their insights into different ways of participation to access the society.

1.2.3 Difficulties to Expand Design Solution to Include More People in Society

The third issue is the inclusion of diverse difficulties of aphasia individuals by expansion of Inclusive Design to include more people in society. Difficulties exist in expansion of the design solution to other aphasia individuals and people in the society because the opinions of diverse aphasia individuals need to be included. It is necessary to include opinions of diverse aphasia individuals based on their capability to find different ways to enter society. In this connection, it is necessary to identify the importance of requirements of communication strategies based on the opinions of different aphasia individuals. They cannot express their opinions properly to identify the importance of requirements of communication strategies based on their difficulties. For this reason, support is required for the expansion process of Inclusive Design to cover diverse individuals (e.g. not only aphasia individuals). Therefore, Inclusive Design needs support to achieve its philosophical goal when this approach is used for aphasia individuals.

1.3 Social Inclusion by the Support of Soft Computing Methods

To address the above-mentioned problems, soft computing methods can support the Inclusive Design to ensure social inclusion of aphasia individuals regardless of their communication difficulties. First, to support redesign of Inclusive Design, soft computing methods address the delicate feelings of aphasia individuals in real situations in society. Specifically, soft computing methods include the expectation of aphasia individuals. Second, soft computing methods can assist the expansion of design solutions to include opinions of diverse aphasia individuals in Inclusive Design. However, communication difficulties restrict the verbal opinions of diverse aphasia individuals. In addition, they cannot include their opinions in terms of numeric value. Their opinions are always subjective, and thus imprecise.

On the other hand, other approaches such as use case, personas or story-telling approaches can be used to support the redesign and expansion of Inclusive Design [32–37]. These approaches can be used to acquire the requirements and the insights of aphasia individuals in the redesign and the expansion of Inclusive Design. In addition, numerical or statistical approaches can also be applied in the redesign and the expansion of Inclusive Design, but aphasia individuals cannot express their requirements and insights properly in terms of numeric importance. Therefore, it is difficult to address the ambiguity of linguistic terms used and judgments made by disabled people using the above numerical or statistical approaches. Therefore, soft computing methods as fuzzy-set theory are crucial in addressing the above-mentioned imprecise linguistic terms used and prioritized by aphasia individuals [31].

1.4 Problem Statement

The main focus of this study is to include isolated aphasia individuals in the society. Aphasia individuals lose their social connection gradually from their friends, relatives or others in society. Regarding this, aphasia individuals expect to participate in society by their limited capabilities, but design solutions using Inclusive Design are not matched based on their difficulties. The difficulties do not match the design solutions created by Inclusive Design because aphasia individuals still face interaction problems to participate in society. The reason is that they cannot convey their needs and wants exactly with their delicate feelings or emotions to others. They even cannot understand the detailed contents of communication with the delicate feelings or emotions from others. Thus, other people cannot understand their wants or needs precisely. Moreover, redesign cannot cover the expectation of more aphasia individuals based on their difficulties. An aphasia individual can identify wants and needs from his/her live experience, but such experience is not met only by the redesign of inclusive design. The reason is that the insights of aphasia cannot be included by redesign of inclusive design to participate in society. Furthermore, difficulties of different aphasia individuals cannot be included through the expansion process of Inclusive Design because of their communication difficulties. Thus, the other people who have different difficulties from extreme users (e.g. aphasia individuals) cannot be included in society by the expansion process of Inclusive Design. Therefore, only Inclusive Design cannot include aphasia individuals as well as other people in society. To address the above-mentioned issues, it is necessary to support the inclusive design to identify interaction problems, redesign and expand the solutions. In that case, soft computing methods can support Inclusive Design.

1.5 Purpose of the Study

The objective of this study is to propose soft computing methods to support Inclusive Design in order to include aphasia individuals in society. The specific objectives of this study are as follows:

- To convey delicate feelings or emotions for social inclusion of aphasia individuals.
- To include more aphasia individuals as well as other people (e.g. other speech-language impaired individuals) in the society based on their difficulties.

In this study, the following soft computing methods are used to support the Inclusive Design in order to achieve these purposes.

- To support the redesign process of Inclusive Design, a fuzzy-set theory is used to manage the delicate feelings or emotions of aphasia individuals after identifying the interaction problems.
- To support the expansion process of Inclusive Design, the opinions of diverse aphasia individuals are included by a hybrid method where linguistics voting is used to include the direct opinions of aphasia individuals. Soft computing methods (e.g. fuzzy analytic hierarchy process) are used to include the opinions of SLT.

1.6 Outline of the Thesis

In this section, I give a short overview of the contents of each chapter of the thesis.

- **Chapter 1: Introduction.** The main objective of the first chapter is to frame the research objectives of this thesis. I present the background of this research, research challenges in the field of Human Factors, significant and contribution of the thesis.

- **Chapter 2: Literature Review.** Various design approaches for disabled individuals and soft computing methods are explored in this chapter.

- **Chapter 3: Interaction Problems and Redesign of Inclusive Design.** The identification of interaction problems of Inclusive Design for social inclusion of aphasia individuals will be explained. In addition, the redesign of Inclusive Design is also described to improve the current design solution for speech-language impaired individuals.

- **Chapter 4: Expansion of Design Solution of Inclusive Design.** The expansion of design solution in Inclusive Design using the support of proposed soft computing methods will be explained.

- **Conclusions and Future Works.** The conclusion from the discussion is summarized in this chapter as well as several suggestions for further research that emerged from the discussion.

2 Review of Literature

This chapter provides explanation of the normalization principle, existing design approaches for disabled people, existing soft computing methods, and related works. In this chapter, several design approaches are discussed such as Barrier-free design, Universal Design, Design for All, Accessible Design, User-centered Design (UCD), Participatory Design and Inclusive Design. In this study, Inclusive Design approach is selected to include aphasia individuals in society. Moreover, fuzzy-set theory, analytic hierarchy process (AHP) and the fuzzy-AHP are explained in this chapter. Fuzzy-AHP is used in this study to support the Inclusive Design for including aphasia individuals as well as other people in society. Furthermore, this chapter also provides some related works about existing design approaches that used for aphasia individuals.

2.1 Normalization

The concept of normalization was developed in Scandinavia and incorporated into Danish law governing services in 1959. The law stated that the services and facilities for persons with mental retardation should be made as close to the normal person as possible.

2.1.1 Background of Normalization

The ideological background of this legislative initiative, "The services and facilities should available for the mentally retarded individual and they have a full right like other healthy citizens" was expressed by Bank Mikkelsen, Director of the Mental Retardation Section at the Ministry of Social Affairs [38]. One decade later, in 1969, Benjt Nirje, as a representative of the Swedish parent association, used the Bank Mikkelson's expression "to let the mentally retarded obtain an existence as close to the normal as possible" to formulate the normalization principle. According to Benjt Nirje, "the normalization principle means making services and facilities available to the mentally retarded patterns and conditions of everyday life which are as close as possible to the norms and patterns of the mainstream of society" [39]. The phrase "norms" means the unwritten rules of behavior that are considered acceptable in a society. Norms explain why and what disabled people do something in given situations. The phrase "mainstream of society" means healthy persons and their activities in the society. In addition, the phrase "as close as possible" into context, implying that mentally retarded people have a right to live in society on the same basis as anyone else [40]. Moreover, the normal patterns and conditions of everyday life are possible when the person with mentally retarded has accessed to services available in the community.

2.1.2 Normalization Principle

Bengt Nirje presented the normalization principle in terms in eight components for the normal patterns or conditions of everyday life of mentally retarded persons [39]. Then, this principle was applied to all the retarded, regardless whether mildly or profoundly retarded, or whether living in the homes of their parents or in group homes with other retarded. The components are as follows:

1. A normal rhythm of the day (e.g. awakening, eating and retiring at a regular time).

2. A normal routine of life (e.g. living in one place, working, attending school, and playing in other places).

3. A normal rhythm of the year (e.g. holidays, special family days).

4. The normal experiences of the life cycle (e.g. family living, schooling, employment).

5. Normal respect for the individual and the right to self-determination.

6. The normal sexual patterns (e.g. bisexual).

7. The normal economic patterns and rights of their society.

8. The normal environment patterns and standards in their community.

Therefore, the brief summary of the normalization principle is represented by Benjt Nirje as "The Normalization principle means that you act right when you make available to all persons with intellectual or other impairments or disabilities those patterns of life and conditions of everyday living that are as close as possible to, or indeed the same as, the regular circumstances and ways of life of their communities and their culture" [40, 41].

2.1.3 Reformulation of Normalization

Further, the normalization principle was reformulated, developed and being brought by Wolfensberger in North America. His aim was to generalize the applicability of the principle of normalization to all human service sectors and to extend it for all socially devalued groups [42]. In his reformulations, Normalization defined as "utilization of means, which are as culturally normative as possible in order to maintain and/or establish personal behavior, and characteristics which are as culturally normative as possible" [43]. It is clear from the reformulation that the concept of normalization is culture-specific, because cultures vary on their norms. The phrase "as culturally normative as possible" implies ultimately an empirical process of determining what and how much is possible. As distinguished from Nirje's definition, which emphasizes normalization as a means, Wolfensberger's definition emphasized both means and goals. In Wolfensberger's reformulation, the goal of normalization is to increase the functional independence of retarded persons so that they may be more easily assimilated in the community. Wolfensberger and Tullman further refined the definition and discussed how it can help, prevent, minimize, or reverse the psychological and behavioral effects of being viewed as different from the rest of society as a result of a physical, mental, or emotional handicap [44]. They defined normalization principle as "Normalization implies, as much as possible, the use of culturally valued means in order to enable, establish, and/or maintain valued social roles for people".

Using the principle of normalization, many ideas and philosophies have been developed so that people with and without disabilities can live a similar social life without being distinguished from each other.

2.2 Existing Design Approaches

This section provides information on a variety of design approaches that are used to design a product or environment for people with disabilities. The design approaches that will be informed here are Barrier-free Design, Universal Design, Design for All, Accessible Design, User-centered Design (UCD), Participatory Design and Inclusive Design.

2.2.1 Barrier-free Design

In the 1950s, disabled veterans and people with disabilities began the barrier-free movement in the US, resulting of standards for "barrier-free" buildings. These architectural barriers make buildings and facilities very difficult for the physically handicapped in normal situations of education, recreation, and employment. Making buildings accessible by handicapped soldiers and others with similar conditions was the target of this movement. A barrier-free environment is shown in Figure 2.1 [45]. Thus, the American National Standards Institute published its first version of "ANSI A117.1,

Figure 2.1: Barrier free design for the disabled and the elderly people [45]

"Making Buildings Accessible to and Usable by the Physically Handicapped" [21]. This standard is applied to all buildings and facilities used by the public places so that all buildings and facilities are open to the physically handicapped. Therefore, Barrier-free design eliminates the obstacles and creates environments that are functional for all potential users [23]. The movement came in Japan, in about 1970 [22]. The underlying idea for the movement can be called "toward barrier-free design," in which elimination of physical barriers of wheelchairs was the top priority. It was no wonder that the wheelchair was a focal point because the issue was so visible to everybody.

2.2.2 Universal Design

The term Universal Design was first proposed by American architect Ronald Mace in 1985 to resolve discrimination against disabled persons. According to his view, if a building is designed from the beginning with a variety of users in mind, it will not need to create such a discriminatory mechanism. He defined Universal Design as "The design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized

Figure 2.2: Universal toilet for everyone [50]

design" [24–26]. He established an organization called the Center for Accessible Housing in 1989 attached to the State University, where the focus was on making barrier-free housing an important theme. Later, this organization was named the Center for Universal Design in 1995. The concept of Universal Design came before the Americans with Disabilities Act of 1990 [46]. The law established the rights of persons with disabilities as civil rights.

Decades after coining Universal Design, Ron Mace argues that barrier free for one person can be a barrier for someone else. It is not enough to simply remove the barrier. The designer must address the issue from a broader angle. Therefore, Ron Mace gathered professionals from different fields to draft the principles of Universal Design [26]. The principles were intended to guide the design process, allow systematic evaluation of designs, and assist in educating both designers and consumers about the characteristics of more usable design solutions [47–49]. For example, an universal toilet can be used by everyone (e.g. disabled, elderly, children or healthy people) as shown in Figure 2.2 [50]. The principles of Universal Design are as follows:

1. Equitable Use: The design is useful and marketable to people with diverse abilities.

2. Flexibility in Use: The design accommodates a wide range of individual preferences and abilities.

3. Simple and Intuitive Use: Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills or current concentration level.

4. Perceptible Information: The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.

5. Tolerance for Error: The design minimizes hazards and the adverse consequences of accidental or unintended actions.

6. Low Physical Effort: The design can be used efficiently and comfortably and with a minimum of fatigue.

7. Size and Space for Approach and Use: Appropriate size and space are provided for approach, reach, manipulation and use regardless of the user's body size, posture or mobility.

Each of these principles was defined and then expanded in a set of guidelines describing key elements that should be present in a design adhering to the principle. Therefore, Universal Design is a set of design principles to create a better quality of life for everyone regardless of the existence of disabilities, differences in abilities, age, or gender.

2.2.3 Design for All

The concept of Design for All was established in 1993 by European Institute for Design and Disability (EIDD) with the mission statement "Enhancing the quality of life through Design for All". The most common and popular definition of Design for All is "Design for All is design for human diversity, social inclusion

Figure 2.3: Metro station for all [52]

and equality" [27]. Design for All was used to build the Copenhagen Metro in Denmark which is shown in Figure 2.3 [52]. Design for All is a philosophy with the aim of producing products, environments, services and systems that are usable by all people, whatever their age, size, and abilities. The philosophies behind Design for All and Universal Design are very nearly the same, and the terms are often used interchangeably [51, 53]. Both methodologies strive for the design of products and environments that are usable by everyone, regardless of their level of ability. In practice, it requires the involvement of end users at every stage in the design process of products, services, and systems.

The Design for All Foundation has come up with a set of guidelines for Design for All, similar to the Universal Design guidelines from the Central of Universal Design. Therefore, products or environments should satisfy these guidelines in order to be classified as good practice in 'Design for All' [54].

1. Respectful: The design should respect the diversity of its users.
2. Safe: The design should be free of risks to all users.
3. Healthy: Design should not constitute a health risk or exacerbate problems from illnesses or allergies.
4. Functional: Design should carry out its intended function without any problems or difficulties.
5. Comprehensible: The design should provide clear information and have coherent spatial distribution and orientation.
6. Sustainable: The design should not misuse resources so that future generations will have the same opportunities.
7. Affordable: All users should have the opportunity to enjoy the product.
8. Appealing: The product should be socially acceptable.

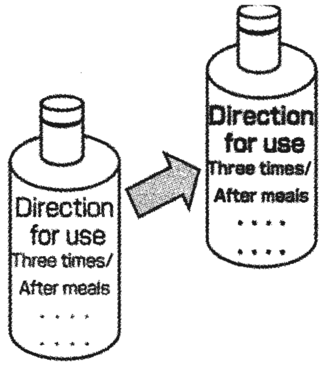


Figure 2.4: Accessible label in a pharmaceutical battle [57]

2.2.4 Accessible Design

According to ISO's guide 71, Accessible Design focused on principles of extending standard design to people with disability who can easily access and use a product, service or environment [55]. In addition, Accessible Design is a subset of Universal Design and both are concerned with addressing the needs of average disabled users. Therefore, the definition of Accessible Design is slightly different from Universal Design provided by the Center for Accessible Housing [56]. It stated that Accessible Design can be defined as the design of facilities, products, and services that satisfy specific legal mandates, guidelines, or code requirements with the intent of providing accessibility to the entities for individuals with disabilities. For example, an accessible label can be read by the elderly with vision impairments as shown in Figure 2.4 [57]. This definition of Accessible Design focuses on the legal implications of the term. The definition is an expansion of the 1991 Center for Accessible Housing's definition [58, 59]. These guidelines were adopted with modifications by the U.S. Department of Justice and became the enforceable ADA Standards for Accessible Design [58]. Its general message is that "No individual shall be discriminated against on the basis of disability in the full and equal enjoyment of the goods, services, facilities, privileges, advantages, or accommodations of any place of public accommodation by any private entity who owns, leases (or leases to), or operates a place of public accommodation" [46, Sec. 302, p. 32].

