Upper Limb-rehabilitation Service System for Chinese Mild-stroke Patients at Home

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ABSTRACTS

With the continuous growth in the popularity of stroke patients in China and the increasing demand for rehabilitation services, the existing traditional hospital rehabilitation model can no longer meet the patients' needs. In recent years, the Chinese government has focused on promoting a new model of "Internet plus medical care" and home rehabilitation.

Of all the symptoms of the stroke, upper limb motor dysfunction is the most common one that causes the decline of the patients' self-care ability and quality of life. Therefore, continuous rehabilitation training plays a vital role in the recovery of limb motor function in stroke patients with hemiplegia and can also serve as a starting point for remote rehabilitation.

This thesis first summarized the fundamental upper limb movements as well as theories, high technologies and assessment methods of upper limb rehabilitation. All the literature review assists designers in understanding the necessary medical knowledge of stroke and rehabilitation. Secondly, the existing products and services of upper limb rehabilitation in China and at abroad are compared and analyzed to explore more design opportunities. Furthermore, based on the observations and interviews, the author summarized the rehabilitation needs, information needs and emotional needs of stroke patients in Shanghai, investigated design pain points, and selected target users for remote rehabilitation.

Finally, a support remote upper limb rehabilitation system concept was established by adopting service design approaches and tools. Furthermore, the concept of a home rehabilitation device and a digital platform, which were two main touchpoints in this system were designed in-depth and made into the prototype for user feedback. The home rehabilitation device integrated a variety of hand grasping exercises by modularization and integrated different upper limb movements through a point-to-line method to solve the problem of lacking multi-function and miniaturization in the home environment. The digital platform used visual interfaces to provide patients with clear instructions and incentive mechanisms which prevent them from giving up rehabilitation halfway.

The findings of this thesis indicated the importance of service design approaches

and tools on systemic thinking and creative ideas. The design results of this project can not only help stroke patients to perform active exercises at home and improve their upper limb motor function, but also provide new visions for the development of future remote rehabilitation service system in China.

Keywords: telemedicine, stroke patients, upper limb-rehabilitation, product-service-system

ACKNOWLEDGMENTS

One year of study at Aalto University taught me how to apply a multidisciplinary approach and creative design thinking to deal with problems in a systemic way comprehensively. It took me over one year to complete this project and explore the opportunities of future stroke rehabilitation. I learned a lot and I would like to show my acknowledgments to everyone I met as well as everything that happened during my study period in Aalto.

First and foremost, I would like to thank my mother and grandfather, both of whom are stroke patients. It was because I had accompanied them for rehabilitation and daily care over the past three years that I had rich experience and high motivation to accomplish this study to help more stroke patients in the future. Great thanks also go to all the stroke patients and therapists who supported me during the field research and shared their professional knowledge and opinions to help me improve my design concepts step by step.

Secondly, I am extremely grateful to my advisor, Dr. Helena Sustar, who provided me with so many useful methods, articles and excellent case studies about service design, and gave me a lot of feedback and insightful suggestions on my thesis documentation. Under her patient guidance, both academic writing and design concepts were improved to a great extent. Besides, I deeply thank my supervisor prof. Mikko Jalas both for his support and supervision during the process and for making learning not a dull thing but a great joy.

My sincere appreciation goes to the department of Creative Sustainability for providing a lot of interesting courses and practical projects, which greatly broadened my horizon and taught me useful methods and tools including world café, open space, road map, participatory methods and facilitation skills. Great thanks also go to Nakagawa Naoko who answered many of our questions about life and study in a new environment. Last but not least, I would like to thank all my team members during each project and all my friends in Finland and China.

Shen LiangYan

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LIST OF ABBREVIATIONS

ADL	Activities of Daily Living
BAT	Bilateral Arm Training
BRS	Brunnstrom Recovery Stage
CIMT	Constraint Induced Movement Therapy
CVA	Cerebral Vascular Accident
FES	Functional Electrical Stimulation
FMA	The Fugl-Meyer Assessment
PC	Personal Computer
PSSD	Product Service System Design
QOL	Quality of Life
TOT	Task-oriented Training
VR	Virtual Reality
WSN	Wireless Sensor Network

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CHAPTER 1

INTRODUCTION

INTRODUCTION

In the first chapter, the author will briefly introduce the thesis topic, background knowledge about the stroke rehabilitation from social, technical, and design perspectives. As stroke patients continue to grow while the hospital resources are limited, the need for remote home rehabilitation is increasing in China. This chapter also introduces the research objectives and process, as well as the research questions. The structure of the entire thesis and the timeline of this project are visualized by the author.

1.1 Background

1.1.1 The definition of stroke

A stroke, also known as a Cerebral Vascular Accident (CVA), is a dangerous disease with a high risk of mortality and disability. A stroke can happen to anyone, of any age, at anytime and anywhere, which gives rise to a loss of many abilities (Mozaffarian, 2016). According to Australian Stroke Foundation's report on symptoms after stroke, common consequences include mobility problems; visual problems; speech and language problems; cognitive and memory problems; eating and swallowing problems; loss of bowel and bladder control; emotional depression and so on (see Figure 1 on the next page).

The degree of loss depends on the location and size of the lesion in the brain. The human brain has four lobes: the frontal lobe, the parietal lobe, the occipital lobe, and the temporal lobe (see Figure 2 on the next page). Different lobes are responsible for various functions (Baile, 2019). For example, if a stroke occurs in the frontal lobe area, symptoms may include problems in movement (weakness in the upper or lower limbs). If a stroke occurs in the parietal area, the patient might have problems in sensations and communication. Therefore, the stroke rehabilitation program is personalized rather than universal because "each patient is characterized by a specific combination of deficits" (National Stroke Association, 2010). In other words, stroke patients need different rehabilitation treatments according to their symptoms.

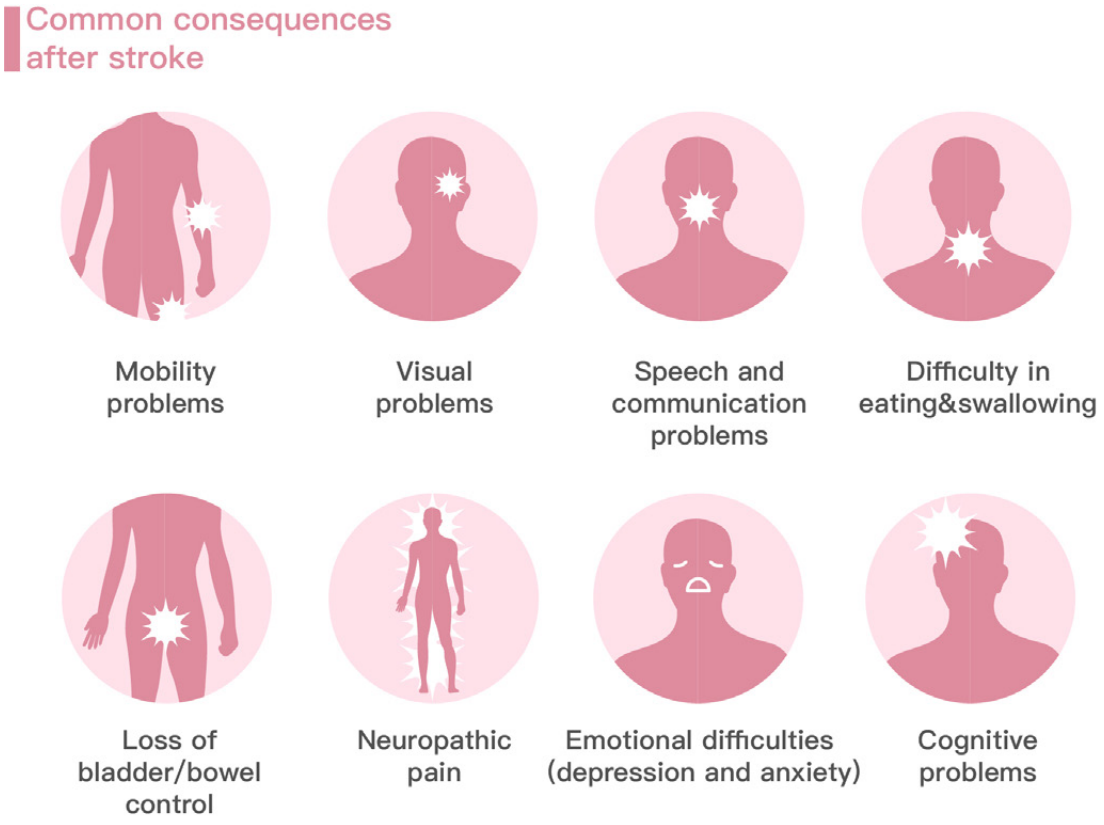


Figure 1: Common consequences after stroke

(Source: https://strokefoundation.org.au/)