2.2.5 User-centered Design

Putting the user in the core of the design process is the guiding principle of a philosophy of User-centered Design (UCD). The main factors of UCD are user behavior and their characteristics. The term 'User-centered Design' was coined in 1986 by Donald Norman, who introduced guidelines so that designers can achieve good usability outcomes [60]. From this viewpoint, designers, researchers, and policy makers have proposed various methodologies and techniques that seek to involve the end user in the design process, and ISO 9241 is one of such methodology. In ISO 9241, the term human-centered design (HCD) used instead of User-centered Design and defines as "an approach to interactive systems development that aims to make systems usable and useful by focusing on the users, their needs and requirements, and by applying human factors/ergonomics, and usability knowledge and techniques" [62]. The main goal of HCD is to increase the usability of the product in order to create maximum user satisfaction. ISO 9241 provides a framework for human-centered design based on six principles. These are: (1) The design is based upon an explicit understanding of users, tasks, and environments; (2) Users are involved throughout design and development; (3) The design is driven and refined by user-centered evaluation; (4) The process is iterative; (5) The design addresses the whole user experience; (6) The design team includes multidisciplinary skills and perspectives. Using the User-centred Design, the double DishDrawer was

Figure 2.5: The double DishDrawer developed by User-centred Design [61]

implemented as shown in Figure 2.5. It uses two independent dishwashing drawers in one unit, allowing the user to run two separate washes at the same time with different items in each, permitting greater control, flexibility, and efficiency [61]. However, the HCD process can easily be integrated in Universal Design or Inclusive Design. Although UCD has some benefits, Norman argues that the UCD approach may be harmful [63]. Norman explained that the focus upon individual user groups might improve things for them at the cost of making it worse for others.

2.2.6 Participatory Design

Participatory Design aims at including users in the design process so that users' voice is reflected in the design of a technology they use [64, 65]. In Participatory Design, all stakeholders such as users, designers or experts cooperate with each other during the design process. The core method of Participatory Design includes workshops and design sessions in which users are encouraged to think creatively and propose their own ideas. Participatory design with workshops is found for designing a digital community calendar as shown in Figure 2.6 [66]. Beyond workshops, ongoing activities in which designers prepare prototypes and mockups and obtain feedback from users in a continuous manner are also crucial. To assist users who are not familiar with design practices, cards are often used as a medium of gathering and structuring data. Moreover, users are

Figure 2.6: Participatory workshop with seniors [66]

given design tools by which they can explore designs on their own. Therefore, the power of Participatory Design is to encourage the active involvement of potential or current end-users of a system in the design and decision-making processes.

2.2.7 Other Design Approaches

This section describes a few design approaches in the field of requirement engineering such as Agile Development, Soft System Methodology (SSM), Goal-oriented Requirements Engineering, and Use Cases.

Agile Development discovers requirements and develops solutions through the collaborative effort of development teams and the end users. The goal of Agile Development is to help software development organizations to quickly develop and change their products and services [67–69]. Thus, Agile Development provides the ability to adapt the products or services to the dynamic market conditions. Therefore, agile development focuses on the talents and skills of individuals, molding the process to specific people and teams [67].

Soft Systems Methodology (SSM) aims to deal with 'fuzzy' problem situations, where multiple stakeholders' diverse objectives exist [70–72]. In this connection, the requirements engineers must cooperate with the users in understanding the problem situation.

Goal-oriented Requirement Engineering deals with the analysis of more complex software systems [73, 74]. At the requirements level, traditional requirement engineering approaches treat requirements as consisting only of processes and data and do not capture the rationale for the software systems. Thus, it is difficult to understand requirements with respect to some high-level concerns in the problem domain [74]. Therefore, Goal-oriented Requirements Engineering attempts to solve this problem.

Use Cases describe possible interactions involving a system and its environment [75]. According to the Unified Modeling Language (UML) specification, a use case is "the specification of a sequence of actions, including variants, that a system (or a subsystem) can perform, interacting with actors of the system" [76, 77].

The above-mentioned approaches can be applied in development process during requirements acquisition. However, it is difficult to apply for the requirements acquisition of aphasia individuals. The reason is that the requirement engineer cannot interact with aphasia individuals properly.

2.3 Inclusive Design

Inclusive Design is an approach of designing with extreme users to find and invent new ways for wider and more accurate participation in the product or environment. Generally, traditional design approaches focus on the needs of mainstream users. Companies often concentrate on satisfying needs of the majority which is usually their main target market. Here, the distribution of users' market of products or environments follows a bell curve shown in Figure 1.3. The center part would represent the mainstream users and the edge of the distribution would represent extreme users. The novice users or low-use end users fall in the left edge of the curve. In Inclusive Design, these extreme users will be selected as main lead users of the design process [78]. To achieve inclusive design based on the difficulties of extreme users, three important tasks are needed to be completed such as identification of interaction problems by the extreme users, redesigning the previous solution, and expanding the product or environment to other people.

2.3.1 Inclusive Design Movements

The DesignAge program was founded in Europe in 1991 to research the efficacy of designs to accommodate aging populations. DesignAge formed the nucleus of the Inclusive Design movement. The result of the Inclusive Design movement established the Helen Hamlyn Centre at the Royal College of Art in the UK in 1999 [79, 80]. In this connection, the term Inclusive Design was first used in 1994 by Coleman and increasingly applied since then, but the early focus was the worldwide implications of the aging population and disability as mainstream design challenges [81]. Roger Coleman, the first Director of the Helen Hamlyn Centre states that "the Inclusive Design focuses on inclusiveness at the social level through a range of products and services that together accommodate the whole population without any difficulties" [82].

2.3.2 Importance to Consider Difficulties of Extreme Users

If products or environments are considered in terms of the capability demands of extreme users, then it will be possible to recognize parts of the population as enabled and disabled according to the level of capability demanded by the product or environment. In that case, the setting of capability demand becomes part of the design decision-making process. It is imperative that we design a world that best matches the diversity present within the population. By recognizing that design can play either an enabling or disabling role, it becomes possible to develop strategies that address the challenge of designing for the whole population. Products and environments can be regarded as placing demands on difficulties of the user population by setting demand levels. This inspires an important theory of Inclusive Design, Design Exclusion, which arises when the demand for using a particular product or environment, exceeds the capabilities of the user.

The concept of design exclusion is unique to differentiate Inclusive Design from Universal design or Design for All because it is not always possible to design one product or service that meets the needs of the entire population [83]. Design Exclusion is particularly useful because identifying why and how end users cannot easily use a product or service enables users to take steps to counter such exclusion. This is because who and how many people cannot use the products or the services. It highlights the aspects of the products and services. Then, the products and the services could be improved. Thus, it possibly include more users. Specifically, by identifying the capability demands placed upon the users by the features of the product or service, it is possible to know the end users who cannot use this product or service, irrespective of the cause of their functional impairment. Therefore, if the product or service is redesigned, then the capability demand is decreased. Thus, a wider range of users are more likely to be included and fewer people are likely to be excluded due to inappropriate design [80].

2.3.3 Identification of Interaction Problems in Inclusive Design

Extreme users face different interaction problems with products or environments based on their difficulties. Thus, only extreme users recognize interaction problems between their changed capabilities and the existing products or environments. They use their live experience to identify the interaction problems. For example, extreme users (e.g. arthritis users) face interaction problems with existing kitchen utensils (e.g. potato peeler) [30]. Here, the extreme users face three interaction problems at peeling potato skin. Thus, they cannot peel potatoes because they cannot grip the peeler handle. The first reason is that the swollen thumb of the extreme user is hurt by sharp edges of the handle. Then finger heads of extreme users slip on metal handles. Finally, finger heads of arthritis users release the narrow handle. In this way, extreme users can identify interaction problems for any products or environments using their real-life experience. However, designers often rely on their knowledge or previous information of products or environments and neglect these extreme users' real interaction problems during design with a traditional approach. As a result, the products or environments do not match with the changed capabilities of extreme users. Therefore, they cannot use the products or environments.

2.3.4 Redesign the Products or Environments in Inclusive Design

Extreme users can provide their insights into different ways to access the products or environments. The inclusion of their insights is important because it finds different ways to include impaired person in the products or environments based on their difficulties. For example, after inclusion of the insights of extreme users in the existing peeler, some improvements are found in the peeler handle [30]. The peeler handle is improved to a rounded shape. The rounded handle can easily pinch at gripping by not only the arthritis users but also mainstream users without hurting their thumb. The metal plate of the potato peeler is changed to rubber. The finger heads of arthritis user as well as mainstream users does not slip on handle, even they hold the peeler with weak grip force. The narrow handle is improved to wide handle which can easily grip not only by finger heads but also hand palm. Moreover, rubber fins are added on the handle. The arthritis users as well as mainstream users can easily position their finger heads on fins. Their fingers can adjust additional pressure without pain. Therefore, the inclusion of the insights of extreme user through redesign process lessens the capability demand, a wider range of users are more likely to be included and fewer people are likely to be excluded due to inappropriate design [83].

2.3.5 Expansion of Product or Environments in Inclusive Design

Design solutions through redesign process can only include those impaired users who have similar difficulties as extreme users. In that case, the users who have different difficulties cannot be included in the products or environments. Consequently, more impaired users are still excluded from the products or environments. To include more impaired users in the products or environments, expansion process is responsible to extend the design solution from extreme users to as much people as possible based on their difficulties. For example, the OXO potato peeler handle is improved so that the handle becomes anti-slip, edgeless handle, and easy for finger positing [30]. As a result, the peeler can use not only by arthritis users but also by other people. When the other people hold the difficulties of extreme users, they can easily use it.

2.4 Soft Computing Methods

This section describes existing soft computing methods that will be suitable to support Inclusive Design for managing ambiguous opinions of aphasia individuals and the knowledge of SLT to support in communication difficulties. In this connection, Fuzzy-set Theory, AHP and fuzzy-AHP will be explained in the next several subsections.

2.4.1 Fuzzy-set Theory

Fuzzy set theory provides systematic calculus to deal with imprecise and incomplete information linguistically and it performs numerical computation by using linguistic labels stipulated by membership functions [31, 84]. The logic revolving Fuzzy sets is Fuzzy Logic which deals with reasoning that is approximate rather than precisely deduced from classical predicate logic. It can be considered as an application of Fuzzy-set theory that deals with expert values in the real world for complex problems [85, 86]. The degrees of truth are often confused with probabilities. However, they are conceptually distinct. The membership function denotes linguistic labels that are fuzzy truth values. It represents membership in vaguely defined sets, and it is not likelihood of some event or condition. The set membership values are allowed to range inclusively between 0 and 1, and the corresponding linguistic form represents imprecise concepts like slightly, very, and extremely. Specifically, it allows partial membership in sets. Fuzzy set is also related to Possibility Theory [84]. The computational paradigm of Fuzzy Logic thus generalizes classical two-valued logic for reasoning under uncertainty. In order to achieve the generalization, notation of membership in set needs to become a matter of degree. This is the essence of Fuzzy sets. By doing generalization, two things are accomplished, ease of describing human knowledge involving vague concepts and enhanced ability to develop cost-effective solutions to real-world problems. Fuzzy Logic is multi-valued logic which is a model-less approach and is a clever disguise of probability theory [84]. The theory of Fuzzy sets provides an effective means of describing behavior of systems which are too complex or too ill-defined to admit precise mathematical analysis by classical methods and tools. It has shown enormous promise in handling uncertainties to a reasonable extent, particularly in decision making models under different kinds of risks, subjective judgment, vagueness and ambiguity. Moreover, a selection of fuzzy if-then rules forms a key component of Fuzzy Inference Systems that can effectively model human expertise in specific applications [87]. Extensive applications of this theory to various fields e.g., Expert Systems, Control Systems, Pattern Recognition, Machine Intelligence etc. have already been well established.

Fuzzy set theory is focused on the rationality of uncertainty due to vagueness and imprecision. A fuzzy set is characterized by a member function. 0 and 1, respectively indicate the minimum and maximum degree of membership, while all the intermediate values indicate degree of partial membership. The membership function of these fuzzy sets is denoted by Equation (2.1).

$$\mu_{\widetilde{M}}(x) = \begin{cases} 0 & x < \alpha \\ \dfrac{x-\alpha}{\beta-\alpha} & \alpha \le x \le \beta \\ \dfrac{\gamma-x}{\gamma-\beta} & \beta \le x \le \gamma \\ 0 & x > \gamma \end{cases} \tag{2.1}$$

There are some kinds of fuzzy numbers such as triangle, trapezoid and bell curve are introduced for different kind of problem. We use triangular fuzzy number in our studies. A triangular fuzzy number is shown in Figure 2.7. It is denoted simply as (α, β, γ), where (α, β, γ) denote left hand number, middle number and right-hand number of triangular membership function. Alternatively, the parameters α, β, γ denote the smallest possible value, the most promising value and the largest possible value, respectively.

2.4.2 Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP) is a prioritization technique based on ratio scale results. AHP is developed by Saaty and it is designed for complex decision making [88]. The idea of AHP is that it compares all possible pairs of hierarchical requirements to determine the priority. When using AHP, the user first identifies the attributes and alternatives for each requirement and uses them to build a

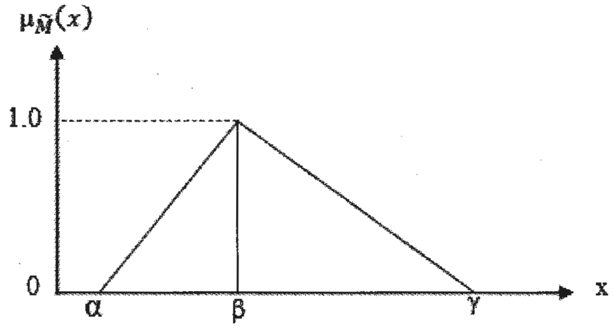


Figure 2.7: A triangular fuzzy number

hierarchy. Then the user specifies his/her preference to each pair of the attributes by assigning a preference scale which is generally 1 to 9, where 1 indicates equal

Table 2.1: Basic scale for pairwise comparisons in AHP

How important	**Description**	**Explanation**
1	Equal importance	Two requirements are of equal value
3	Moderate difference in importance	Experience slightly favors one requirement over another
5	Essential difference in importance	Experience strongly favors one requirement over another
7	Major difference in importance	Experience strongly favors one requirement over another
9	Extreme difference in importance	The evidence favoring one over another is of the highest possible order of affirmation
2 4 6 8	Intermediate values between	When compromise is needed
Reciprocals	If requirement i has one of the above numbers assigned to it when compared with requirement j, then j has the reciprocal value when compared with i	

value and 9 indicates extreme value. The scale according to Saaty is shown in Table 2.1 [89]. AHP converts the user's evaluations to numerical values and a numerical priority is derived for each element of the hierarchy. Note that a redundancy might exist when using the AHP method to prioritize requirements. A consistency ratio should be calculated after using the AHP method to judge if the prioritization is valid.

To fully understand AHP, it is easiest to divide AHP into three different phases.

1. Comparing every pair of requirements, this is the "engine" of AHP, according to Saaty [88, 90].

2. Derives a priority vector of relative weights for these requirements, i.e. the principal eigenvector.

3. Calculate the by-product from 2, i.e. the inconsistency measure.

First, we take the requirements that should be prioritized (the total amount of requirement is n), and put them into a matrix, where the rows have the index of i and columns have the index of j. The matrix is called W and the elements in the matrix are called w. The requirement that is placed in row i and column j gets the index ij. Therefore, the element w_{ij} has the *row index* $= i$ and *column index* $= j$.

Each matrix element consists of the comparison between two requirements (i and j), which gives us the following relationship:

$$W_{ij} = \frac{w_i}{w_j} \tag{2.2}$$

An important notice is that the person that does the prioritization does not put any value on w_i and w_j, instead he or she decides the value for w_{ij} which is the ratio between w_i and w_j. That leads us to another important relationship, which is that for every index of i, j, k has the following relationship:

Table 2.2: Matrix of pairwise comparisons

	Req. 1	Req. 2	...	Req. n
Req. 1	1	W_{12}	W_{1j}	W_{1n}
Req. 2	W_{21}	1	W_{2j}	W_{2n}
...	W_{i1}	W_{i2}	1	W_{in}
Req. n	W_{n1}	W_{n2}	W_{nj}	1

$$W_{ij} = (W_{ji})^{-1}\,, \; W_{ij} = W_{ik}W_{kj} \tag{2.3}$$

With the information from Equations (2.2) and (2.3) and the matrix in Table 2.2, we can see that some pairwise comparisons are doing twice. The problem with human perception and judgments are subject to change if the human becomes tired or something changes the human psychological state (i.e. the level of blood sugar is dropping, and thereby the concentration). To solve this problem, Saaty proposed that we should only compare a_{ij}, $j > i$ [88,90]. We only need to do half the comparison, since Equation (2.3) says that $w_{ij} = 1/w_{ji}$. Therefore, it is really easy to apply Equation (2.3) to the comparisons that are not necessary. This leaves us to the diagonal, with the comparison with requirement w_i and w_j they will always be equal (i.e. the reciprocal value 1).

The next step according to Saaty is to calculate the eigenvector v. The elements of the eigenvector correspond to the priorities of the requirements. The elements of the eigenvector correspond to the priorities of the requirements. Gass and Rapcsák describe it in the following way: If W is a consistent matrix, i.e. if Equation (2.3) holds for all the indices of i, j, k, then W is of rank one and $\lambda_{max}=n$ [91]. If the relationship $\lambda_{max}= n$ is true, W is a positive reciprocal matrix.

$$Wv = \lambda v \tag{2.4}$$

Equation (2.4) is the mathematical definition of the relationship between the eigenvalue and the eigenvector. This is nothing that is specific for AHP but is valid for all matrices. This means that v must be the eigenvector of W that corresponds to the maximum eigenvalue λ. This means that we take every prioritization in your matrix and calculate the sum of the j columns.

$$w_{11} + w_{21} + w_{i1} + \ldots + w_{(n-1)1} + w_{n1} = z \tag{2.5}$$

Then we divide each element in the column with the sum, z, we calculated with Equation (2.5). The next step is to add up the element in row i. The final step is to divide each row sum with the amount of requirements n.

The final phase is to calculate the consistency rate of the prioritization method. Consistency analysis is done to avoid the judgment error; hence it is important to find out if the person is consistent in his/her judgment. The consistency index (CI) is calculated by Equation (2.6).

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \tag{2.6}$$

where the eigenvalue (λ_{max}) can be obtained by summing products between each element of the Eigenvector multiplied by the total of columns of the reciprocal matrix. If the λ_{max} value is close to n, then there have been little judgment errors and the result will be more consistent. Finally, we need to calculate the consistency ratio (CR) for identifying whether the calculated CI is acceptable or

Table 2.3: Random indices for AHP

1	2	3	4	5	6	7	8	9	10
0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.48

not. The *CR* is a ratio from *CI* and ratio index (*RI*), where *RI* is one of the random indices. The *RI* table is shown in Table 2.3. According to Saaty a *CR* result of *0.10* or less is to be considered acceptable [89]. Otherwise, it indicates that there has been a serious judgment error in the prioritization process, and it should be restarted.

Therefore, AHP can be applied in requirement prioritizing as follows:

1. Structure all requirements in a matrix, so that the matrix represents all unique pairs [92].

2. Compare all the unique pairs in the matrix, with the scale in Table 2.3.

3. For the presentation, use Saaty's idea about priority vector and relative weights for these requirements, i.e. the principal eigenvector.

4. Calculate how consistent the prioritizing person has been in his/her judgment. The consistency index indicates how trustworthy the results are, and also how much judgment error that the prioritizing person has done in the comparisons.

2.4.3 Fuzzy-AHP

Fuzzy Analytic Hierarchy Process (Fuzzy-AHP) embeds the fuzzy theory to basic Analytic Hierarchy Process (AHP), which was developed by Saaty [88]. Since basic AHP does not include vagueness for personal judgments, it has been improved by benefiting from a fuzzy logic approach. In Fuzzy-AHP, the pairwise comparisons of both criteria and the alternatives are performed through the linguistic variables, which are represented by triangular numbers [93]. One of

Table 2.4: Linguistic terms and corresponding triangular scale of fuzzy-AHP

Number	**Linguistic meaning**	**Fuzzy triangular scale**
1	Equally important	(1, 1, 1)
3	Moderately important	(2, 3, 4)
5	Strongly important	(4, 5, 6)
7	Very strongly important	(6, 7, 8)
9	Extremely important	(9, 9, 9)
2 4 6 8	Intermediate values of importance	(1, 2, 3) (3, 4, 5) (5, 6, 7) (7, 8, 9)

the first fuzzy-AHP applications was performed by van Laarhoven and Pedrycz [94]. They defined the triangular membership functions for the pairwise comparisons. Afterwards, Buckley has contributed to the subject by determining the fuzzy priorities of comparison ratios having triangular membership functions [95]. Chang also introduced a new method related with the usage of triangular numbers in pairwise comparisons [96]. Although there are some more techniques embedded in Fuzzy-AHP, within the scope of this study, Buckley's methods are implemented to determine the relative importance weights for both the criteria and the alternatives [95]. Decision Maker compares the criteria or alternatives via linguistic terms shown in Table 2.4.

According to the corresponding triangular fuzzy numbers of these linguistic terms, for example if the decision maker states, "Criterion *1* (C1) is Weakly Important than Criterion *2* (C2)", then it takes the fuzzy triangular scale as (2, 3, 4). On the contrary, in the pairwise contribution matrix of the criteria, comparison of *C2* to *C1* will take the fuzzy triangular scale as (1/4, 1/3, 1/2). The pairwise contribution matrix is expressed in Equation (2.7), where indicates the expert's preference of the i-th criterion over the j-th criterion, via fuzzy triangular numbers.

$$\widetilde{A} = \begin{bmatrix} (1,1,1) & \cdots & \widetilde{d}_{1n} \\ \vdots & \ddots & \vdots \\ \widetilde{d}_{n1} & \cdots & (1,1,1) \end{bmatrix} \tag{2.7}$$

According to Buckley [95], the geometric mean of the fuzzy comparison values for each criterion is calculated using Equation (2.8); where, $\tilde{r}_i$ represents the triangular values.

$$\widetilde{r}_i = \left(\prod_{j=1}^{n} \widetilde{d}_{ij} \right)^{1/n}, \quad i=1,\ 2,\ \ldots, n \tag{2.8}$$

The fuzzy weights of each criterion can be determined using Equation (2.9). First, the vector summation of each $\tilde{r}_i$ value, and the (-1) power of the summation vector are determined. The fuzzy triangular number is then replaced so that its order is increased. To find the fuzzy weight of criterion *i* ($\tilde{w}_i$), we multiply each $\tilde{r}_i$ by the following reverse vector:

$$\widetilde{w}_i = \widetilde{r}_i \otimes (\widetilde{r}_1 \oplus \widetilde{r}_2 \oplus \ldots \oplus \widetilde{r}_n)^{-1} = (lw_i, mw_i, uw_i) \tag{2.9}$$

Operator $\otimes$ is used for multiplication of matrix and operator $\oplus$ is used for summation of matrix. $\tilde{w}_i$ represents the fuzzy triangular numbers; therefore, we have to apply defuzzification by the Centre of area method proposed by Chou and Chang [97], as expressed using Equation (2.10).

$$M_i = \frac{lw_i + mw_i + uw_i}{3} \tag{2.10}$$

Here, M_i is a non-fuzzy number normalized using Equation (2.11).

$$N_{i(Norm)} = \frac{M_i}{\sum_{i=1}^{n} M_i} \tag{2.11}$$

These above steps are performed to find the normalized weights of both criteria and the alternatives. Then by multiplying each alternative weight with related criteria, the scores for each alternative is calculated. According to these results, the alternative with the highest score is suggested to the decision maker. After calculating the normalized weight with Equation (2.4), consistency analysis is performed to avoid the judgment error [98].

2.5 Related Works

The majority of previous studies used User-centered Design (UCD) or Participatory Design (PD) approaches [60, 99, 100]. Most UCD and PD methods make fundamental assumptions about the communication skills of those who will participate. They are founded on the premise that participants will have the requisite skills, for example, to communicate orally, to understand and produce written text, to comply with instructions. Those who do not have these skills cannot readily participate.

Several communication support applications have been developed using HCD or PD to assist people with aphasia, but a small number of communication support application have been designed to assist communication for people with aphasia. Mahmud et al. implemented an email tool for language impairments using UCD approach [19]. Their tool was developed for sending email where other tasks cannot be performed. Thus, this tool is insufficient to assist other task for daily activities of diverse disabled users. Those that have used a PD approach to design have mostly used proxies. In other words, either SLT played the roles of the aphasic participant or the caregivers of aphasic participants provided feedback. For example, SLT played as proxies for aphasia users in the development of PhotoTalk [20], an application that allows people with aphasia to capture and manage digital photographs to support face-to-face communication. Thus, designers were able to specify only few real user requirements for diverse aphasia individuals. Koppenol et al. similarly designed an application that uses photographs to support communication and used SLT as proxies [101]. Kane et al. design a context-aware communication tool for improving interpersonal communication for people with aphasia [102]. They used PD at the design process, but they considered only two context such as current location and conversation partner. The human factors of aphasia individuals such as their difficulties, limitation, age, education and other environmental factors did not consider at design process.

Moreover, using the design approaches, a few studies are found to design communication support applications for disabled people. Nganji and Nggada developed a disability-aware software engineering process model where the process takes into account the needs of people with disabilities from the beginning of the life cycle [103]. Newell et al. states that approaches like UCD, Universal Design or Design for All are not entirely suitable for the development of communication support application, especially aimed at people with special needs [104]. They suggest User Sensitive Inclusive Design where designers develop a real empathy with their user groups (including those with disabilities). The above study shows the need of approaches with clear information on how users with different abilities may be part of the design of a tool. Furthermore, Wobbrock et al. proposed an ability-based design concept and showed how designers should focus on the abilities of the users instead of their disabilities in an effort to create systems that leverage the full range of human potential [105]. Although the above-mentioned approaches can be used to develop communication support application, it does not provide any clue the inclusion of aphasia individuals in society.

Furthermore, a few studies are found to apply AHP for designing products or services. Gülçin Büyüközkan and Gizem Çifçi developed a hybrid method where fuzzy-AHP and 'technique for order performance by similarity to ideal solution' (TOPSIS) are combined to evaluate a set of hospital web site alternatives in order to reach the best qualified alternative that satisfies the needs and the expectations of customers [106]. Ayağ and Özdemir applied fuzzy-AHP to evaluating conventional machine tools, especially used for general use in manufacturing systems. In this connection, they realized their approach in a leading cutting tool manufacturer in Turkey [107]. Kuo et al. combined fuzzy-AHP and fuzzy data envelopment analysis (DEA) for assisting organisations to make the supplier selection decision [108]. When they applied their approach in auto lighting 'original equipment manufacturer' (OEM) company in Taiwan, they found that their approach is very suitable for practical applications. From the above-mentioned studies, we found that soft computing methods can be applied in design field. Thus, soft computing methods can support the inclusive design for the social inclusion of aphasia individuals.

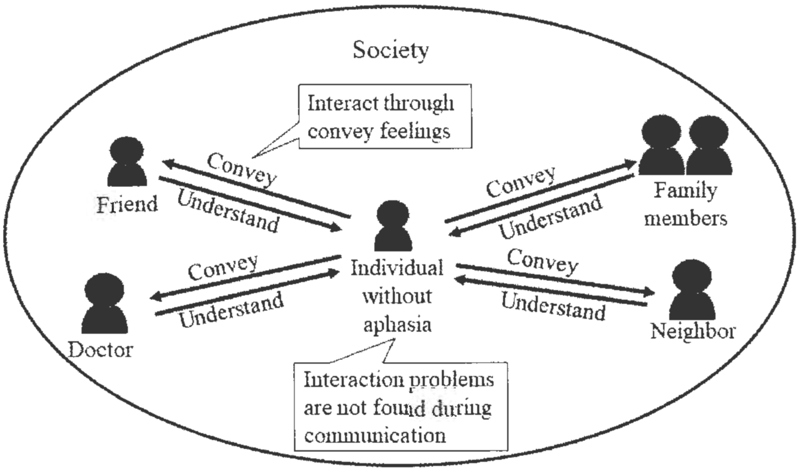
3 Identification of Interaction Problems and Redesign for Social Inclusion by Fuzzy-set Theory

This chapter describes how to include insights of aphasia individuals and their live experience to find different ways for social inclusion. In this connection, the importance of delicate feelings or emotions are described for social inclusion of aphasia individuals. Then, the identification of interaction problems will be explained for social inclusion of aphasia individuals based on their difficulties and experiences. Next, a redesign process will be explained to improve the previous design solution when they convey their delicate feelings or emotions to others. Finally, a case study will be described to identify interaction problems and redesign for social inclusion of aphasia individuals.

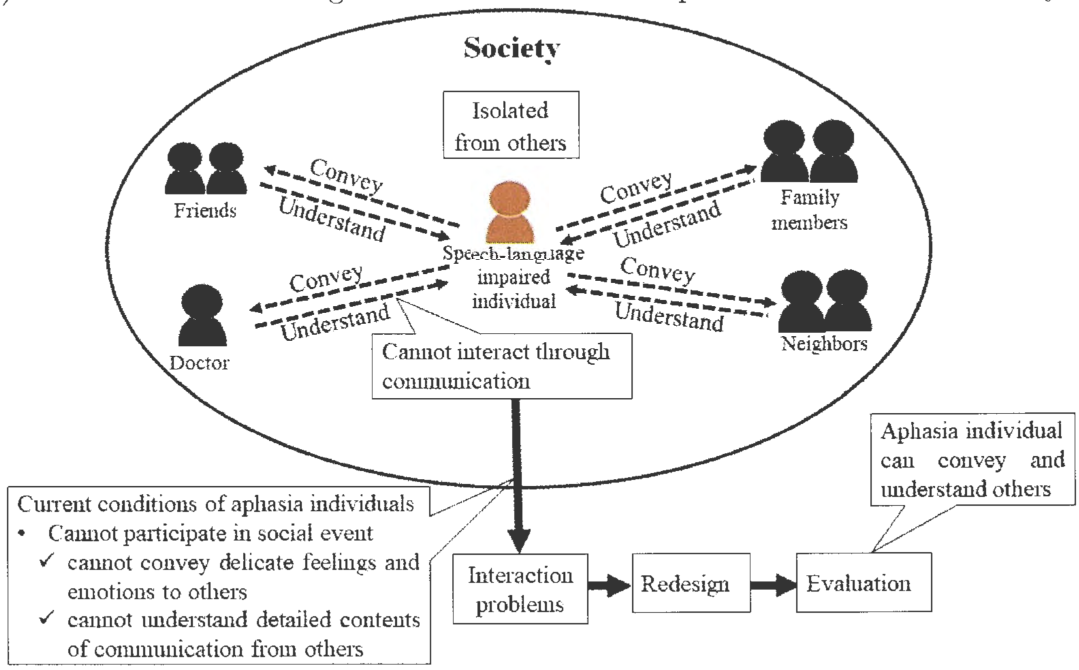
3.1 Importance of delicate feelings or emotions for social inclusion

As described in the section 1.2 of Background, aphasia individuals cannot be included in the society sufficiently. They cannot convey their wants or needs using their delicate feelings or emotions to others. They cannot understand the detailed contents of communications from other people. An aphasia individual recognizes interaction problems as an extreme user, but they cannot express delicate feelings or emotions to convey their needs and wants exactly to others. Other people cannot understand them precisely for social inclusion. Thus, interaction problems cannot be identified easily in inclusive design due to communication difficulties.

The interaction problems faced by aphasia individual in society are shown in



(a) Communication among an individual without aphasia and others in society



(b) Communication among an aphasia individual and others in society

Figure 3.1: Scenarios of interactions in society (a) Communication among an individual without aphasia and others in society (b) Communication among an aphasia individual and others in society

Figure 3.1 (b). The individuals without aphasia can participate in social events by conveying their delicate feelings or emotions to others, and they can also understand the detailed contents of communication from others as shown in

Figure 3.1(a). They face no interaction problems with other people in society during communications. On the other hand, aphasia individuals are confronted with problems to interact with others to participate in social events. They cannot participate in social events properly because they cannot convey delicate feelings or emotions to others with their own voice as shown in Figure 3.1 (b). In addition, aphasia individuals cannot understand the detailed content of communication with the delicate feelings or emotions from others. For example, when they attend a family party, they want to be involved, but they felt alone even though they were standing with other people by communication difficulties. These interaction problems of aphasia individuals affect their social relationships and participation in different social life domains [109–111]. Thus, people with aphasia are often isolated from others in society, but they wish to be included in the society in an ordinary way. In that case, aphasia individuals need support to interact with others by conveying delicate feelings or emotions. These above interaction problems are dependent on aphasia individuals. To include aphasia individuals in society, it is important to solve the interaction problems of each individual. Therefore, the solving process of interaction problems is also shown in Figure 3.1 (b).

Furthermore, redesign cannot cover the expectation of more aphasia individuals. An aphasia individual can identify wants and needs from their live experience, but such experience is not met only by inclusive design. He or she gives insights into different ways of participation to access products or environments, but other people cannot include his or her insights in the society. After identifying interaction problems, insights of aphasia individuals are included in the redesign process of products and environments as shown in Figure 3.1 (b).

3.2 Identification of User Interaction Problems

This section explains the identification of interaction problems for social inclusion. Specifically, this section describes recruitment of extreme users and the survey questionnaire for social inclusion.