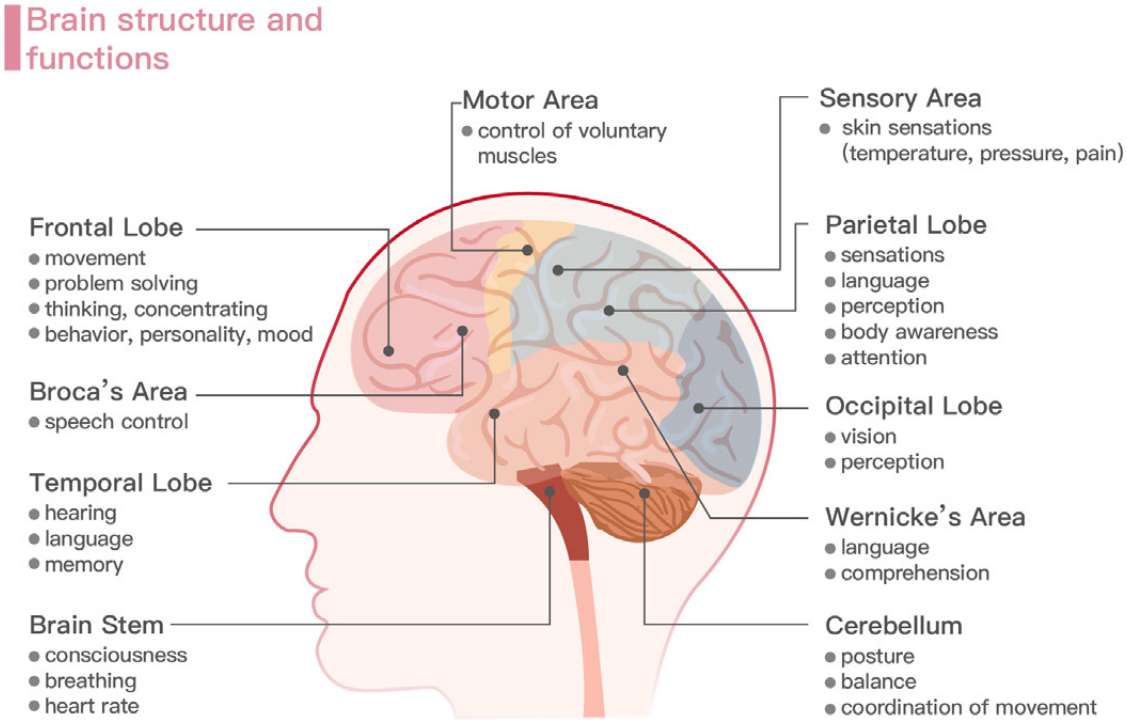


Figure 2: Brain Structure and Functions (Source: Baile, 2019)

Among all the typical symptoms after the stroke, weakness in the upper limb is a considerable issue with significant consequences (Fregni & Pascual, 2006). For example, Lawrence (2001) reported that of 1259 registered stroke patients, 75% of survivors had upper limb problems after the stroke. Furthermore, reduced function of upper limbs causes a decrease in self-care ability and quality of life in stroke patients because the upper limbs are the main system for human contact and operation with the surrounding environment (Nichols et al., 2005).

1.1.2 Social background: Stroke in China

Strokes are the leading causes of death and adult disability in China (Liu, 2011). China has a population of around 1.4 billion (with one-fifth of the world's population), while the annual stroke death rate is about 1.6 million, approximately 157 per 100 000 people (Liu, 2011). In addition, China has 2.5 million new stroke cases each year (Chen, 2008), 70% to 80% of those survivors cannot live independently because of their disability (Wu et al., 2003).

However, through the implementation of new policies, the Chinese government has gradually paid more attention to stroke treatment and rehabilitation. For instance, in 2016, the "Healthy China 2030" issued by the State Council highlighted that the internet and other high technologies should be used to provide all the disabled with sustainable rehabilitation services. That means in 2030, a unified and authoritative health information platform will be established to support remote rehabilitation. (State Council of China, 2016). According to a new policy for Shanghai is that since January 1st, 2018, patients in Shanghai are not permitted to recover in hospitals after one year, so rehabilitation at home is becoming an inevitable trend.

1.1.3 Technical background: The importance and development of rehabilitation

With the rapid development and popularization of high-tech such as the Internet, artificial intelligence, and wearable device technology, the demand and feasibility of remote rehabilitation services are increasing. Remote rehabilitation service system, also called "remote rehabilitation", refers to supporting therapists to provide medical rehabilitation guidance and services remotely through the network (Brennan & Barker, 2008).

The World Health Organization (WHO) has proposed in 1976 that remote community rehabilitation is a cost-effective, wide-coverage, creative way to provide rehabilitation services for the sick, injured, and disabled at the family and community environment (Liao & Zhou, 2011). At present, countries such as the United States and Australia have successfully applied remote rehabilitation technology to home and community through rehabilitation robots and smart wearable devices (Fan, 2017).

In China, although the population is quite large, and the remote rehabilitation technology has not been very mature, the government divides stroke rehabilitation into three levels to promote the remote rehabilitation. As claimed by the Chinese Stroke Rehabilitation Guide (2012), Level-One rehabilitation is an early stage of rehabilitation, which refers to the early treatment in the emergency room or neurology department of the hospital. Most of patients spend their time on the bed. Level-Two rehabilitation refers to rehabilitation in the ward or rehabilitation center, the patients are trained according to the instructions and supervision by therapists. Level-Three rehabilitation means that patients are discharged from the hospital and have continuous rehabilitation in the community or at home. Strengthening Level-Three rehabilitation is a key for promotion at the current stage in China, which enables patients to obtain better motor function, activities of daily living (ADL) and quality of life (QOL) (Zhang et al.,2004).

1.1.4 Design background: How service design intervenes in the medical field

The Product-Service-System-Design (PSSD) attaches importance to the system thinking to promote social development and innovation. Marc Stickdorn has proposed five service design principles: user-centered, co-creative, sequencing, evidencing, and holistic (Stickdorn & Schneider, 2011). In recent years, with the promotion of the concept of “Internet + medical” and the development of technology, the traditional medical model also needs to be updated to emphasize patient-centered and continuously improve the user experience of medical products and services. Furthermore, the medical and health field is a complex system, which includes patients, family members, doctors, nurses, hospital administrators, government agencies, and other stakeholders. Therefore, how to coordinate the relationship among various stakeholders and put the patients at the center of the solutions with service design thinking, which is exactly the role of a service designer (Craig, 2014).

In traditional stroke rehabilitation services, almost all the user scenarios occur in the hospital, including diagnosis, treatment, rehabilitation, payment, medicine purchase and so on. Still, these services cannot meet all the needs of patients. In addition, sometimes poor user experience may lead to conflicts between doctors and patients. Therefore, it is an inevitable trend in the future to explore a new stroke rehabilitation system and clarify the relationship between the main stakeholders by using service design tools to meet the potential needs of stroke patients and therapists. For example, Xin Xiangyang, the director of the Design Department of Jiangnan University, points out that the medical service is a kind of "the trust product." That means when decision-makers want to optimize the service process, they should consider not only physical products but also the behavior of patients and doctors to understand their potential needs. This change can be realized through the visual design of complicated medical knowledge or service design of the whole process (Xin & Wang, 2014). In addition, in 2017, Du and other rehabilitation therapists proposed the vision of a future remote rehabilitation system that would use the network as a bridge between doctors and patients. Besides, smart sensors attached to patients could collect parameters such as motion trajectory, motion speed, and angular velocity, and transmit data wirelessly (Du, Yuan & Qu, 2017).