3.2.1 Recruitment of extreme users

Aphasia participants are recruited as extreme users through a rehabilitation services center. The recruitment criteria are: Adults (over 18 with no upper age limit) with a diagnosis of aphasia resulting from brain damage; at least six months post-onset of aphasia; medically stable; willing to participate and complete questionnaires; able to consent to the study; absence of psychiatric conditions; absence of any other neurological condition. Further, to ensure the recruitment of people with key characteristics relevant to the study, the following sampling criteria is used : people with different degrees of aphasia severity (severe, moderate, mild). Participants were excluded if any one of the recruitment criteria were not met.

3.2.2 Questionnaires for social inclusion

Survey questionnaires are offered to the aphasia individuals to get feedback about delicate feelings or emotions. Varieties of categories of questions are identified for social inclusion of aphasia. We would like to ask about 1) How much important is it to convey delicate feelings to others in order to actively participate in society? 2) How much can they convey their delicate feelings to others? and 3) How much can they understand the feelings of others? The responses are collected from the aphasia individuals with this questionnaires. After collecting the responses for each question, the interaction problems are identified based on the answer of each extreme users.

3.3 Redesign for Social Inclusion

The redesign process includes the insights of extreme users to find other ways for social inclusion. The delicate feelings or emotions are important for sufficient communication of aphasia individuals. However, the expressions for delicate feelings or emotions look similar, but there are many ways to convey these expressions to others. The way to express these delicate feelings or emotions by an aphasia individual will be matched more based on his/her difficulties. An aphasia individual would like to express his/her own feelings or emotions in a proper way. He/she would like to select a way to express these delicate feelings or emotions which match to his/her conditions.

Since extreme users cannot convey their delicate feelings or emotions to others with their own voice, Fuzzy-set theory can support the redesign of Inclusive Design to convey the delicate feelings or emotions to others. Therefore, this section describes how to manage ambiguous expressions of aphasia individuals for delicate feelings or emotions by a Fuzzy-set theory after identifying the interaction problems. A Fuzzy-set theory is used to convey delicate feelings based on the difficulties of aphasia individuals. As a result, aphasia individuals can achieve their expectations to convey delicate feelings to others and similarly others can understand their wants or needs precisely.

3.3.1 Improvement of Interaction of Aphasia Individuals to the Society

Interaction problems are arisen between aphasia individuals and others in society. These interaction problems are solved by the redesign process based on the difficulties of aphasia individuals. Thus, the design solution suits the real condition of the aphasia individuals. As a result, aphasia individuals can improve their interaction in society by conveying their delicate feelings or emotions to others.

3.3.2 Redesign Supported by Fuzzy-set Theory

Aphasia individuals would like to convey delicate feelings or emotions to others. In this connection, they provide their insights to convey delicate feelings or emotions. They can convey their delicate feelings or emotions by pointing to an analog scale instead of their own voice. Here, the analog scale represents the in-between situations (e.g. physical conditions, level of tiredness etc.) of aphasia individuals. In this connection, they provide their insights by pointing area of each delicate feeling or emotion on an analog scale through survey questionnaires. Their pointed areas become the width of the triangular fuzzy numbers as shown in Figure 3.2 and the membership function of these fuzzy set can be denoted by Equation (2.1), where (α, β, γ) denote the left-hand number, middle number, and right-hand number of each candidate of delicate feelings or emotions, respectively. For example, the triangular fuzzy number for 'very bad' can be represented by 0, 1, 1.5 as shown in Figure 3.2. The triangular number (0, 1, 1.5) for 'very bad' is presented with three parameters such as the smallest possible value, the most promising value and the largest possible value, respectively. Table 3.1 shows the triangular fuzzy membership values for delicate feelings or emotions.

Table 3.1: Triangular fuzzy membership numbers for conveying delicate feelings or emotions

Delicate feelings or emotions	**Triangular fuzzy number**
Very bad	(0, 1, 1.5)
Pretty bad	(1.25, 2, 2.5)
Not really good	(2.25, 3, 3.5)
A little bad	(3.25, 4, 4.5)
A little good	(4.25, 5, 5.5)
A fairly good	(5.25, 6, 6.5)
Pretty good	(6.25, 7, 7.5)
Very good	(7.25, 8, 9)

Currently, aphasia individuals can convey their delicate feelings or emotions by pointing to an analog scale instead of their own voice. Here, the analog scale represents the in-between situations (e.g. physical conditions, level of tiredness, or level of understanding) of aphasia individuals. For example, an aphasia individual feels 'a little good' and he wants to convey it to others. He/she cannot convey in-between physical conditions like very good, a little good to others with his own voice. In that case, he can use a pen and paper to point his delicate feelings or emotions on an analog scale based on his difficulties. Therefore, the candidates for the fuzzy set will be the delicate feelings or emotions of aphasia individuals that are found based on the pointed location. The order of candidates will be exhibited in accordance with the maximum to minimum possibility value of each

Algorithm 3.1: Conveying delicate feelings or emotions	
Step 1:	Identify I and $\mu_i(x)$, $\forall i \in I = \{1, 2, \ldots, n\}$. Here, I is the index of delicate feelings or emotions $\mu_1(x), \mu_2(x), \mu_3(x), \ldots, \mu_n(x)$. n is the no. of index.
Step 2:	Ask a question to the aphasia individual about his/her current conditions.
Step 3:	Ask him/her to answer the question with a pointed location x.
Step 4:	For the pointed location x, calculate $\mu_i(x)$, $\forall i \in I$. Identify the Set $I' = \{i \mid \mu_i(x) > 0\}$.
Step 5:	Show him/her the list of delicate feelings or emotions corresponding to $i' \in I'$.
Step 6:	If the aphasia individual selects his/her desired delicate feelings or emotions as i'' index from I'. Then, go to Step 7. Otherwise, go to Step 8.
Step 7:	For all x, set $\mu_{i''}(x) := \mu_{i''}(x + \Delta x)$ *or* $\mu_{i''}(x) := \mu_{i''}(x - \Delta x)$. Go to Step 10.
Step 8:	For all $i \in I'$, set $\mu_i(x) := \mu_i(x + \Delta x)$ *or* $\mu_i(x) := \mu_i(x - \Delta x)$. Go to Step 9.
Step 9:	Repeat steps 3 to 6 for new candidate list of delicate feelings or emotions.
Step 10:	End procedure.

candidate. If aphasia individuals move the pointed location to x+Δx or x-Δx to adjust their delicate feelings or emotions, the candidate list is also changed based on the possibility value of each candidate for the new pointed location. The overall scenarios are shown in Figure 3.3 and Figure 3.4 with an example to convey delicate feelings or emotions for physical condition. Algorithm 3.1 presents the procedure to convey the delicate feelings or emotions based on the pointed location of aphasia individuals.

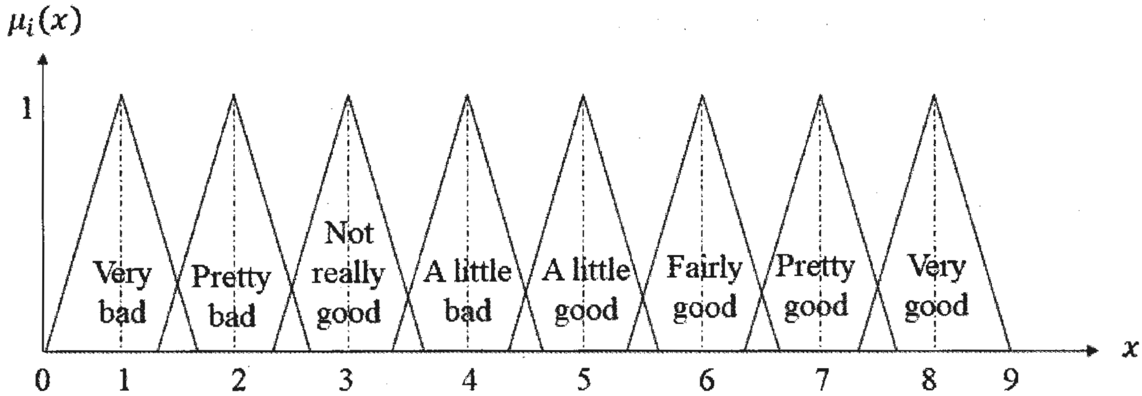


Figure 3.2: Representation of delicate feelings or emotions in triangular fuzzy form

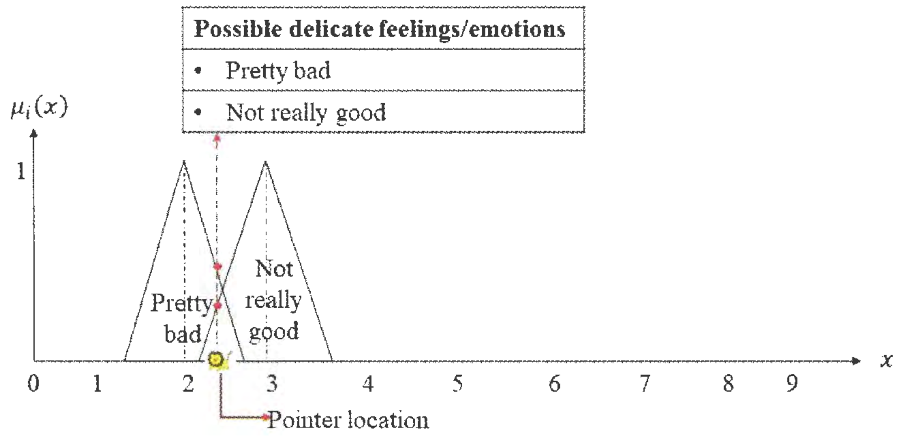


Figure 3.3: Pointed location and corresponding delicate feelings or emotions

For example, when aphasia individuals point an area between "very bad' and 'very good' for physical condition, then the possible delicate feelings or emotions for physical conditions are selected based on the pointed location. In the case of Figure 3.3, if an area between two triangular forms is pointed, possible candidates of delicate feeling are regarded as 'Pretty bad' and 'Not really good'. Suppose the possibility value for these two candidates 'Pretty bad' and 'Not really good' are 0.5 and 0.3, respectively. Thus, the candidate 'Pretty bad' holds the top position of the candidate list. If aphasia individuals move the pointed location to $x+\Delta x$ to adjust their delicate feelings or emotions, the possibility value of candidate are changed to 0.4 for 'Not really good' and 0.2 for 'Pretty bad' as shown in Figure 3.4. Thus, the candidate 'Not really good' holds the top position of the candidate list.

The representation of delicate feeling in analog scale in triangular fuzzy form is shown in Figure 3.2.

Fuzzy-set theory can help us to manage these delicate feelings or emotions. After redesigning the solution, the possible delicate feelings or emotions can be selected according to the pointed location. Consider a list of delicate feelings or emotions to convey physical condition and tiredness is shown in Table 3.2.

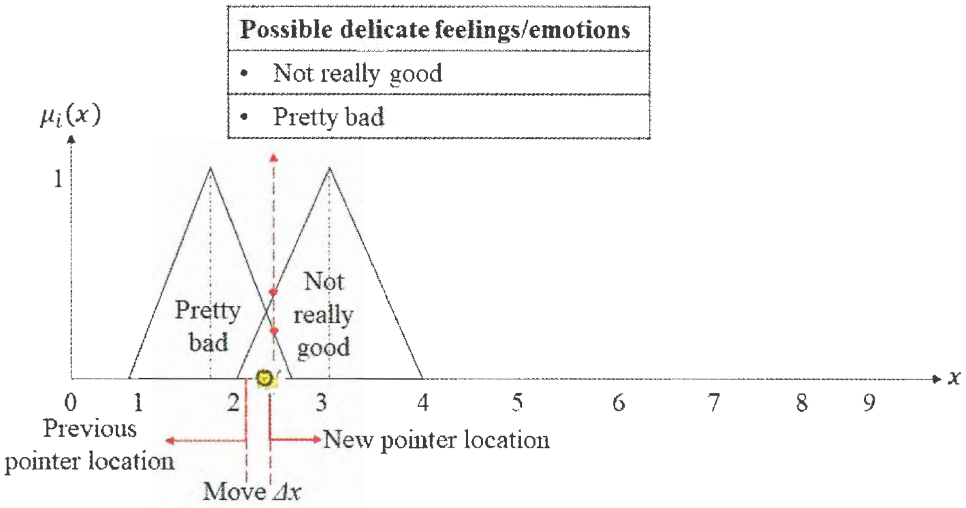


Figure 3.4: After moving the pointer Δx, the new pointed location and corresponding delicate feelings or emotions

Table 3.2: Delicate feelings or emotions to convey physical conditions and tiredness

Feelings or emotions about	Delicate feelings	
	Worst to usual	**Usual to best**
Physical condition	Very bad	Very good
	Pretty bad	Pretty good
	Not really good	A fairly good
	A little bad	A little good
Tiredness	Quite tired	Not a little tired
	Very tired	Not tired at all
	A Somewhat tired	Not so tired
	A little tired	Not very tired

3.4 Case Study to Identify Interaction Problems and to Convey Delicate Feelings or Emotions

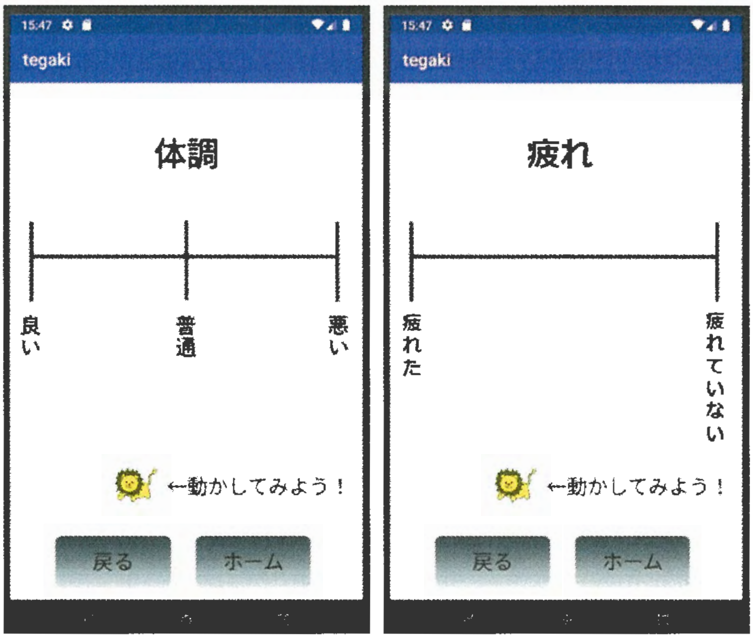
A case study was conducted with survey questionnaires from two aphasia individuals for social inclusion. An existing prototype has shown them which are used to convey feelings or emotions for physical condition and tiredness. The aphasia individuals answered the survey questions based on this prototype. We asked aphasia individuals through a survey questionnaire how much they can convey others about feelings or emotions, physical condition, and tiredness. The purpose of the survey questionnaire was to identify the interaction problems for social inclusion. The interaction problems are identified based on the responses from two aphasia individuals. We also asked the aphasia individuals about their delicate feelings or emotions with another survey Questionnaires for the redesign of Inclusive Design. Finally, the prototype will be improved by solving the interaction problem through redesign.

Table 3.3: Survey questionnaires for social inclusion

No.	Questions to convey feelings	Please circle the corresponding item			
1	How much can you convey your delicate feelings or emotions to others?	1 Can do well	2 Can do some extent	3 can do a little	4 Can not
2	How much can you understand the delicate feelings or emotions of others?	1 Can do well	2 Can do some extent	3 can do a little	4 Can not
3	How much important is it to convey delicate feelings and emotions to others in order to actively participate in society?	1 Very important	2 Somewhat important	3 A little important	4 unimportant
4	How much can you tell your physical conditions to others?	1 Can do well	2 Can do some extent	3 can do a little	4 Can not
5	How much can you understand physical conditions of others?	1 Can do well	2 Can do some extent	3 can do a little	4 Can not
6	How much important is it to convey your physical conditions to others in order to actively participate in society?	1 Very important	2 Somewhat important	3 A little important	4 unimportant
7	How much can you convey your tiredness?	1 Can do well	2 Can do some extent	3 can do a little	4 Can not
8	How much can you understand the tiredness of others?	1 Can do well	2 Can do some extent	3 can do a little	4 Can not
9	How much important is it to convey your tiredness in order to actively participate in society?	1 Very important	2 Somewhat important	3 A little important	4 unimportant

3.4.1 Questionnaires for Identifying User Interaction Problems

We requested cooperation regarding this survey verbally by a meeting and provide a Questionnaires for obtaining the response of the aphasia individuals. Three categories of questions are identified for social inclusion of aphasia. We would like to ask about 1) How much important is it to convey delicate feelings to others in order to actively participate in society? 2) How much can they convey their delicate feelings (about physical conditions, tiredness or emotions) to others? and 3) How much can they understand the feelings of others? The responses of the aphasia individuals are collected using these questionnaires. The questionnaires are shown in Table 3.3. In addition to the questionnaires, an existing prototype of communication support application was provided to aphasia individuals which was completed without using Inclusive Design. The interface of the existing prototype is shown in Figure 3.5.



(a) (b)

Figure 3.5: (a) Interface for conveying physical condition (b) Interface for conveying tiredness

Table 3.4: Responses of survey questionnaires from two aphasia individuals

Categories	Questions	Responses	
		Aphasia individual 1	Aphasia individual 2
Feelings or emotions	Q1	3 (Can do a little)	3 (Can do a little)
	Q2	3 (Can do a little)	3 (Can do a little)
	Q3	2 (Somewhat important)	3 (A little important)
Physical conditions	Q4	2 (Can do some extent)	2 (Can do some extent)
	Q5	4 (Cannot do)	4 (Cannot do)
	Q6	1 (Very important)	3 (A little important)
Tiredness	Q7	2 (Can do some extent)	4 (Cannot do)
	Q8	3 (Can do a little)	4 (Cannot do)
	Q9	1 (Very important)	4 (Unimportant)

3.4.2 Results for Identifying User Interaction Problems

To identify interaction problems, the responses of aphasia individuals (as extreme users) were collected on a numeric Likert value. Two aphasia individuals were participated in survey questionnaires and provide their responses. The first aphasia individual is male, and he is 58 years. He suffered from Broca's aphasia with the problem of memory impairment. He suffered two strokes, one in March 2015 and another in November 2016. He can communicate with others, but his speech is non-fluent. He lives at home with his wife and children. The second aphasia individual is also male, he is 40 years. He suffered from stroke at February 2018. He lives with his mother. He can communicate with others with a little fluent speech by rehabilitation. Thus, he returned to his job. From the point of view of second aphasia individual, this communication support application will be useful to more severe aphasia individuals than him. The response of survey questionnaires for social inclusion from two above aphasia individuals is shown in Table 3.4.

3.4.3 Discussions for Identifying User Interaction Problems

The first aphasia individual responded that it was important to some extent for him to convey delicate feelings or emotions to others. He can communicate with others, but his speech is non-fluent. It was also very important for him to convey his physical conditions and tiredness to others in order to actively participate in society. He could convey his physical conditions and tiredness some extent to others. He could understand a little the tiredness, but could not physical conditions of others. He also has memory impairment with Broca's aphasia. He needs supports to convey his physical conditions and tiredness to others. Nevertheless, he cannot recall sometimes any words in his communication due to memory impairment and symptoms of Broca's aphasia. As a result, he cannot express his delicate feelings properly by his own voice. He has recovered his communication abilities by his efforts and supports from SLT and his family. However, he will be more included in the society by conveying his physical conditions and tiredness more properly to others with his delicate feelings or emotions.

The second aphasia individual was milder than the first one. He can communicate with others with a little fluent speech, and he has returned to his job by rehabilitation. Therefore, it was less important for him to convey his physical conditions and tiredness to others and to understand physical conditions and tiredness of others. Nevertheless, he responded that his delicate feelings or emotions could be conveyed to others in his daily life. He has already been included in the society compared with the first aphasia individuals by his continuous efforts and supports from SLT and families. However, he will be more included in the society by conveying his delicate feelings or emotions to others by inclusive design.

3.5 Case Study for Redesign to Convey Delicate Feelings or Emotions

This section describes the redesign of the prototype for conveying delicate feelings for physical condition and tiredness by using identified user interaction problems.

Table 3.5: Survey requests to convey delicate feelings or emotions for physical condition

① Please mark the area between "good physical condition" and "bad physical condition" that applies to 'a little good' physical condition. bad — usual — good
② Please mark the area between "good physical condition" and "bad physical condition" that applies to 'a little bad' physical condition. bad — usual — good
③ Please mark the area between "good physical condition" and "bad physical condition" that applies to 'fairly good' physical condition. bad — usual — good
④ Please mark the area between "good physical condition" and "bad physical condition" that applies to 'not really good' physical condition. bad — usual — good
⑤ Please mark the area between "good physical condition" and "bad physical condition" that applies to 'very good' physical condition. bad — usual — good
⑥ Please mark the area between "good physical condition" and "bad physical condition" that applies to 'very bad' physical condition. bad — usual — good
⑦ Please mark the area between "good physical condition" and "bad physical condition" that applies to 'pretty good' physical condition. bad — usual — good
⑧ Please mark the area between "good physical condition" and "bad physical condition" that applies to 'pretty bad' physical condition. bad — usual — good

Table 3.6: Survey requests to convey delicate feelings or emotions for tiredness

① Please mark the area between "tired" and "not tired" that applies to 'a little tired'.	tired	Not tired
② Please mark the area between "tired" and "not tired" that applies to 'not too tired'.	tired	Not tired
③ Please mark the area between "tired" and "not tired" that applies to 'somewhat tired.	tired	Not tired
④ Please mark the area between "tired" and "not tired" that applies to 'not so tired'.	tired	Not tired
⑤ Please mark the area between "tired" and "not tired" that applies to 'very tired'.	tired	Not tired
⑥ Please mark the area between "tired" and "not tired" that applies to 'not tired at all'.	tired	Not tired
⑦ Please mark the area between "tired" and "not tired" that applies to 'quite tired'.	tired	Not tired
⑧ Please mark the area between "tired" and "not tired" that applies to 'not a little tired'.	tired	Not tired

3.5.1 Questionnaires to Convey Delicate Feelings or Emotions

Only the first aphasia individual pointed on the analog scale for conveying delicate feelings for physical condition and tiredness. Currently, the first aphasia participant cannot convey properly his delicate feelings or emotions to others. It is important for him to convey physical condition and tiredness with his delicate feelings or emotions to others. Since he is a non-fluent speaker, he expects to convey delicate feelings or emotions to others with a voice. Therefore, we would like to ask the first aphasia individual about his delicate feelings or emotions with another survey questionnaires for the redesign of Inclusive Design. The survey requests are shown in Table 3.5 and Table 3.6. We asked aphasia individual to point out his following delicate feelings or emotions using a survey questionnaire 1) physical conditions between 'usual' and 'good' (e.g. 'a little good', 'fairly good', 'very good' and 'pretty good'); 2) physical conditions between 'bad' and 'usual' (e.g. 'a little bad', 'not really good', 'very bad' and 'pretty bad'); and 3) tiredness between 'tired' and 'not tired' (e.g. 'a little tired', 'not too tired', 'somewhat tired', 'not so tired', 'very tired', 'not tired at all', 'quite tired' and 'not a little tired'). The responses of the first aphasia individuals were collected on the analog scale of each question.

3.5.2 Results of Questionnaires to Convey Delicate Feelings or Emotions

The first aphasia individual pointed on the analog scale of the questionnaires as shown in Table 3.5 and Table 3.6 to convey his feelings or emotions for physical condition and tiredness between best and worst condition. According to his pointed location on the analog scale, the fuzzy representation for physical conditions and tiredness is shown in Figure 3.6 and Figure 3.7.

According to the aphasia participant as shown in Figure 3.6, the delicate feelings or emotions 'very bad' for the physical condition will take the first position between bad and usual condition. He pointed the delicate feelings or emotions 'not really good' and 'pretty bad' in a very close location on the analog scale. The delicate feelings or emotions 'not really good' and 'pretty bad' take places respectively after the 'very bad' position. Next, he thinks that 'a little bad' is close to usual condition and thus he pointed it as a neighbor of usual. He thinks that 'pretty good' and 'very good' are close and he pointed

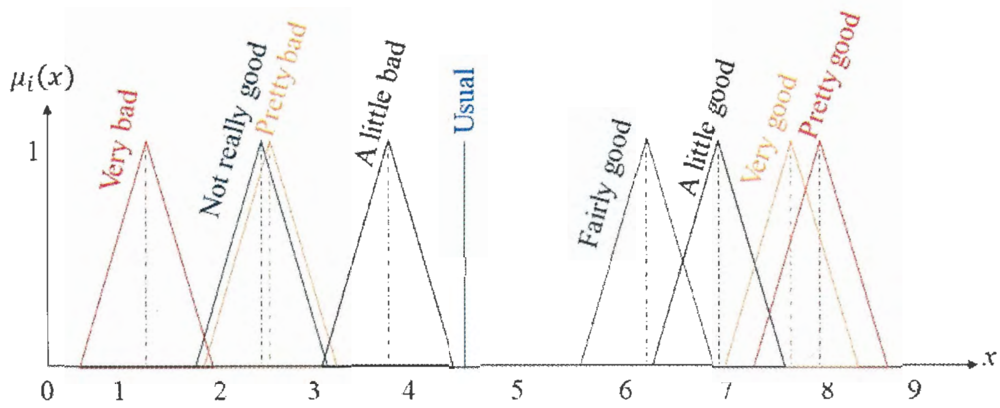


Figure 3.6: Delicate feelings or emotions in triangular fuzzy form to convey physical conditions

'pretty good' and 'very good' respectively on the last two position. He also thinks that 'fairly good' is the neighbor of usual condition, thus he pointed 'fairly good' after the usual condition and he pointed 'a little good' beside the 'fairly good' delicate feelings or emotions.

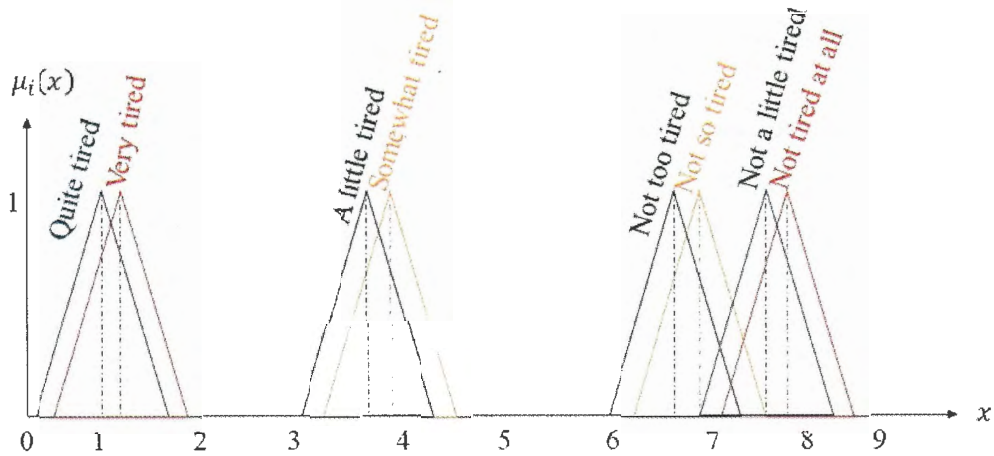


Figure 3.7: Delicate feelings or emotions in triangular fuzzy form to convey tiredness

The aphasia participant also pointed location on the analog scale to convey the delicate feelings or emotions for tiredness to others as shown in Figure 3.7. He thinks that 'quite tired' and 'very tired' are very close and he pointed location

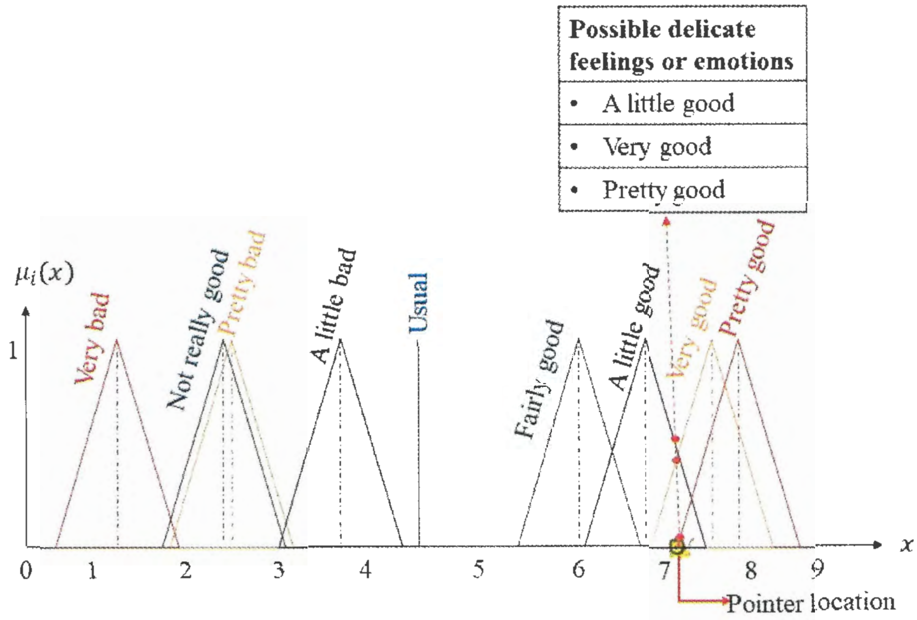


Figure 3.8: Pointed location and corresponding delicate feelings or emotions for conveying physical conditions

'quite tired' in the first place then place 'very tired'. He then pointed location for the delicate feelings 'a little tired' and 'somewhat tired' almost middle of analog scale respectively. He pointed location on the analog scale for 'not tired at all' in the last position. The delicate feelings or emotions 'Not a little tired' is pointed too close as 'not tired at all'. Finally, he pointed the delicate feeling or emotions 'not too tired' and 'not so tired' far from 'somewhat tired' and near the place 'not a little tired'. He thinks that 'not too tired' and 'not so tired' are very close to him to convey tiredness.

3.5.3 Conveying Delicate Feelings or Emotions by Fuzzy-set Theory

Aphasia participant would like to convey his physical conditions and tiredness with delicate feelings or emotions to others. They are represented by analog scale in triangular fuzzy form as shown in Figure 3.6 and Figure 3.7.

When aphasia individuals point an area between 'very bad' and 'very good' physical condition, then the possible candidate of delicate feelings or emotions for physical conditions are selected based on the pointed location. In the case of Figure 3.8, if an area among three triangular forms is pointed, possible candidate of delicate feelings or emotions and their order is regarded as 'A little good', 'Very good' and 'Pretty good'. If aphasia participant moves the pointed location to $x+\Delta x$, his delicate feelings or emotions and order are changed to 'Very good', 'A little good' and 'Pretty good' as shown in Figure 3.9.

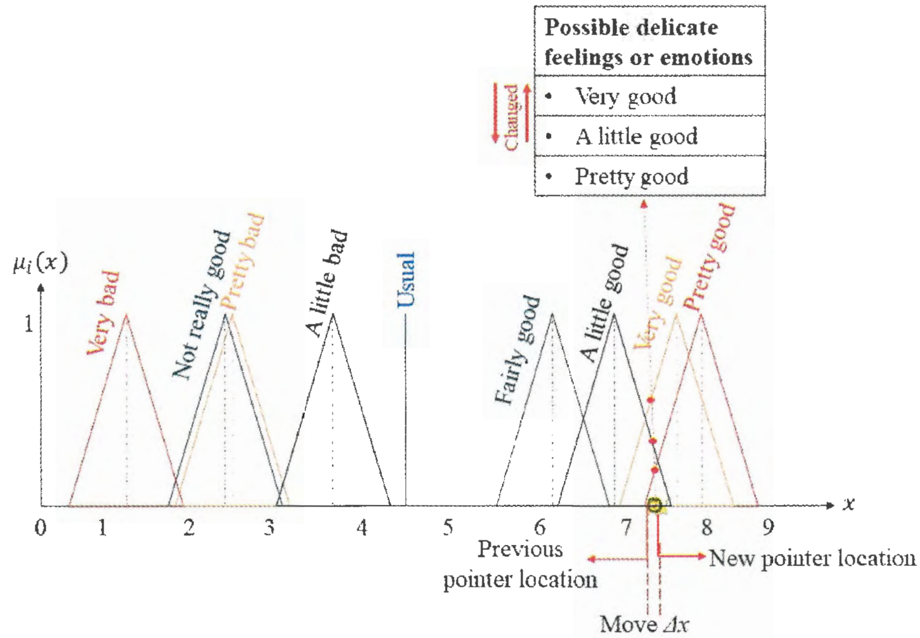


Figure 3.9: After moving the pointer Δx, the new pointed location and corresponding delicate feelings or emotions for conveying physical conditions

In the same way, when aphasia individuals point an area between 'tired' and 'not tired' in tiredness, then the possible candidate of delicate feelings or emotions for tiredness are selected based on the pointed location. In the case of Figure 3.10, if an area among two triangular forms is pointed, possible candidates of delicate feelings or emotions are regarded as 'Very tired' and 'Quite tired'. If aphasia participant moves the pointed location to $x+\Delta x$, his delicate feelings or emotions are changed to 'A little tired' as shown in Figure 3.11.