1.1.5 Motivation for the study

Both the author's mother and grandfather are stroke patients. By participating in the rehabilitation treatment and daily care of stroke patients, the author had a personal experience and understanding of the stroke. The initial motivation is to use this study to have a deeper understanding of the stroke to help more patients like the author's mother. Therefore, this study aims to promote the application of Level-Three rehabilitation in China through the PSSD of future remote home rehabilitation. Thus, more stroke patients can have continuous effective rehabilitation to improve their ADL and QOL at home.

1.2 Objectives and Research questions

This study aims to apply the Product-Service-System-Design (PSSD) methods to form a remote rehabilitation system with a home rehabilitation device and a digital platform to ensure the effectiveness of upper limb training for most mild stroke patients in Shanghai and enhance the user experience of both patients and therapists. This thesis has the following main objectives:

- Understand both the physical and psychological needs of stroke patients;
- Investigate and study the existing safe and effective limb training methods, theories and technologies for stroke patients;
- Combine different training methods into one modularized product;
- Construct a system with a digital platform that will enable the patients at home to connect with therapists in the hospital and record patients' daily situation and tiny progress;
- Evaluate the product's effectiveness and the system's feasibility based on feedback from stroke patients and therapists.

The main research question of this thesis therefore is:

How to build a support system to help the post-stroke patients at home exercise effectively and improve their upper limbs' function by adopting service design approach and tools?

The main research question is supported by the following two sub-questions:

1. How service design approach and tools can be integrated into finding stroke patients' issues and potential needs when it comes to remote rehabilitation?

2. What kinds of products, services and system can be provided for the stroke patients at home with the remote intervention of therapists?

1.3 Research Process

This project takes mild Chinese stroke patients as the research object. Furthermore, this thesis mainly uses literature research, case study analysis, observations, interviews, and service prototyping as research tools.

(1). Literature Research and case study analysis:

To achieve the first and second objectives, the author examined a substantial amount of literature via the Internet and library resources to achieve a basic background understanding, which was crucial in developing the general research framework. The framework has always been adjusted according to the expansion and update of the data. Basic knowledge about human upper limb movements, upper limb rehabilitation theories, techniques, and assessments as well as the case studies about existing upper limb rehabilitation products and services were mainly obtained by above listed methods.

(2). Observations and Interviews

To achieve the third and fourth objectives, observations of the living environment and daily behavior of the stroke patients were utilized by the author to discover the potential needs of the target users. In addition, the interviews with the stroke patients and therapists gathered information about different stakeholders' needs, habits, issues, and relationships between each other. A list of questions and cards were prepared to regard them as a supporting tool for inspiring users' inner thoughts. Furthermore, information sheets and consent forms were prepared to address ethics concerns of the field research. In addition, the author took her mother as the research subject by spending two days in shadowing, one day in the hospital and one day at home. Finally, all the interview data were analyzed and visualized by using PSSD tools such as persona, customer journey map, and stakeholder map. Based on the findings of the research, the outcomes of ideation and design included a service system map focusing on two main touchpoints: a concept of a home rehabilitation device and a digital platform interface design.

(3). Service Prototyping

To achieve the fifth objective, after determining the appearance and function of rehabilitation device as well as the interface of the platform, a simple prototype was used to get some user feedback from patients, their family members and therapists, so that the research can be updated and iterated in the future.

(4). Preparation on ethics of the field research
All patients and therapists who were interviewed have signed the information sheet and consent form. These two documents ensured that participation at the interview was voluntary nature and both therapists and patients had the right to discontinue participation at any time without obligation to disclose specific reasons. Furthermore, study participants were informed that the study did not present any possible risks to the participants and that their names would be anonymized. Moreover, the findings were only used to generate knowledge and ideas for the development of the remote rehabilitation system for stroke patients in China and to contribute to this master thesis. The complete information sheet and consent form are in the appendix.

1.4 Contributions

This thesis contributes to the field of product and service design in the following aspects:
(1). Apply service design principles to guide the design process and propose a better rehabilitation system.
Marc Stickdorn has proposed five popular service design principles: user-centered, co-creative, sequencing, evidencing, and holistic (Stickdorn et al., 2011). In this study, the author put stroke patients in the service center and had insight into their needs. In addition, the participation of patients and therapists were mobilized in the design process by stimulating their creativity and enthusiasm through the organization of interviews and workshops. Furthermore, the utilization of the persona, the user journey map, and the stakeholder map guided the subsequent design practice and solved the issues from a more systematic perspective.

(2) Apply service design tools to deliver design concepts
The invisible services in the backstage were embodied visually through service design tools, including the system map, the circular business canvas, and the service blueprint to increase users' perception and acceptance of the services. In addition, service prototypes were applied to collect user feedback to achieve optimization and iteration of the solutions.

This thesis contributes to the field of medical rehabilitation in the following aspects:
(1). Find a better way for stroke patients to continue upper limb rehabilitation after

discharge.
A suitable rehabilitation training system and products can give stroke patients opportunities to regain upper limb functions and improve the quality of daily life even when they are not in the hospital.

(2). Explore a new pattern of work for therapists in the future.
The remote rehabilitation provides the therapists with the possibility of new work patterns and more effective work experience in the future. In addition, having a better understanding of patients' physical and psychological needs can avoid the contradiction between doctors and patients.

Furthermore, this thesis helps better to integrate the service design field and medical rehabilitation field. The design of rehabilitation products requires designers to understand relevant medical knowledge. In the second chapter of this study, theories and technologies related to upper limb rehabilitation after stroke can help subsequent designers to understand the basic knowledge about stroke and rehabilitation quickly. While in the third and fourth chapters of this study, medical researchers can also promptly know the possibility of future rehabilitation system with the help of service design principles and tools.

1.5 Structure and timeline of the thesis

In order to design a remote upper limb-rehabilitation system for stroke patients, the author formulated a research framework with the help of the Double Diamond design process proposed by the British Design Council (Tschimmel, 2012), as shown in Figure 3. The discover stage helped people understand the background of this study and basic knowledge about strokes and upper limb-rehabilitation. The define stage analyzed all the research data and information as well as defined the main pain points and design opportunities based on findings. The develop stage helped the author to optimize the entire service process and user experience through the design of the main touch points in the service. At the deliver stage, the author applied the service design tools to visualize the remote upper limb-rehabilitation system concept. Finally, two main touchpoints in the system, a concept of a home rehabilitation device and a digital platform were tested and iterated through prototype testing. Furthermore, the timeline of the project is visualized in Figure 4 on the next page.