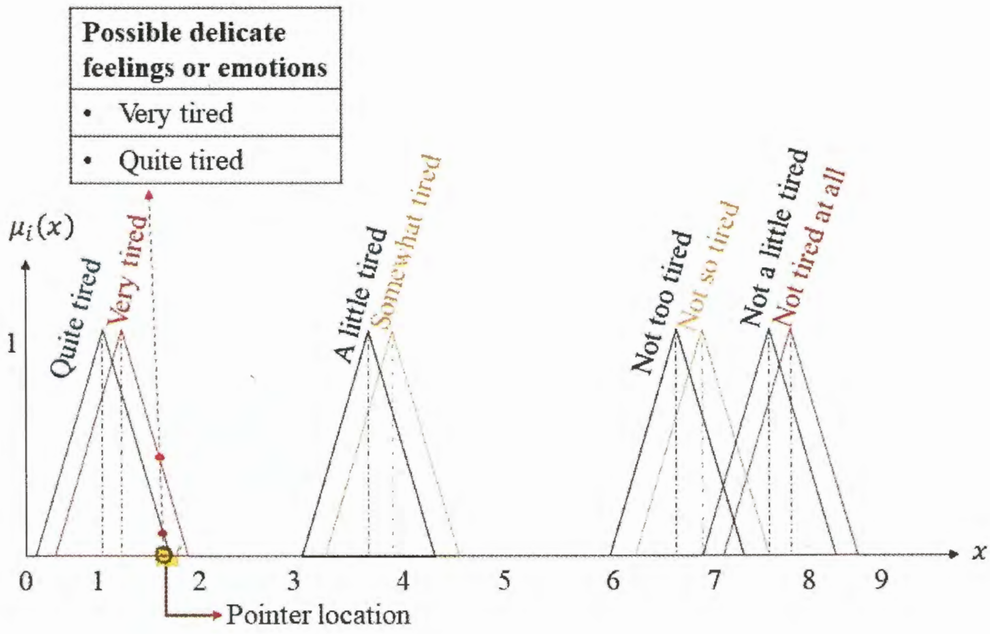


Figure 3.10: Pointed location and corresponding delicate feelings or emotions for conveying tiredness

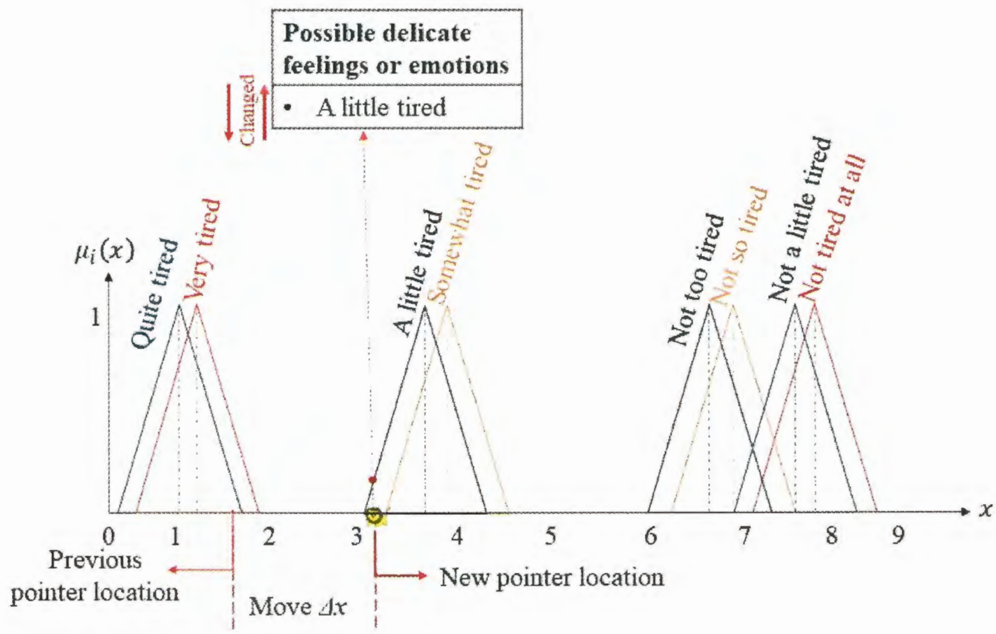


Figure 3.11: After moving the pointer Δx, the new pointed location and corresponding delicate feelings or emotions for conveying tiredness

(a) (b)

Figure 3.12: (a) Improved interface for physical condition (b) Improved interface for tiredness

Fuzzy-set theory can help us to manage these delicate feelings or emotions for physical condition and tiredness as shown in Table 3.2. After redesigning the solution, the possible delicate feelings or emotions for physical condition and tiredness can be selected according to the pointed location.

3.5.4 Improvement of Design Solutions

The interfaces of the existing prototype as shown in Figure 3.5 can be improved by the Fuzzy-set theory to convey delicate feelings or emotions as shown in Figure 3.12. To improve the prototype, the pointed location is used to support the aphasia participant who want to convey his delicate feelings or emotions to others. His pointed location on analog scale to convey his delicate feelings for physical conditions and tiredness are shown in Figure 3.6 and Figure 3.7.

The delicate feelings or emotions will be displayed based on the pointed location on the analog scale of the improved prototype for case study as shown in Figure 3.13 and Figure 3.14. For example, aphasia participant feels 'Pretty bad' and he wants to convey his delicate feelings or emotions to others based on his difficulties. Thus, he points an area between 'bad' and 'good' physical conditions, then the possible candidates of delicate feelings or emotions are selected based on the pointed location as shown in Figure 3.13 (a). The possible candidates of delicate feelings or emotions and their order are regarded as 'Not really good' and 'Pretty bad' for the pointed area as shown in Figure 3.13 (a). His desired candidate 'Pretty bad' is placed in the second position on the candidate list. For this reason, he wants to display the list in a more accurate manner. Therefore, aphasia participant moves the pointed location for 'Pretty bad' to $x+\Delta x$ to adjust his delicate feelings or emotions and the order of delicate feelings or emotions are changed to 'Pretty bad' and 'Not really good' as shown in Figure 3.13 (b). In this way, he gets the desired delicate feelings or emotions at the top of the list.

Furthermore, aphasia participant feels 'Not too tired' and he wants to convey his delicate feelings or emotions to others based on his difficulties. Thus, he points an area between 'tired' and 'not tired' for tiredness, then the possible candidates of delicate feelings or emotions for tiredness are selected based on the pointed location as shown in Figure 3.14 (a). The possible candidates of delicate feelings or emotions are regarded as 'Not so tired' and 'Not too tired' for the pointed area as shown in Figure 3.14 (a). He found that the list of possible delicate feelings or emotions do not have his desired item. Therefore, aphasia participant moves the pointed location for 'Not too tired' to $x+\Delta x$ to adjust his desire delicate feelings or emotions, the delicate feelings or emotions are changed to 'Not too tired' and 'Not so tired' respectively as shown in Figure 3.14 (b). Now, he gets his desired delicate feelings or emotions to convey the tiredness.

3.5.5 Evaluation Process after Redesign for Social Inclusion

The evaluation of redesign was performed by the first aphasia individual who identify interaction problems and provides his insights for the redesign. In this

(a) (b)

Figure 3.13: (a) Conveying delicate feelings or emotion for physical conditions to others (b) After moving the pointer Δx to adjust his delicate feelings or emotions for physical conditions

connection, interfaces of the prototype as shown in Figure 3.5 (a), Figures 3.12 (a) and 3.13 for physical condition after the redesign and before the redesign were provided to the first aphasia individual for evaluation. We asked his opinions through survey questionnaires about the improved interfaces after the redesign compared to before the redesign. He responded the survey questionnaires using these interfaces to convey and understand his delicate feelings or emotions for physical conditions for sufficient communication.

For social inclusion of the first aphasia individual after the redesign, the responses for the questionnaires were collected on a percentage scale (0 to 100). 100% means that he can completely convey and understand the delicate feelings or emotions to participate in society after the redesign. 0% means that his level of conveying and understanding for delicate feelings or emotions did not improve after the

(a) (b)

Figure 3.14: (a) Conveying delicate feelings or emotion for tiredness to others (b) After moving the pointer Δx to adjust his delicate feelings or emotions for tiredness

redesign.

The questionnaires were designed in two categories. The first category was for the quantitative opinions of the first aphasia individual to convey delicate feelings or emotions for physical conditions. We asked about 1) How much properly can you convey to others using the improved interfaces after the redesign compared to before the redesign? 2) How much more can you actively participate in society using the improved interfaces after the redesign compared to before the redesign? The second category was for the quantitative opinions for understanding delicate feelings or emotions for physical conditions. We asked about 1) How much properly can you understand the physical conditions of others using the improved interfaces after the redesign compared to before the redesign? 2) How much properly can others understand your physical conditions using the improved interfaces after the redesign compared to before the redesign? In addition to these above questions, open-ended questions were also attached to each question. The questionnaires are shown in Table 3.7. The responses were collected from the first aphasia individuals with these questionnaires. On the basis of his responses, it is easily determined which interfaces can sufficiently include him in society.

Table 3.7: Survey requests to evaluate the redesign for social inclusion

1-1. How much properly can you convey your physical conditions to others using the improved interfaces after the redesign compared to before the redesign?	
I can convey all my feelings with the improved application 100%	It is the same as the previous application even if I use the improved application 0%
100 90 80 70 60 50 40 30 20 10 0	
1-2. What should you do to properly convey your physical conditions to others using the improved interfaces after the redesign compared to before the redesign?	
2-1. How much more can you actively participate in society by conveying delicate feelings or emotions for physical conditions to others using the improved interfaces after the redesign compared to before the redesign?	
I can participate in everything with the improved application 100%	It is the same as the previous application even if I use the improved application 0%
100 90 80 70 60 50 40 30 20 10 0	
2-2. What should you do to actively participate more in society by conveying delicate feelings or emotions for physical conditions to others using the improved interfaces after the redesign compared to before the redesign?	
3-1. How much properly can you understand the physical conditions of others using the improved interfaces after the redesign compared to before the redesign?	
I can understand everything with the improved application 100%	It is the same as the previous application even if I use the improved application 0%
100 90 80 70 60 50 40 30 20 10 0	
3-2. What should you do to properly understand the physical conditions of others using the improved interfaces after the redesign compared to before the redesign?	
4-1. How much properly can others understand your physical conditions using the improved interfaces after the redesign compared to before the redesign?	
I can understand everything with the improved application 100%	It is the same as the previous application even if I use the improved application 0%
100 90 80 70 60 50 40 30 20 10 0	
4-2. What should others do to understand your physical conditions properly using the improved interfaces after the redesign compared to before the redesign?	

3.5.6 Evaluation Results for Social Inclusion

As shown in Table 3.8, the first aphasia individual responded that he could properly convey 50% delicate feelings or emotions for the physical conditions to others with the improved interfaces after the redesign compared to before the redesign. He also believed that he could actively participate in society 30% by conveying delicate feelings or emotions to others with the improved interfaces after the redesign. Moreover, he could properly understand 70% delicate feelings or emotions of others with the improved application after the redesign. Furthermore, he thought that others could understand 70% of his delicate feelings or emotions with the improved interfaces after the redesign. He suggested that the delicate feelings or emotions could be conveyed more if all the delicate feelings or emotions could be displayed at once based on his pointed location on the analog scale. The response of survey questionnaires after the redesign for social inclusion from the first aphasia individual are shown in Table 3.8.

Table 3.8: Responses of survey questionnaires for social inclusion after the redesign from the first aphasia individual

Categories	Questions	Responses
Conveying delicate feelings or emotions for physical condition to others	1-1	I can properly convey 50% delicate feelings or emotions to others
	2-1	I can actively participate in society 30% by conveying delicate feelings or emotions to others
Understanding delicate feelings or emotions for physical condition of others	3-1	I can properly understand 70% delicate feelings or emotions of others
	4-1	Others can understand 70% of my delicate feelings or emotions

3.5.7 Discussion

The first aphasia individual can be more included in society by the delicate feelings or emotions for physical conditions through the improved interfaces after the redesign based on the Fuzzy-set theory compared to before the redesign as shown in Table 3.8. According to his responses as shown in Table 3.8, he can 30% actively participated in society by conveying delicate feelings or emotions for physical conditions because it is related to his situations and the improved interfaces of the physical conditions after the redesign. He suffered from Broca's aphasia with the problem of memory impairment caused by two strokes. He can communicate with others, but his speech is non-fluent because he cannot process the languages properly in his brain. Although he could convey his delicate feelings or emotions for physical conditions to some extent to others during communication, his expressions were not understood properly by others. Due to the memory impairment and the language processing problems of Broca's aphasia, he cannot recall sometimes any words/proper words in his communication. As a result, he cannot express his delicate feelings or emotions properly to others by his own voice. However, he has somewhat included in society through his limited communication abilities, and with the support of SLT and his family. He can be more included in society by conveying his physical conditions more properly to others with his delicate feelings or emotions. In this connection, the contribution of redesign was to include his insights through Fuzzy-set theory for sufficient communication. It is noted that the insights of the first aphasia individual were delicate feelings or emotions in this study. He identified delicate feelings or emotions for physical conditions with a fuzzy membership function based on a survey questionnaire. After the redesign, delicate feelings or emotions were expressed as a scale, and candidate(s) of delicate feelings or emotions were shown based on his specified position x in the design solution. If the candidate(s) was unable to properly express his delicate feelings or emotions, then the function of conveying the delicate feelings and emotions can be realized by controlling the position of the fuzzy membership function from x to x+Δx or x-Δx. The position of delicate feelings or emotions was difficult to control without the help of Fuzzy-set theory. As a result, he can be more included in society by conveying his delicate feelings or emotions through the improved interfaces after the redesign based on the Fuzzy-set theory than before the redesign.

The first aphasia individual cannot properly convey his own thinking to others because he was Broca's non-fluent aphasia. He had no problems with hearing and understanding, but it was difficult to him to speak the contents of communication. The difficulty of speaking become the barrier of his social inclusion before the redesign. He could convey delicate feelings or emotions for physical conditions in some extent for his barrier before the redesign as shown in Table 3.4. In this connection, interfaces for physical conditions using smartphone applications before and after the redesign have been evaluated. The experimental result showed that the social participation of the target aphasia individual can be improved by 30% after the redesign as shown in Table 3.8. This improvement was found after the redesign because the possible candidate(s) of delicate feelings or emotions were shown using Fuzzy-set theory based on the priority. The order of candidate(s) of delicate feelings or emotions are changed after managing the Δx. Although he had memory impairment, he could recall delicate feelings or emotions without difficulty because of this priority management. The management of candidate(s) of delicate feelings or emotions was very helpful to him because it became a supporter for him. Consequently, he can convey 50% of his delicate feelings or emotions for physical conditions with the improved interfaces after the redesign as shown in Table 3.8. Therefore, Fuzzy-set theory contributed to improving social participation by properly conveying the delicate feelings or emotions to others. However, 30% active participation in society is not a high value. The reason of low participation in society is caused by his difficulty of conveying delicate feelings or emotions. In low social participation, the contribution of conveying of his delicate feelings or emotions is greater than that of understanding them. This contribution of conveying enables him to express his own thinking to others.

However, actively participation in society of aphasia individual can be improved from 30% by considering other factors of social inclusion. Dalemans et al. mentioned that the social participation is influenced by personal, social and environmental factors [112]. Personal factors are related to personal characteristics of aphasia individuals such as tiredness, pain, stress and communication skills. The social factors are the role of the SLT, family members and the characteristics of the communication partner(s), namely willingness, skills and knowledge. The environmental factors refer to quietness and familiarity of the place in which the person with aphasia live [112, 113]. In this study, only one factor was considered for social inclusion which is delicate feelings or emotions. In that sense, using the factor delicate feelings or emotions, 30% is a considerable result for actively participating in society with the improved interfaces after the redesign. Thus, the participation of aphasia individuals in the society can be improved from 30% if the insights of aphasia individuals related to the above-mentioned factors are included through the redesign.