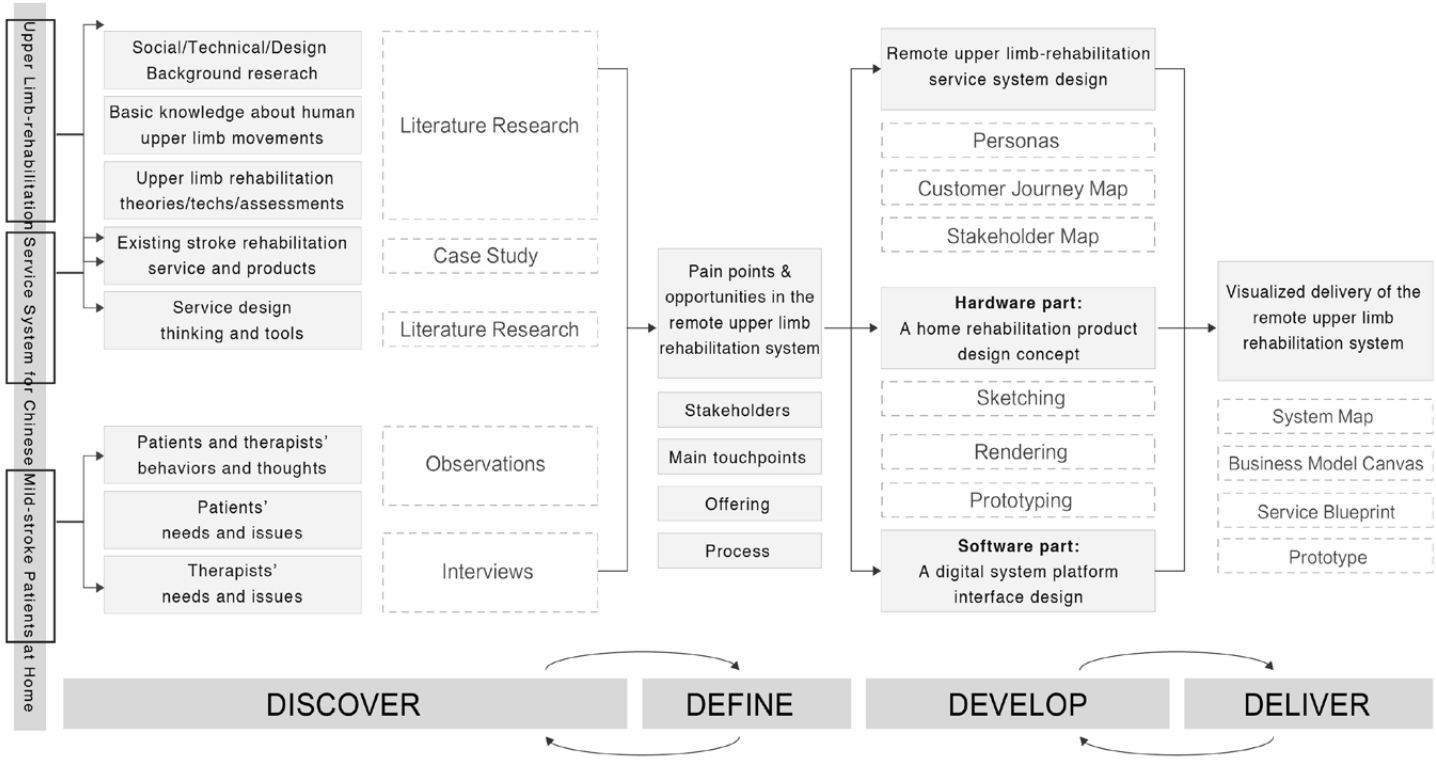


Figure 3: The structure of the thesis

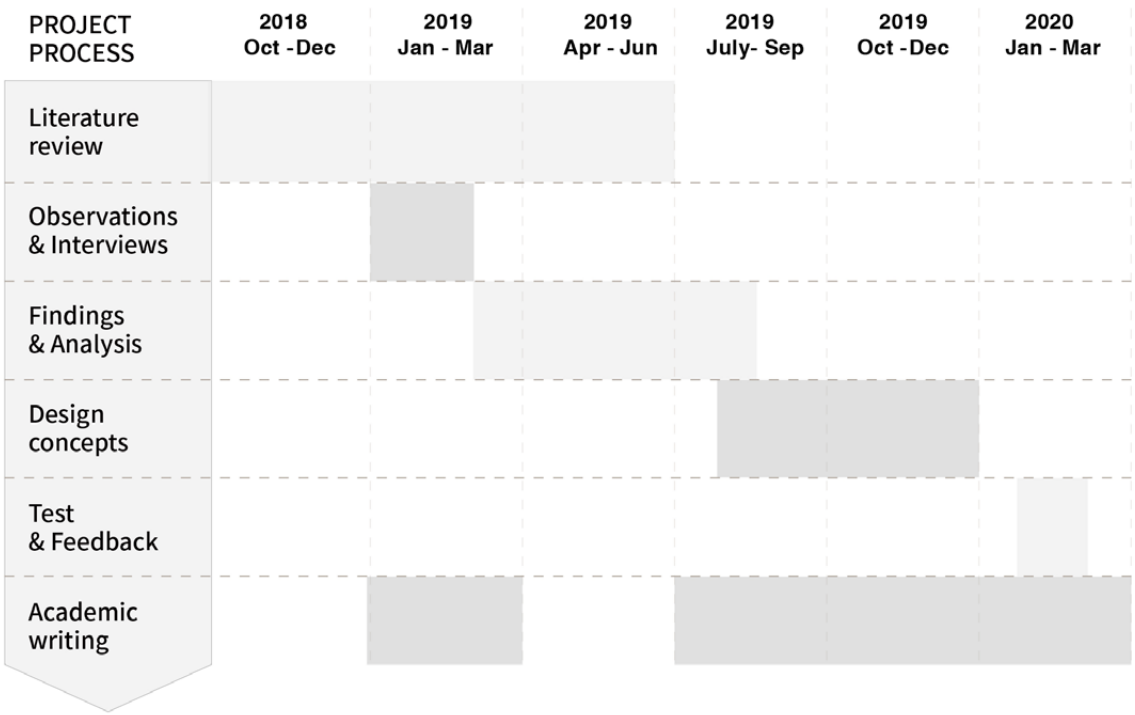


Figure 4: The timeline of the project

CHAPTER 2

LITERATURE REVIEW

LITERATURE REVIEW

In this chapter, background knowledge about human upper limb movements was analyzed from three aspects: the composition of the human upper limbs, the range of joint movements, and the relationship between upper limbs and targets. Secondly, three fundamental theories of upper limb rehabilitation, three main principles of high technologies, and two rehabilitation assessment methods were summarized to clarify their advantages and limitations. After that, case studies of four upper limb rehabilitation products and services for stroke patients were compared to explore more possibilities of future development.

2.1 Background knowledge about human upper limb movements

The human upper limb is one of the components of the human body, and its elemental physiological composition includes bones, muscles, nerves, joints, and skin. In addition, the upper limb can be divided into the following parts: shoulders, arms, elbows, forearms, wrists, hands, and fingers. The shoulder joints, the elbow joints, the wrist joints, and the finger joints connect different body parts and thereby generating upper limb movements (TeachMe Series, 2020). Based on Drake's book "Gray's Anatomy for Students", the basic movements of each part of the upper limbs are explained in detail (Drake, 2009). The author summarized the information in Table 1, with the purpose of overall understanding of the types and characteristics of human upper limb movements and laying a foundation for the follow-up rehabilitation training methods and evaluation of upper limbs.

All the upper limb movements have joints' range of motions, which are an essential criterion in subsequent rehabilitation assessment. Furthermore, among all upper limbs' parts, the hands have more fine mobility, and one of its primary functions is to manipulate objects by grasping. In 2014, Dollar classified the movements of the hands in a more detailed frame, which is shown in Figure 5. From left to right, all the movements are divided into two dimensions, which are power and precision, and then organized by different tasks and the objects. The objects are mainly cylindrical and spherical, which are the two most common shapes in daily life, such as

toothbrushes, cups, pens, tableware, door handles, and so on. It is because of these movements that there is a relationship between people and things (Dollar, 2014).

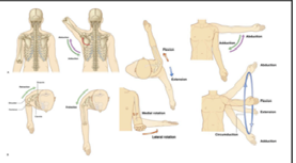
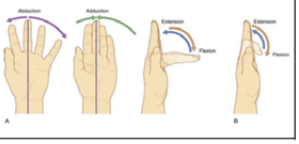
Parts	Upper limb movements	Pictures
Shoulders & Arms	1. Flexion——Extension 2. Abduction——Adduction 3. Protraction——Retraction 4. Internal rotation——External rotation 5. Circumduction	
Elbows & Forearms	1. Flexion——Extension 2. Supination——Pronation	
Wrists	1. Flexion——Extension 2. Abduction——Adduction 3. Circumduction	
Hands & Fingers	1. Flexion——Extension 2. Abduction——Adduction 3. Circumduction	

Table 1: Different parts' upper limb movements (Source: Drake, 2009)

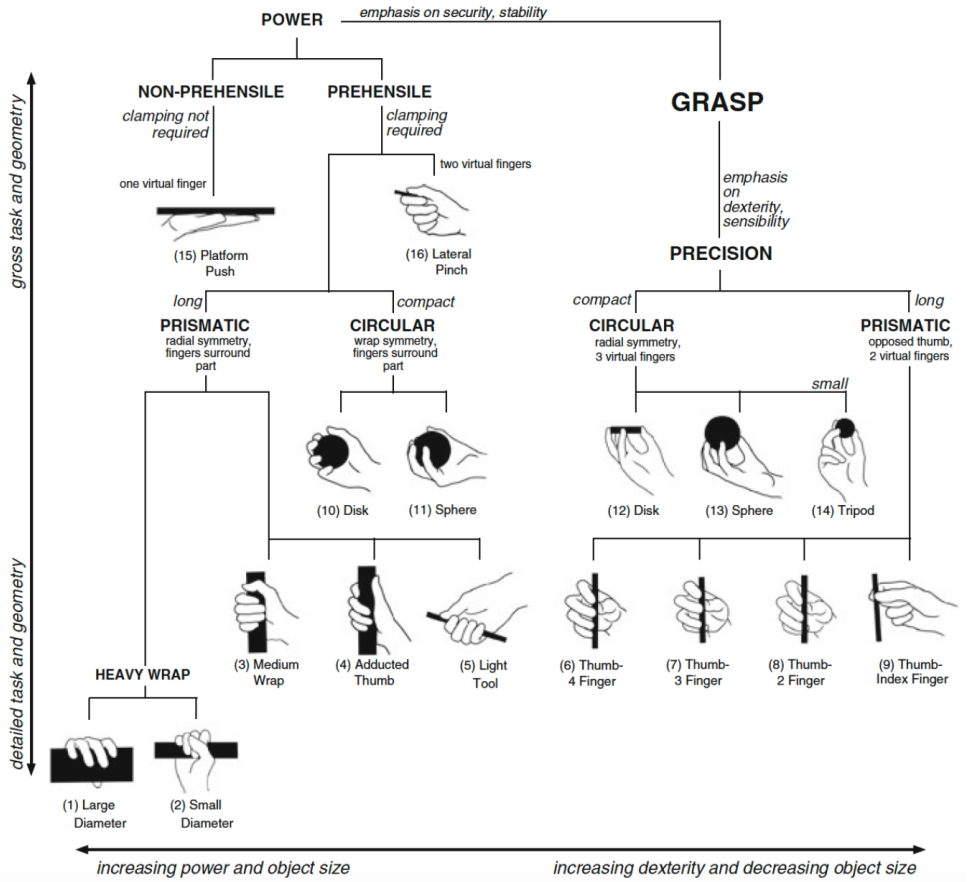


Figure 5: Movements of the hands (Dollar, 2014)

In addition to grasping, the human upper limbs can perform many other movements. Gilbraith proposed the concept of "Therbligs", which refers to the basic elements of human motion (Lin, Yang & Huang, 2003). The American Industrial Engineering Association subsequently subdivided "Therbligs" into eighteen types, including those closely related to upper limb movements:

- search to determine the position of the target
- select to decide the motion to grasp the target
- reach to approach or leave the target
- grasp to touch and hold the target
- hold to keep the state of the target
- move to keep the target from one position to another
- release to drop the target object
- rest without the useful motion

By analyzing and disassembling these human upper limb movements, the author gained the basic understanding of the compositions of upper limbs, the range of motion, and the relationship with the objects to lay a foundation for determining the methods of remote upper limb rehabilitation training later.

2.2 Upper limb rehabilitation theories

2.2.1 Constraint Induced Movement Therapy (CIMT)

(1) Definition: Constraint-Induced Movement Therapy (CIMT) is a treatment to increase the practical use of the more impaired upper limbs for stroke patients (Reiss,2012). In other words, CIMT forces the use of patient's affected side of the upper limb by constraining or reducing the use of the unaffected side.

(2) Characteristics: Three main characteristics, including "repetitive training", "transfer package" as well as "constraining use of the less affected side" form an integrated and systemic CIMT treatment (see Figure 6). Firstly, "repetitive training" refers that patients need to perform repetitive and concentrated exercises with the more affected arm six to seven hours every day with moderate rest during about three weeks (Taub, Uswatte & Pidikiti, 1999). Secondly, "transfer package" is a combination of behavioral strategies to enhance patients' adherence (Taub et al., 2013). It consists of a behavioral contract made by patients and therapists together to detail what activities should be done; a daily home diary to record patients'

improvements or problems during rehabilitation; a motor activity log to track amount and quality of use of the more affected limb in 30 ADL activities such as brushing teeth, wearing clothes, using utensils, etc. (Taub et al., 2013; Bonifer, 2003; Wolf et al., 2006). Thirdly, "constraining use of the less affected side" emphasizes the stroke patient's initiative on the more affected upper limbs and functional applications in real life. As a result, patients can significantly increase the actual use of the affected limbs in daily life and improve ADL abilities.

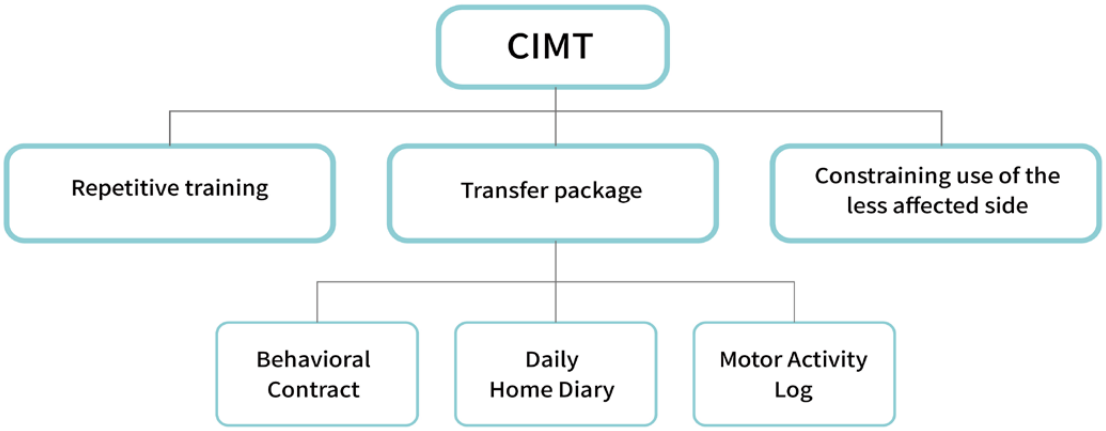


Figure 6: Characteristics of CIMT (Taub, 2013 & Bonifer, 2003)

(3) Limitations: However, CIMT is more suitable for mildly impaired stroke survivors who are individuals with some active wrist and hand movements (Stoykov & Corcos, 2009). In addition, CIMT over-emphasizes the training of patients' affected side of upper limbs, while ignoring the coordinated training of both sides of the upper limbs. Moreover, patients might lose motivation and patience due to massive repetitive exercise.

2.2.2 Bilateral Arm Training (BAT)

(1) Definition: Bilateral Arm Training (BAT) is a treatment including repetitive practice that use both limbs to complete movements in symmetrical and alternating patterns (Stoykov & Corcos, 2009).

(2) Characteristics: BAT has four main categories (see Figure 7): 1) assisted bilateral arm training, 2) repetitive reaching practice with the hand fixed, 3) isolated muscle repetitive task practice, and 4) whole arm functional task training (Waller & Whitall,

2008). Waller and Whitall also claim the primary reason to apply BAT is that our daily activities and necessary self-care skills mostly require both upper limbs to participate, for example, getting up from bed, dressing, bathing, eating, and toileting. Furthermore, device-driven bilateral arm training can help patients train motions such as flexion, and extension, pronation and supination of different parts of upper limbs in passive, active assist and resistance modes (Stoykov & Corcos, 2009).

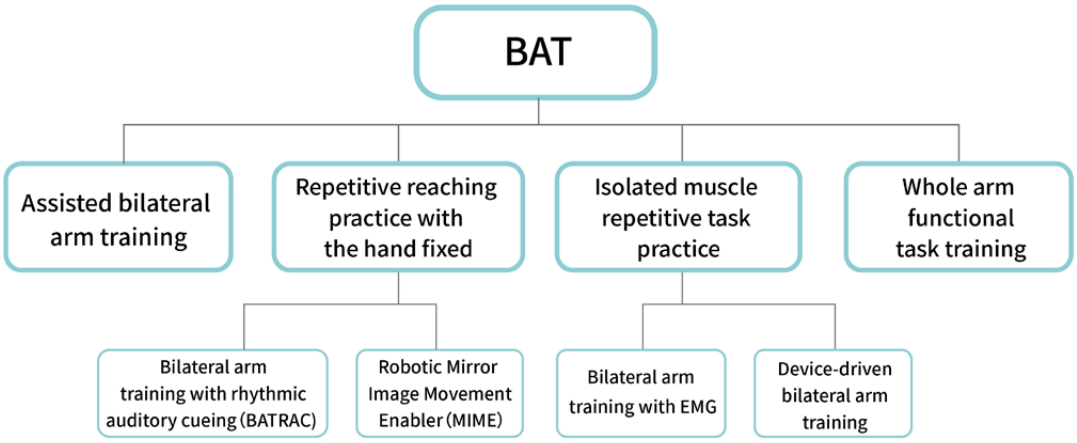


Figure 7: Categories of BAT
(Source: Waller and Whitall, 2008; Stoykov and Corcos, 2009)

(3) Limitations: There are many categories of BAT. Some are suitable for patients with moderate to severe stroke, others are suitable for patients with mild stroke. Therefore, different categories and models must be selected according to the specific conditions of the patient to activate their most effective roles.