4 Expansion of Design Solution of Inclusive Design Supported by Soft Computing Methods

Design solutions through the redesign processes of inclusive design can only include those aphasia individuals in society who have similar difficulties as extreme users. In that case, the aphasia individuals who have different difficulties cannot be included in society by the design solution of inclusive design. Consequently, more aphasia individuals are still excluded from society. In this point, it is necessary to support the expansion process of inclusive design. To include more aphasia individuals in society, the opinions of different aphasia individuals should be included through expansion of inclusive design. To achieve this goal, it is necessary to include the diverse opinions of aphasia individuals during the customer requirements (CRs) specification for social inclusion. The reason is that the importance of requirements of the social inclusion can only be identified by aphasia individuals. Then, it should be fitted to their capabilities. In that case, inclusion of their opinions is a way to include aphasia individuals in the society. Therefore, this study proposes a new method for prioritizing CRs to expand the design solution for inclusion of more aphasia individuals as well as others people in society. The idea of the expansion is shown in Figure 4.1.

Due to the communication difficulties of aphasia individuals, they cannot express their opinions properly to identify the importance of requirements for social inclusion based on their difficulties. In that case, voting is a way to include their opinions. In this study, voting is used to include diverse wants or needs of aphasia individuals in their daily activities. In addition, this study uses fuzzy-AHP so that SLT knowledge can be included to support ambiguous opinions from aphasia individuals in their communication difficulties. Therefore, a hybrid method using voting and fuzzy-AHP is proposed for requirements

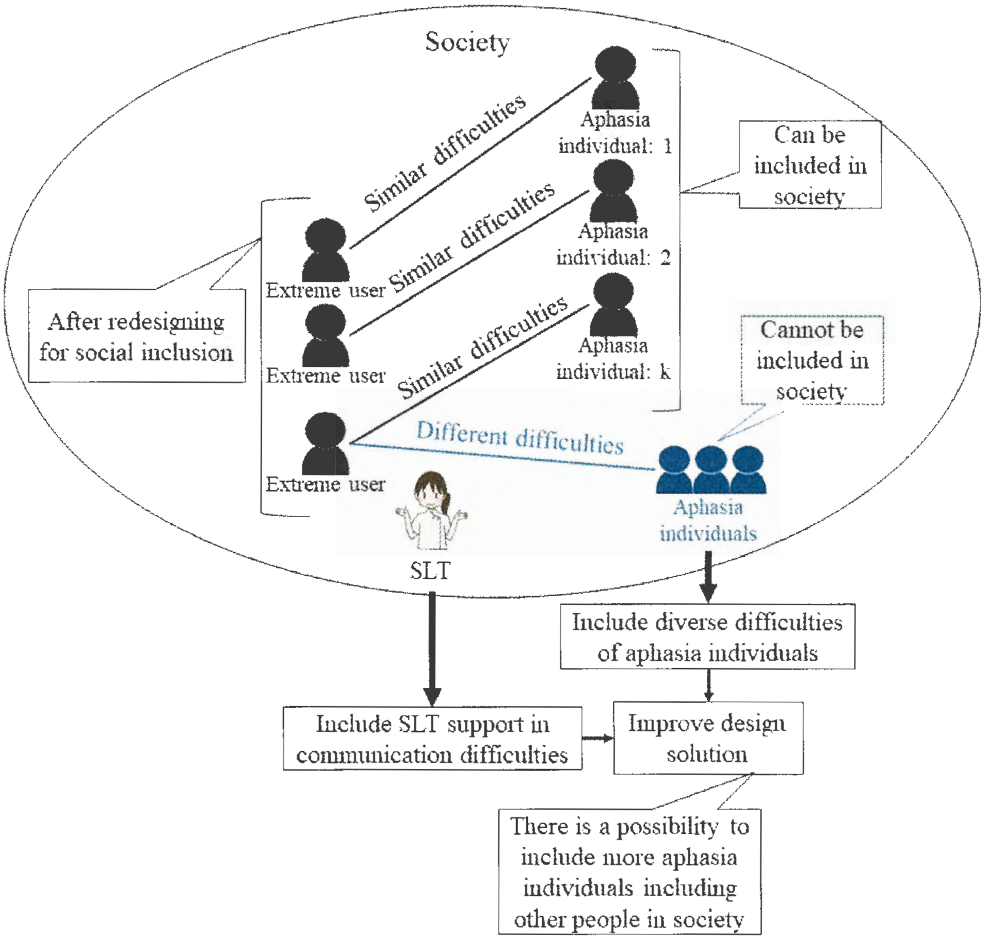


Figure 4.1: Expansion of design solution to include more aphasia individuals in society

prioritization to include more difficulties of aphasia individuals and SLT knowledge. As a result, more aphasia individuals including other people can be included in the society based on their difficulties. Furthermore, a case study is conducted to check the effectiveness of the proposed hybrid method for CRs prioritization. In the case study, 49 individuals with aphasia participated in the voting process.

Table 4.1: Linguistic values for requirements

Requirements	**Customer vote**		
	C_1	...	C_k
CR_1	VL	...	H
...	...	...	...
CR_n	L	...	VH

4.1 Soft Computing Methods to Support Expansion of Inclusive Design

This section represents the proposed hybrid methods using voting and fuzzy-AHP for requirements prioritization to include more difficulties of aphasia individuals and SLT knowledge.

4.1.1 Inclusion of Diverse Difficulties of Aphasia Individuals by Linguistic Voting

This study adopts linguistic voting to include diverse difficulties of aphasia individuals. A linguistic voting technique will be integrated into fuzzy-AHP to consider not only the SLT evaluations, but also the aphasia individuals' opinions on the CRs. In this connection, the target Aphasia Individuals are asked to assign four levels of importance for each CR as very low (VL), low (L), high (H), and very high (VH). A matrix is constructed that includes all CRs and it is filled with the CR vote from each user k as shown in Table 4.1.

Each linguistic vote provided by the target users is counted. The vote-counting matrix V is presented in Table 4.2.

4.1.2 Inclusion of SLT Knowledge to Support Aphasia Individuals by Fuzzy-AHP

SLT knowledge is included by fuzzy-AHP to support aphasia individuals in communication difficulties. SLT has knowledge to include ambiguity and diverse opinions from aphasia individuals. Aphasia individuals have diverse opinions based on their difficulties. They should be included in requirement prioritization for social inclusion. SLT can judge and prioritize the importance of such requirements by their professional knowledge to speech language impairments. In this study, SLT knowledge is included through the pairwise comparison of importance of each requirement. Thus, inclusion of the opinions of SLT is important to improve the daily activities of aphasia individuals. To evaluate the weight using fuzzy-AHP, SLT used the Saaty's pairwise comparison matrix shown in Table 2.4 [88]. The pairwise comparison matrix is expressed in Equation (4.1), where $\tilde{CR}_{ij}$ indicates the SLT's preference of the i-th criterion over the j-th criterion, via fuzzy triangular numbers.

$$\tilde{A} = \begin{bmatrix} (1,1,1) & \cdots & \widetilde{CR}_{1n} \\ \vdots & \ddots & \vdots \\ \widetilde{CR}_{n1} & \cdots & (1,1,1) \end{bmatrix} \tag{4.1}$$

SLT knowledge should be included to identify a fuzzy membership function. Aphasia individuals face difficulties to identify a fuzzy membership function

Table 4.2: Linguistic vote count for requirements

Requirements	**Linguistic terms**			
	VL	**L**	**H**	**VH**
CR_1	1	2	1	0
...	...	...	...	...
CR_n	0	1	1	2

because they cannot convey their opinions to others by ambiguous expressions and diverse difficulties. In this study, SLT identified the fuzzy membership function as Figure 4.2. SLT designs the VL and VH levels of importance of the fuzzy triangular set narrower than the others because disabled individuals can easily overestimate the importance of these two fuzzy sets. On the other hand, SLT considered that the fuzzy triangles for L and H should be wider than those of VL and VH. The characteristics of the triangular fuzzy set membership function were suggested by SLT as VL= 0, 0.5, 1, L= 0.5, 3, 5.5, H= 4.5, 7, 9.5, and VH= 9, 9.5, 10, as shown in Figure 4.2.

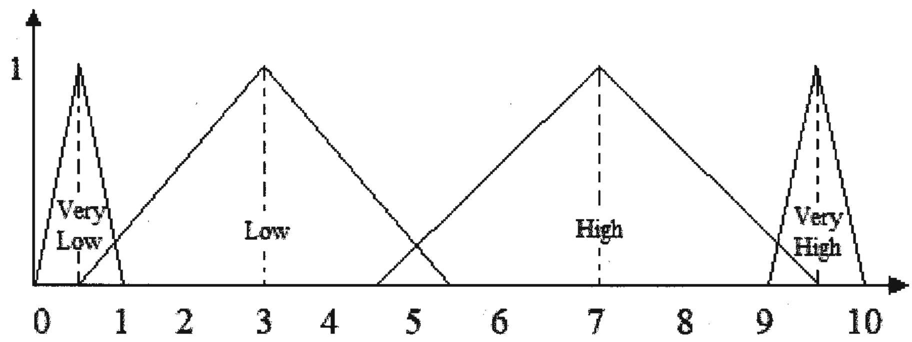


Figure 4.2: Membership function for Preference importance suggested by SLT

4.1.3 Flow Diagram of Requirements Prioritization to Include More Difficulties

A flow chart of the proposed method is shown in Figure 4.3. The starting point of the flow chart consists of determining the CRs, and then performing two tasks: CR voting and fuzzy-AHP, to evaluate the partial weight. After obtaining the partial weight from the fuzzy-AHP, we combined this value with the CR vote shown in Figure 4.3. This is followed by defuzzification to obtain the final weight, according to which we rank the CRs.

4.1.4 Detailed Description of the Flow Diagram

This section describes the details of each step in the flow diagram.

Step 1: n CRs are determined with the help of an SLT.

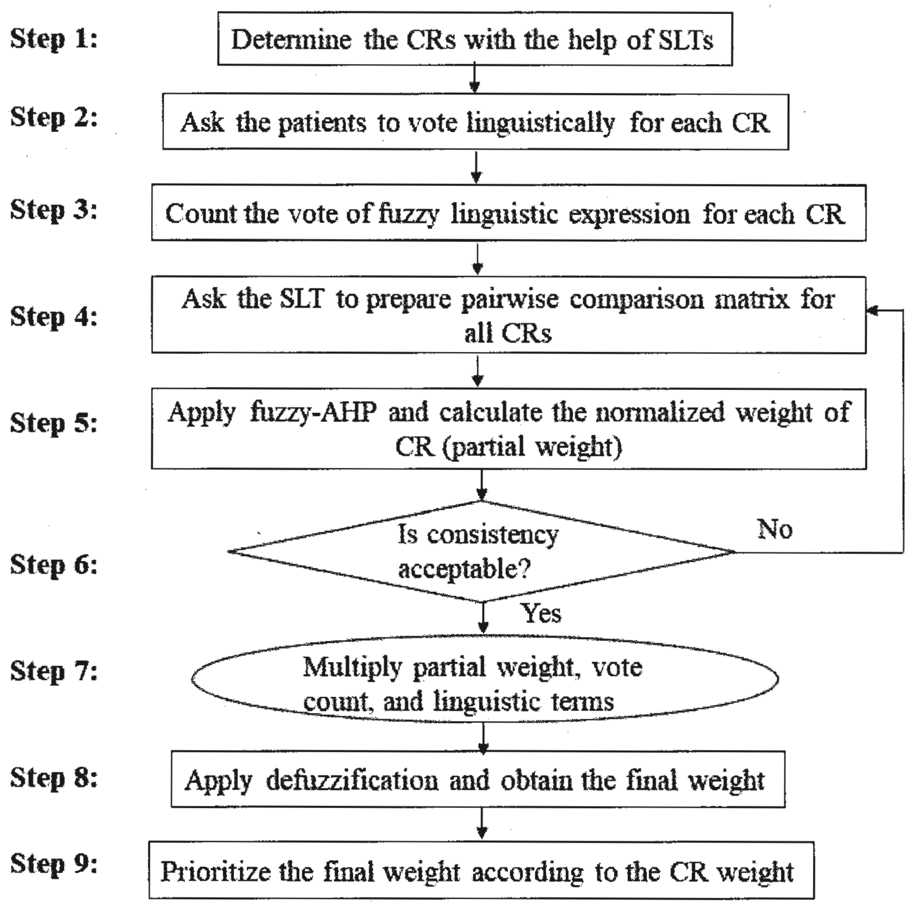


Figure 4.3: Flow diagram of the hybrid proposed technique for prioritizing requirements

Step 2: The linguistic votes are collected from extreme users. Then vote matrix is constructed that includes all CRs and it is filled with the CR vote from each user k, as shown in Table 4.1. After that we expressed these votes in the level of importance as a triangular fuzzy membership function, as shown in Figure 4.2.
Step 3: Each linguistic vote provided by the target users was counted. The vote-counting matrix V is presented in Table 4.2.
Steps 4 and 5: The partial weight is evaluated for each CR using fuzzy-AHP. To evaluate the weight using fuzzy-AHP, a pairwise comparison of all CRs by the SLT was needed. The pairwise contribution matrix is expressed in Equation (4.1); where, $\tilde{CR}_{ij}$ indicates the SLT's preference of the i-th criterion over the

j-th criterion, via fuzzy triangular numbers.

According to Buckley [95], the geometric mean of the fuzzy comparison values for each criterion is calculated using Equation (4.2); where $\tilde{r}_i$ represents the triangular values.

$$\tilde{r}_i = \left(\prod_{j=1}^{n} \widetilde{Pr}_{ij} \right)^{1/n}, \quad i=1,\ 2,\ldots,\ n \tag{4.2}$$

The fuzzy weights of each criterion can be determined using Equation (4.3). First, the vector summation of each $\tilde{r}_i$ value, and the (-1) power of the summation vector are determined. The fuzzy triangular number is then replaced such that its order is increased. To find the fuzzy weight of criterion i $(\tilde{W}_i)$, we multiply each $\tilde{r}_i$ by the following reverse vector:

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \ldots \oplus \tilde{r}_n)^{-1} = (lw_i, mw_i, uw_i) \tag{4.3}$$

Operator $\otimes$ is used for multiplication of matrix and operator $\oplus$ is used for summation of matrix. $\tilde{w}_i$ represents the fuzzy triangular numbers; therefore, we have to apply defuzzification, as expressed using Equation (4.4).

$$M_i = \frac{lw_i + mw_i + uw_i}{3} \tag{4.4}$$

Here, M_i is a non-fuzzy number normalized using Equation (4.5).

$$CR_{i(Norm)} = \frac{M_i}{\sum_{i=1}^{n} M_i} \tag{4.5}$$

Step 6: After calculating the partial weight using Equation (4.5), consistency analysis is performed to avoid judgment error [98].
Step 7: After assessing the partial CR weight, we multiplied this weight by the CR voting and corresponding linguistic value. Equation (4.6) is used to calculate the final weight; where j, V, and L represent the number of linguistic terms, vote count, and linguistic values, respectively.

$$\widetilde{CR}_i = \sum_{j=1}^{4} CR_i(Norm) \times V_{ij} \times L_i \tag{4.6}$$

Step 8: The output of Equation (4.6) is also a fuzzy number that requires defuzzification. Therefore, we applied Eqs. (4.4) and (4.5) to obtain the final value of the weight.
Step 9: Finally, we used this CR weight to rank the customer requirements.

4.2 Case Study for Requirement Prioritization Based on the Proposed Soft Computing Methods

We present a case study on the prioritization of CRs in a communication support application aimed to assist individuals with aphasia. The requirements vary for each individual. This case study was completed to check the effectiveness of proposed soft computing method. Although the communication support application was not designed using inclusive design, the proposed method satisfied more aphasia individuals. In this point, if we use the proposed method in inclusive design for social inclusion, it will satisfy more aphasia individuals including other people.

This case study involved 49 individuals with aphasia to determine the importance of different requirements. Their ages ranged between 34 and 85 years. Among them, 36 were male and 13 were female. They had experienced aphasia for 1 to more than 30 years due to stroke or head injury. They were released from medical care at an acute stage and had received rehabilitation from speech-language therapists. They spend their lives at their homes with support from their family, but their daily activities are affected by their symptoms and physical conditions. Their language abilities are not enough to perform daily activities independently.

This case study was approved by the ethical committee of Kanagawa University. Informed consent and written permission were obtained from these people before their participation in the survey.

4.2.1 Requirement Identification

The SLT determines 10 requirements in Step 1 of Figure 4.3 for the communication support application listed in Table 4.3.

Table 4.3: Requirements in their daily communications

	Details
CR1	Picture card for daily communication
CR2	Written notes for daily communication
CR3	Conversation notes for daily communication
CR4	Images in picture cards and conversation notes
CR5	Color images in picture cards and conversation notes
CR6	Drawing option for picture cards and conversation notes
CR7	Images illustrated instead of images on picture cards or conversation notes
CR8	Descriptions attached to the images
CR9	Large characters with the images
CR10	Play voice slowly when using picture cards or conversation notes

Table 4.4: Linguistic values for each CR

Requirements	**Customer votes**				
	C_1	C_2		C_{48}	C_{49}
CR1	*L*	*H*		*VH*	*L*
CR2	*L*	*M*		*VH*	*H*
CR3	*L*	*H*		*H*	*L*
CR4	*M*	*H*		*H*	*L*
CR5	*VH*	*H*	...	*VH*	*L*
CR6	*VH*	*H*		*H*	*VH*
CR7	*M*	*H*		*VH*	*L*
CR8	*L*	*H*		*VH*	*VH*
CR9	*VH*	*H*		*M*	*L*
CR10	*L*	*M*		*VH*	*VH*

4.2.2 Voting by 49 Aphasia Individuals

In this case study, voting was important to calculate the final CR weight. Therefore, in Steps 2 and 3 of Figure 4.3, the SLT organized a meeting attended by 49 people with aphasia and collected the votes for each CR through survey questionnaires. We counted each CR vote by its corresponding linguistic value, presented in Table 4.4. The overall linguistic vote count for all participants is presented in Table 4.5.

Table 4.5: Linguistic vote count for CRs

Requirements	**Linguistic terms**			
	VL	**L**	**H**	**VH**
CR1	22	8	9	10
CR2	8	7	13	21
CR3	19	9	14	7
CR4	13	11	13	12
CR5	8	5	15	21
CR6	21	11	10	7
CR7	9	17	12	11
CR8	7	6	16	20
CR9	9	9	16	15
CR10	5	3	10	31

4.2.3 Performing Pairwise Comparison

The SLT implemented the pairwise requirement comparison method in AHP [82], which produced a matrix with 100 (10 × 10) cells, as mentioned in Steps 4 and 5 of Figure 4.3, for the 10 requirements. The pairwise value was measured on an integer scale of 1 to 9, as proposed by Saaty [89] and is shown in Table 2.4. The pairwise comparison matrix is presented in Table 4.6.

In this study, we analyzed the consistency as mentioned in Step 6 of Figure 4.3 using the method provided by Saaty [98]. The consistency rate value was determined as 0.10. This was an acceptable value without judgment error, which was confirmed by the design team and the SLT. After performing consistency analysis, we extended this pairwise matrix in the triangular fuzzy membership function using Table 2.4. Finally, the normalized weight was evaluated using fuzzy-AHP, as mentioned in Step 5 of Figure 4.3.

Table 4.6: Pairwise CR comparison matrix

	CR1	**CR2**	**CR3**	**CR4**	**CR5**	**CR6**	**CR7**	**CR8**	**CR9**	**CR10**
CR1	1	1/3	1/2	1/3	1/3	6	1/5	1/2	5	1/2
CR2	3	1	1	2	1/2	5	2	2	3	1/5
CR3	2	1	1	1	1	7	3	3	5	1/3
CR4	3	1/2	1	1	1/5	5	1	1	3	1/3
CR5	3	2	1	5	1	7	5	3	4	1/3
CR6	1/6	1/5	1/7	1/5	1/7	1	1/4	1/5	1/4	1/7
CR7	5	1/2	1/3	1	1/5	4	1	1/2	4	1/4
CR8	2	1/2	1/3	1	1/3	5	2	1	3	1/3
CR9	1/5	1/3	1/5	1/3	1/4	4	1/4	1/3	1	1/5
CR10	2	5	3	3	3	7	4	3	5	1

4.2.4 CR Weight Calculated Using Proposed Method

Equation (4.6) combines the customer votes corresponding to the linguistic values and the weight of fuzzy-AHP to calculate the final CR weights, as mentioned in Step 7 of Figure 4.3. Finally, we prioritized the requirements given in Steps 8 and 9 of Figure 4.3 according to the final CR weights. In Table 4.7, we present the final CR weights and their rankings determined using AHP, fuzzy-AHP, and the proposed method. Figure 4.4 shows a comparison graph of these three methods. The x-axis of the graph represents the CRs, while the y-axis represents the weight of the corresponding requirement.

4.3 Discussions

This section presents the effects of opinions from aphasia individuals on CR weight and the expansion of the design solution to include more aphasia individuals as well as other people in society.

4.3.1 Effect of opinions from aphasia individuals on CR Weight

Voting was used to calculate the final CR weights. Table 4.7 shows that voting changed the overall ranking in the proposed method. We found that the ranking

Table 4.7: CR weight and ranking using different methods

	CR weights			Ranking	
	AHP	**Fuzzy-AHP**	**Proposed**	**AHP/ Fuzzy-AHP**	**Proposed**
CR1	0.066	0.071	0.046	8	8
CR2	0.104	0.103	0.110	4	3
CR3	0.126	0.124	0.084	3	4
CR4	0.080	0.081	0.067	5	6
CR5	0.174	0.172	0.188	2	2
CR6	0.017	0.017	0.011	10	10
CR7	0.077	0.080	0.066	6	7
CR8	0.075	0.075	0.083	7	5
CR9	0.032	0.033	0.032	9	9
CR10	0.250	0.244	0.312	1	1

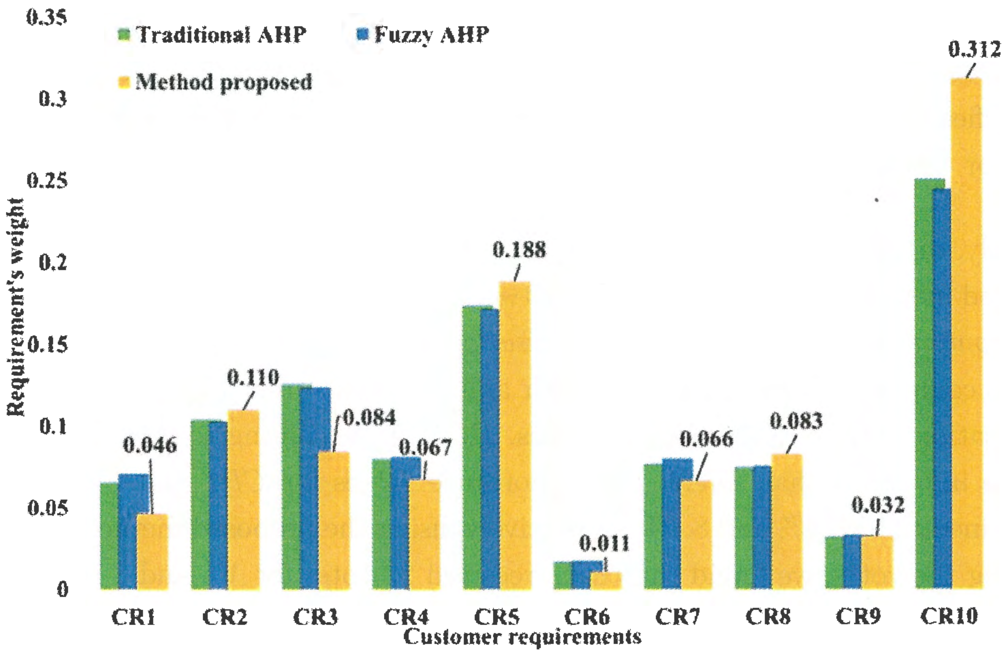


Figure 4.4: Weight of CR for AHP, fuzzy-AHP, and the proposed method

proposed was extensively influenced by the voting based on requirement importance, and the ranking for the corresponding linguistic vote count changed. According to the comparison graph shown in Figure 4.4, several CR weights increased, some decreased, and others had their ranking changed.

First, with the proposed method, the *CR2*, *CR5*, *CR8*, and *CR10* weights increased. Let us consider two requirements: *CR5 (color images in picture cards or conversation notes)* and *CR10 (play voice slowly when using picture cards or conversation notes)*. These two requirements are important not only to the SLT, but also to individuals with aphasia. In the pairwise comparison, the SLT suggested that the importance of *CR5* and *CR10* was high. The importance values of 31.2% for *CR10*, and 18.8% for *CR5*, were determined using the proposed method. Here, *CR5* received 31 linguistic votes for *VH* and 10 linguistic votes for *H*. The votes for *VH* and *H* constituted 83.7% of the overall votes for *CR5*. The *CR10* requirement received 21 votes for *VH* and 15 votes for *H*. The votes for *VH* and *H* constituted 73.5% of the overall votes for *CR10*.

Thus, the overall weight of these two requirements increased and was affected by user votes. It is possible to make a quick decision regarding improvements after observing the greater *CR* weights. For example, if the product somehow dissatisfies the users, then it can be improved by concentrating on requirements *CR10* or *CR5*, or any other requirement with a greater weight.

Secondly, the *CR1*, *CR3*, *CR4*, *CR6*, *CR7*, and *CR9* weights decreased using the proposed method. Let us again consider two requirements: *CR1 (picture card for daily communication)* and *CR3 (conversation notes for daily communication).* During communication, individuals with aphasia rarely used picture cards and conversation notes outside of their homes. However, according to the SLT, *CR3* is more important than *CR1.* The importance values for *CR1* and *CR3* were determined to be 4.6% and 8.4%, respectively, using the proposed method. After counting the votes, we found that *CR1* received 22 votes for *VL* and 8 votes for *L*. The votes for *VL* and *L* constituted 61.2% of the overall votes for *CR1. CR3* received 19 votes for *VL* and 9 votes for *L*. The votes for *VL* and *L* constituted 57.1% of the overall votes for *CR3.* Therefore, the final weights of *CR1* and *CR3* decreased, which means that the design team should put less effort into these requirements because CR1 and CR3 are less important to the users than to the SLT.

However, the *CR2*, *CR3*, *CR4*, *CR7*, and *CR8* ranks changed in the hybrid proposed method. Let us observe the *CR2* and *CR3* requirements, where *CR2* refers to "written notes for daily communication" and *CR3* refers to "conversation notes for daily communication". Some aphasic individuals can communicate by writing notes. Therefore, the SLT set positive importance to this requirement, while the users provided the highest linguistic vote, *VH*, to *CR2.* The SLT's importance for *CR3* was high, but most users provided the lowest linguistic vote, *VL*, to this requirement. This resulted in the lower weight of CR3 when compared to *CR2.* This means that "conversation notes for daily communication" is less preferable than "written notes for daily communication" to individuals with aphasia. This changed the ranking after the linguistic votes were applied to the requirements of *CR2* and *CR3.* Accordingly, the other rankings also changed after combing the linguistic votes.

Furthermore, differences in the CR weights are found in the proposed method as shown in Table 4.7 because the proposed method always gives importance to the opinions of aphasia individuals. For this reason, the ranking is affected by the opinions of aphasia individuals. However, 49 aphasia individuals have been participated in the proposed study for requirements' prioritization, it is not enough to cover the wide range of diversity with these 49 aphasia individuals. Therefore, it would be possible to cover difficulties of diverse aphasia individuals with the proposed method if we include more aphasia individuals in the proposed study to cover the wide range of diversity.

4.3.2 Expansion of the Design Solution to Include More People in Society

The proposed method can include more aphasia individuals as well as other people in the society. The opinions of different aphasia individuals can be possibly included based on their difficulties. Moreover, the opinions of SLT represent difficulties of many aphasia individuals. When we combined both opinions through proposed methods, it will be matched to the difficulties of more aphasia individual. Moreover, the requirements with higher priority are included in the design solution because both SLT and aphasia individuals provide higher importance than other requirements. This means that these higher priority requirements are important to include more people. Alternatively, the requirements with lower priority become lower importance for the aphasia individuals as well as SLT. Thus, these lower importance requirements should not be included in the design solution. If all user requirements are included and implemented without prioritization, then the design solutions become difficult to use for diverse people. As a typical result, the requirements *CR5* (*color images in picture cards or conversation notes*) and *CR10* (*play voice slowly when using picture cards or conversation notes*) are important not only to the SLT, but also to individuals with aphasia. According to the knowledge of SLT, these two requirements are very important to participate in society. The overall weight of these two requirements are also greater than others. If the prototype is improved with these two requirements, this will be obviously improved than previous version. Therefore, we can apply the proposed hybrid method to improve the design solution for expansion because it will include diverse opinions of aphasia individuals based on their difficulties. Since the prototype includes diverse difficulties of aphasia individuals, other people including more aphasia individuals can convey their physical conditions and tiredness with delicate feelings or emotions to others. As a result, more people can be included in society.

Social inclusion can be possible because the design solution uses the opinions of different aphasia individuals through voting and AHP. It is also found from previous studies that the users are satisfied with the prototype created using one of the above two techniques. Rengell et al. [114] obtained the user's vote for each CR that reflects the final priority. The reflection of votes by 10 users was shown in their satisfaction charts, in which nine users were highly satisfied. Similarly, the user's vote for each CR has been reflected in the proposed CR prioritization as shown in Table 4.7. Moreover, Deng-Neng Chen et al. [115] statistically analyzed the satisfaction data of 252 users and proved that users were more satisfied using the AHP-based prototype than the rank-based prototype for the selection of mobile phone. Accordingly, the fuzzy-AHP method was used to prioritize requirements in the proposed method here. A pairwise comparison for each CR was performed by the speech-language therapist. Therefore, the prioritizing CRs using the proposed method, based on voting and fuzzy-AHP, have the possibility of including more aphasia individuals in society.

Furthermore, the proposed methods can possibly include more people in society because it uses SLT knowledge and opinions of aphasia individuals. SLT knowledge is important to include more people in society. SLT knowledge is included by fuzzy-AHP to support aphasia individuals in communication difficulties. SLT has knowledge to include ambiguity and diverse difficulties of aphasia individuals. Aphasia individuals have diverse opinions based on their difficulties. They should be included in requirements prioritization for social inclusion. SLT can judge and prioritize the importance of such requirements by their professional knowledge to speech language impairments. In this study, SLT knowledge is included through the pairwise comparison of importance of each requirement. The inclusion of SLT knowledge is important to include more aphasia individuals. Therefore, there is a possibility to include more people with aphasia in society using the proposed method.

5 Conclusions and Future Works

This study investigated the ways of social inclusion of aphasia individuals by the support of soft computing methods in Inclusive Design. This study was started from the interaction problems between aphasia individuals and others in society that arise daily in different situations. To retrieve the interaction problems, survey questionnaires are provided to the aphasia individuals in three categories. We would like to ask about 1) How much can they convey their delicate feelings (about physical conditions, tiredness or emotions) to others? 2) How much can they understand the feelings of others? and 3) How much important is it to convey delicate feelings to others in order to actively participate in society? In addition to the questionnaires, an existing prototype of communication support application is provided to the aphasia individuals. They use the prototype and provide their opinions through this questionnaires. However, aphasia individuals have their wants and needs of daily activities with delicate feelings or emotions, but they cannot convey with their own voice exactly. In that case, their opinions are collected on an analog scale to redesign the design solution. After collecting their opinions on Likert value, interaction problems are identified based on their difficulties. In addition, the opinions of analog scale value are used for redesign of inclusive design to convey their delicate feelings or emotions. Fuzzy theory is used to represent their delicate feelings or emotions to others. Based on these, the prototype was improved to convey their exact feelings or emotions to others in daily life.

Furthermore, the design solution is expanded for inclusion of more aphasia individuals in society. Still, the improved design solution using redesign also cannot be expanded based on the interaction problems. The reason is that the design solution was completed based on the difficulties and opinions of extreme users. In that case, design solutions can include only those aphasia individuals who have similar difficulties as extreme users. Thus, a lot of aphasia individuals are still excluded from society. To expand the design solution, different aphasia individuals' opinions are included through linguistic voting, and SLT's opinions are included through fuzzy-AHP. Voting was carried out to determine the importance of requirements of aphasia individuals, and fuzzy-AHP was used to address the ambiguity of linguistic terms and judgments made by aphasia individuals. The above-mentioned methods were combined to calculate the weight of aphasia individuals' requirements for prioritization. It can be easily understood from the requirement weight that which requirement can include more aphasia individuals in society. Therefore, it was clearly demonstrated that this method can be useful because it considers the opinions of aphasia individuals through a voting process, which results in an increased level of social inclusion. This will preserve the philosophical goal of inclusive design.

This study focuses on Broca's and Wernicke's aphasia. In the investigation of this study, more aphasia individuals as well as other people can be included in society by conveying their delicate feelings or emotions to others. They can break their isolation when they express their wants or needs with delicate feelings or emotions to others. As a result, they can actively participate in society as an ordinary person. However, this study investigates how they convey physical conditions and tiredness with the delicate feelings or emotions to others. In the future, other ways of communication and the factors will be investigated to include more speech-language impaired individuals as well as other people in society.

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Index