2.2.3 Task-Oriented Training (TOT)

(1) Definition: The Task-Oriented Training (TOT) enables patients to actively participate in upper limb movement training by purposeful tasks and specific instructions (Yoo & Park, 2015). For example, compared to the flexion and extension of elbows, grasping, reaching, and releasing an object are specific tasks because the completion of them involves the input of multiple senses and information. After the brain has integrated all the information, it can order relevant muscles to complete this specific task and promote hand-eye coordination. However, if the upper limb only does pure flexion and extension without particular goals, the brain will gradually lose the information input and motivation (Huang, 2007).

(2) Characteristics: The author summarized the four characteristics of TOT by studying the clinical report of task-oriented training treatment by rehabilitation therapist Chen et al. (2009), as shown in Figure 8 below:

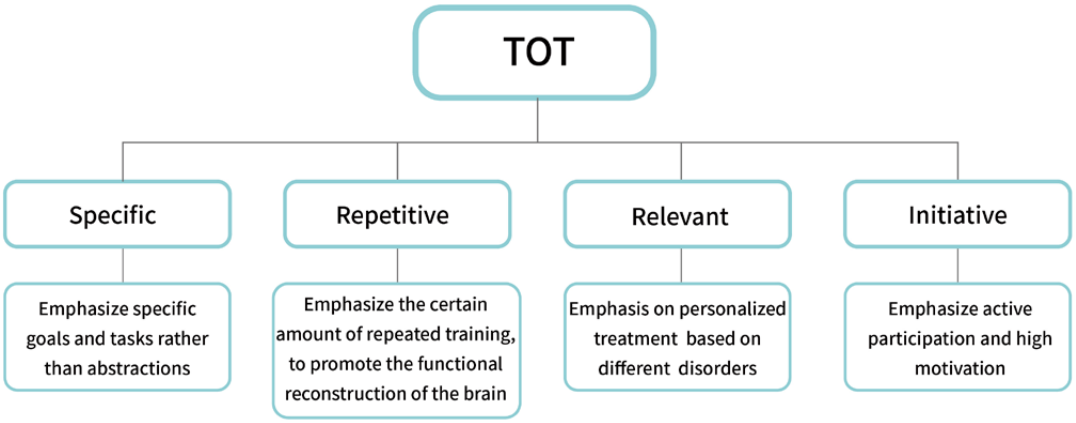


Figure 8: Characteristics of TOT (Source: Chen et al., 2009)

(3) Limitations: TOT usually needs to be combined with other theories or technologies in order to work better. For example, many studies have shown that task-oriented training therapy combined with functional electrical stimulation, virtual reality technology, or motor imagery therapy can more effectively promote the recovery of upper limb function (Li et al., 2017; Chen et al., 2009).

2.2.4 Conclusions

This section summarizes three fundamental theories of upper limb rehabilitation CIMT, BAT and TOT. Table 2 (on the next page) concludes the main principles, target groups, main advantages, and limitations of three theories described above, which all provide theoretical support for subsequent product and service design. Through analysis, we can find that for patients with mild stroke recovering at home, combining BAT and TOT to form the task-oriented bilateral upper limb training is a more feasible solution. The reason is that patients need to participate in daily activities that require high involvement of both upper limbs when they return home.

	CIMT	BAT	TOT
Main Principles	Force the use of patient's affected side of the upper limb by constraining or reducing the use of unaffected side	Emphasize the training of both upper limbs to complete movements in symmetrical or alternating patterns	Emphasize the initiative by asking patients to complete purposeful tasks
Target Groups	Severe and moderate stroke patients	Mild and moderate stroke patients	Mild and moderate stroke patients with clear consciousness
Main Advantages	• Increase the training intensity and the practical use of the affected side	• Increase the use of both limbs in daily life • Different modes (active, passive and active assisted movement)	• Improve patients' participation and motivation through task objectives and timely feedback
Limitations	• Ignore the coordinated training of both sides of upper limbs • Patients might lose motivation and patience due to massive repetitive exercise	• Choose different modes according to the patient's specific conditions • Patients might lose motivation and patience due to massive repetitive exercise	• It is necessary to combine TOT with other theories or technologies to better play its role

Table 2: Conclusions of upper limb rehabilitation theories

2.3 Upper limb rehabilitation techniques

2.3.1 Functional Electrical Stimulation (FES)

(1) Definition: Functional Electrical Stimulation (FES) is a technique, which applies a certain intensity of low-frequency electrical flow to the nerves that control one or more groups of muscles (Kim, Lee & Song, 2014).

(2) Applications: The purpose of FES is to strengthen the range of joint motion such as wrist and finger extension and shoulder flexion as well as improve muscle function such as contractility, endurance, and induce reflex activity (Bitensky,2010). Many studies have reported the effectiveness of FES for improving functional motor recovery. For example, by studying 46 Chinese stroke patients, Lin and Yan claimed that three-week FES of the impaired upper limbs after stroke could improve patients' motor recovery (Lin & Yan, 2011). In addition, FES can be used alone or in

combination with other treatments. For example, according to the study from Alon et al., patients with mild paresis who received upper limb task-oriented training with FES improved their upper limb functional use more than those who without FES (Alon, Levitt & McCarthy, 2007). In addition, Kim et al. (2014) demonstrated that when used in conjunction with FES, mirror therapy could more effectively promote the active participation of stroke patients and improve motor function.

(3) Limitations: Nevertheless, for the patients who lack active movement, it is challenging to achieve motor function improvements only by FES (Kim et al., 2014). Thus, the intervention is ineffective in patients with severe loss of motor function.

2.3.2 Virtual Reality (VR)

(1) Definition: Virtual Reality (VR) is a computer-based technology, which provides patients with interactive multi-sensory stimulation and real-time feedback on performance (Saposnik, 2011). Patients can be immersed in activities similar to real-world objects and events by using some input devices such as keyboards, mouse, wearable gloves, helmets, as well as robots (Ogourtsova, 2016).

(2) Applications: In practical applications, according to the level of immersion and the degree of interaction, the VR system is divided into three categories: immersive VR system, non-immersive VR system (also named desktop VR system), and semi-immersive reality system (Bamodu & Ye, 2013). Among them, the desktop VR system where the screen of the computer is a window for users to observe the virtual environment, is the least immersive, least expensive and requires the least sophisticated components. Thus, it is widely used in practical applications (Boian et al., 2002). In addition, Vogiatzaki and Krukowski (2016) put forward that the training based on desktop VR system can range from simple goal-directed limb movements, achieving a given goal like putting a cup of tea on the table and improving lost motor skills like virtual driving. All of them help in recovering the motor skills and limb-eye coordination.

(3) Limitations: However, there is concern that the wide use of VR in the clinic is not possible due to the cost of the required hardware and software (Ogourtsova, 2016). In addition, VR treatment has negative effects, especially when there is a significant delay in the image information reflecting exercise behavior, which will seriously affect the training effect of VR.

2.3.3 Wireless Sensor Network (WSN)

(1) Definition: A Wireless Sensor Network (WSN), based on different kinds of sensors, is applied to capture and monitor the human body's movement, postures, and activities (Macedo, Afonso, Rocha & Simoes, 2014).

(2) Applications: s depicted in Figure 9, core components of WSN include a base station connected to a Personal Computer (PC) and several nodes that collect sensory information from the users. Moreover, the node consists of several sensors for data collection, a microcontroller with memory for data processing, a radio transceiver for data transmission, and a battery for powering all the circuits in the device. Applying WSN can bring a lot of benefits and breakthroughs in rehabilitation training and supervision. Firstly, WSN is a low-cost technology that does not require patients to spend a lot of money on devices (Hadjidi et al., 2013). Secondly, due to the lack of wires as well as the small size and lightweight sensors, patients are allowed to move freely while exercising. Moreover, sensors can be classified into different types so that WSN can monitor different vital signals and motion signals (Li, 2017)

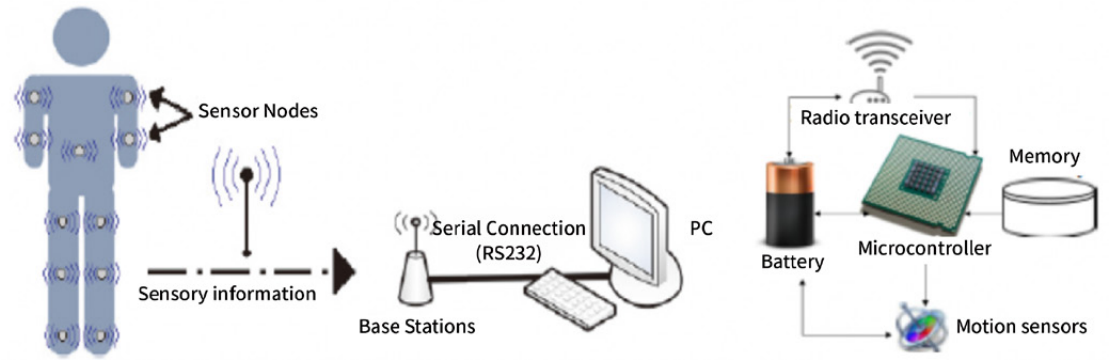


Figure 9: Core components of WSN (Source: Macedo, 2014; Hadjidj, 2013)

(3) Limitations: However, WSN also has challenges and limitations. Sensor nodes, for example, must be lightweight and small enough to provide the highest degree of comfort and convenience to stroke patients. In addition, if the sensor node does not have good contact with the skin, it may deviate from its initial position and affect the data quality and when errors occur, how to correct them in time is also a challenge. Furthermore, the high-speed sampling of the sensor and the transmission of a large amount of generated data consume a lot of energy, while the continuous charging of the node battery is burdensome for the disabled patients.

2.3.4 Conclusions

This section analyzes three new technologies for upper limb rehabilitation. Table 3 summarizes these three technologies based on their main principles, target groups, main advantages and limitations that improve the technical feasibility of subsequent product and service concept design. Techniques applied to stroke rehabilitation should be selective and cautious. It can be obtained through analysis that for patients with mild stroke recovering at home, too complicated wearable devices and interactions tend to fatigue patients and reduce the effectiveness of exercises. Therefore, a low-cost, lighter sensor (WSN) technology is more suitable for initial remote rehabilitation programs.

	FES	VR	WSN
Main Principles	Apply a certain intensity of low-frequency electrical current to the nerves that control one or more groups of muscles	A computer-based technology which provides patients with interactive multi- sensory stimulation and real-time feedback on performance	Apply to capture and monitor human body's movement, postures, and activities based on different kinds of sensors
Target Groups	Stroke patients with severe loss of motor function	Mild stroke patients with clear consciousness	Mild and moderate stroke patients
Main Advantages	• Strengthen the range of joint activity such as wrist and finger extension and shoulder flexion • Improve muscle function	• Increase immersion and interactivity during training; • Add fun and variety to training tasks	• An easily deployable system • The expansion of mobility because of no wires • Low-cost technology • Monitor different vital signals
Limitations	• It is difficult to achieve improvement in motor function only through FES • It is necessary to combine other theoretical or technical methods	• The technology and cost are relatively high; • The delay of image information will seriously affect the training results	• Sensor nodes must be lightweight and small enough • Sensor nodes need to have good contact with the skin • Energy consumption

Table 3: Conclusions of upper limb rehabilitation technologies

2.4 Upper limb rehabilitation assessments

Functional assessments after stroke are essential for therapists to decide on the individualized treatment plan and goals (Kim et al., 2016). In China, face-to-face assessment is adopted by a therapist, who then supervises the patient in the process of rehabilitation treatment to make appropriate adjustments. Assessments of upper limb rehabilitation after stroke used in the hospital include Brunnstrom Approach and the Fugl-Meyer Assessment (FMA) (Fan, 2017). Since this study focuses on upper limb rehabilitation, only the upper limb part of different assessments is provided here.

2.4.1 Brunnstrom Recovery Stages (BRS)

(1) Outline: BRS was proposed by Signe Brunnstrom, a Swedish occupational therapist in the 1970s. Based on the detailed observation of limb movements in stroke patients with hemiplegia, six stages of recovery were established based on the parts of the body and the severity of brain injury, as shown in Table 4 below (Brunnstrom Approach,2019).

Stage	Arm	Hand
1	Flaccidity	No hand function
2	Beginning development of spasticity; limb synergies or some of their components begin to appear as associated reactions	Gross grasp beginning, minimal finger flexion possible
3	Spasticity increasing; synergy patterns or some of their components can be performed voluntarily	Gross grasp, hook grasp possible, no release
4	Spasticity declining; movement combination deviating from synergies are now possible	Gross grasp present, lateral prehension developing, small amount of finger extension & some thumb movement possible
5	Synergies no longer dominant, more movement combinations deviating from synergies performed with greater ease	Palmar prehension, spherical & cylindrical grasp & release possible
6	Spasticity absent except when performing rapid movement, isolated joint movements performed with ease	All types of prehension, individual finger motion, full range of voluntary extension possible

Table 4: Brunnstrom Six stages of recovery (Brunnstrom Approach,2019)

This study focuses on the stroke patients in the fourth, fifth, and sixth stages of the BRS. At these three stages, spasticity and synergies begin to decline, and more movement combinations can be performed with less restriction, but the movement speed is still slow. In addition, based on the previous stages of treatment, the patient will be able to make more controlled and deliberate movements in the affected limbs. Whatever stage the patient is in, he or she needs continuous rehabilitation exercise to promote motor function until the patient restores the self-care ability completely.

(2) Limitations: Oher assessment scales in the later period are mainly based on BRS, which proves that BRS has a significant influence. However, BRS only measures the motor recovery in a qualitative way without accurate scores, which contributes to the assessment results that cannot accurately reflect the small changes and details during the rehabilitation training. BRS is not conducive to the generation of personalized treatment plans in the later stage.

2.4.2 The Fugl-Meyer Assessment (FMA)

(1) Outline: The Fugl-Meyer Assessment (FMA) is one widely used scale based on BRS and quantifies specific assessment categories (Fugl-Meyer et al., 1975). It consists of 5 domains: motor function, sensation, balance, joint range of motion, and joint pain (Kim, 2016). Each domain includes multiple items, while each item consists of three points (0= cannot perform, 1= performs partially, 2= performs fully), and the FMA has 226 points in total. Among the five domains of FMA, the motor domain is used widely and divided into 66 points for the upper limb and 34 points for the lower limb (Gladstone, Danells & Black, 2002). Table 5 shows the wrist part of FMA and the entire upper limb FMA is listed in the appendix.

B. WRIST support may be provided at the elbow to take or hold the starting position, no support at wrist, check the passive range of motion prior testing		**none**	**partial**	**full**
Stability at 15° dorsiflexion elbow at 90°, forearm pronated shoulder at 0°	less than 15° active dorsiflexion dorsiflexion 15°, no resistance tolerated maintains dorsiflexion against resistance	0	1	2
Repeated dorsifexion / volar flexion elbow at 90°, forearm pronated shoulder at 0°, slight finger flexion	cannot perform volitionally limited active range of motion full active range of motion, smoothly	0	1	2
Stability at 15° dorsiflexion elbow at 0°, forearm pronated slight shoulder flexion/abduction	less than 15° active dorsiflexion dorsiflexion 15°, no resistance tolerated maintains dorsiflexion against resistance	0	1	2
Repeated dorsifexion / volar flexion elbow at 0°, forearm pronated slight shoulder flexion/abduction	cannot perform volitionally limited active range of motion full active range of motion, smoothly	0	1	2
Circumduction elbow at 90°, forearm pronated shoulder at 0°	cannot perform volitionally jerky movement or incomplete complete and smooth circumduction	0	1	2
	Total B (max 10)			

Table 5: The wrist part of FMA (Fugl-Meyer, 1975)

(2) Limitations: The FMA assessment program is comprehensive, quantitative, and more sensitive to changes in rehabilitation. However, there are a lot of scoring items, which take about 30 minutes for all 226 points to be tested. The whole process requires patients to maintain concentration for a long time to cooperate with the assessment.

2.4.3 Conclusions

At present, there are a large number of studies, which explore effective assessment methods for the remote rehabilitation system, most of which are based on the FMA form. For example, in 2016, Kim used Kinect, a depth-sensing camera developed by Microsoft to detect three-dimensional movements of human joints, to develop an online Fugl-Meyer evaluation tool. Patients used Kinect to record upper limb movements, and the artificial intelligence network calculated FMA scores automatically and sent results to the therapist's computer for evaluation. Forty-one patients with hemiplegia stroke were included in the study, and the effectiveness was verified by experiments (Kim et al., 2016). Although these studies are not yet widespread, they offer several possibilities for remote evaluation.

In short, the design of the remote rehabilitation assessment method is more applied in the field of medical research and requires multiple clinical trials and verifications, so it will not be discussed in depth in this study. So far, video calls combined with online Fugl-Meyer Assessment seem to be feasible for the early remote rehabilitation system.

2.5 Upper limb rehabilitation service and products

2.5.1 Stroke rehabilitation service system

As mentioned in chapter one, the Chinese government divides stroke rehabilitation into three levels:
1) Level-One rehabilitation is an early stage of rehabilitation, which refers to the early treatment in the emergency room or neurology department of the hospital.
2) Level-Two rehabilitation refers to rehabilitation in the hospital or institution; the patients are trained according to the instructions and supervision by therapists.

3) Level-Three rehabilitation means that patients are discharged from the hospital and have continuous rehabilitation in the community or at home (Zhang, 2012).

As shown in Figure 10 (on the next page), at present, the Level-One and Level-Two rehabilitation services are relatively detailed, but the follow-up services after patients return home have yet to be planned further. This level is a key for the promotion of remote home rehabilitation at the current stage in China.

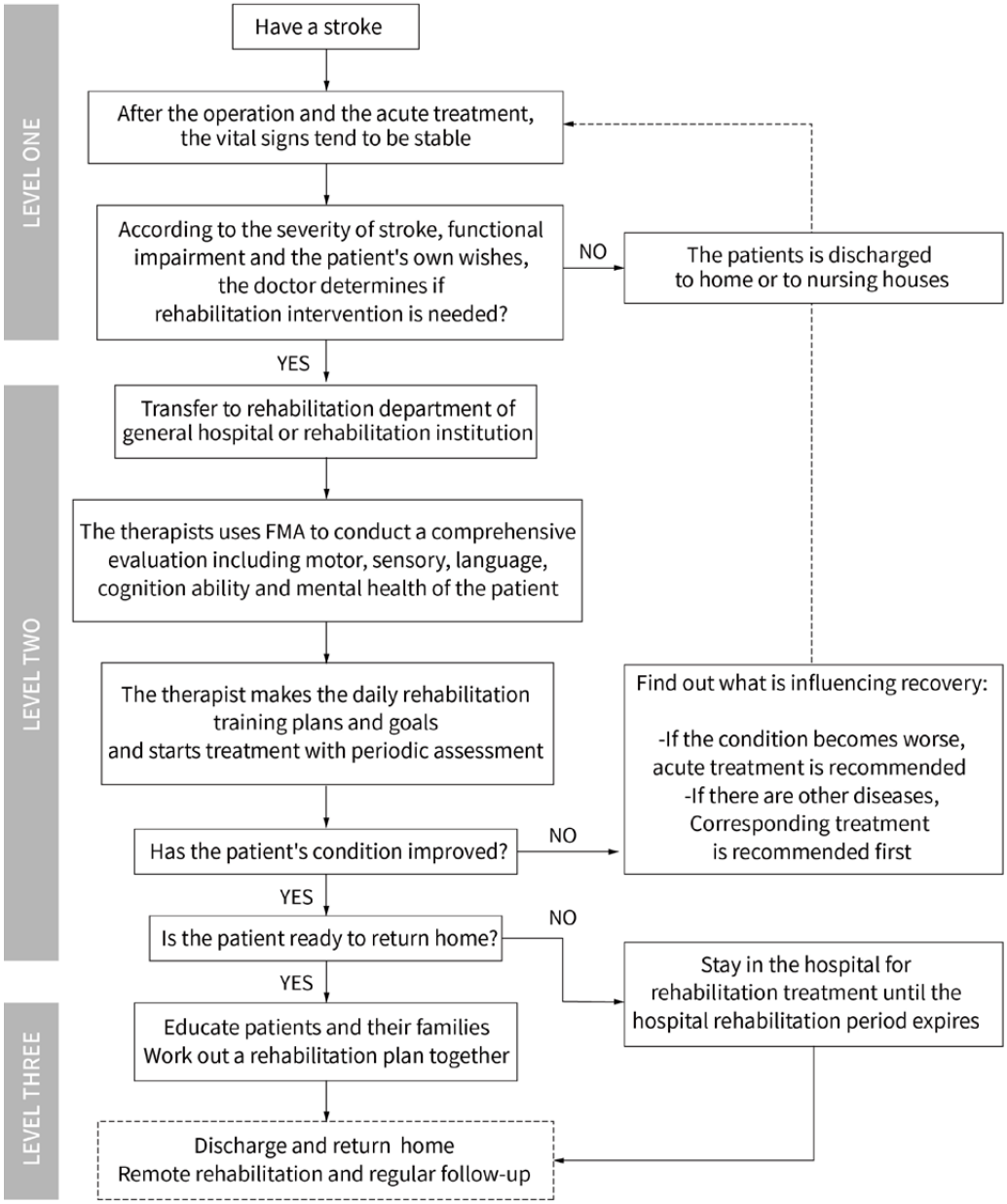


Figure 10: Three levels of rehabilitation in China (Zhang, 2012)

Remote rehabilitation in China is still in its infancy. Compared with China, foreign developed countries have less population base but higher trust between people. Nevertheless, both theoretical research and practical services for stroke rehabilitation are more mature.

Firstly, many clinical trials and researches have reported the advantages and future development of remote rehabilitation system. For example, in 2004, Donnelly et al. demonstrated that if a stroke patient was able to obtain professional rehabilitation services in the community or family after discharged from the hospital, the patient's participation could be fully mobilized due to the family support as well as therapists' remote supervision and feedback (Donnelly, Power, Russell & Fullerton, 2004). In addition, in 2007, Deutsch, Lewis & Burdea claimed that training at home has the potential to save time and expenses for both patients and therapists, and a therapist could even supervise several patients who exercised at the same time through multiple settings. Furthermore, in 2011, Di Loreto et al. emphasized the importance of telerehabilitation, which could not only provide stroke patients with the most appropriate and individualized exercise, but also the evolution of patients' performance could be quickly recorded, evaluated and modified by therapists at a distance.

Secondly, when it comes to practical services, the author collected the authoritative stroke-related institutions in the following countries (see Table 6). Each of them cooperated with different partners to provide more comprehensive in-hospital and out-of-hospital services for stroke patients. For example, World Stroke Organization drives global effort to improve stroke prevention, treatment, and recovery by providing tools and resources like a mobile app that help the public to calculate the risk of stroke and take action to reduce it. European Stroke Association aims to reduce the burden of stroke and improve stroke care by providing medical education to healthcare professionals and the lay public. American Stroke Foundation's mission is to empower stroke survivors and their families to overcome the challenges of life after stroke by providing online and offline lessons about skills, strategies, and technology to deal with these changes. Chest Heart and Stroke (CHSS) cooperates with several local general hospitals and community hospitals in Scotland to effectively organize stroke nurses and therapists to provide long-term remote rehabilitation services for stroke patients after discharge. The author concludes the specific services and methods in the following Table 7:

Stroke-related institutions	Websites
World Stroke Organization	http://www.world-stroke.org/
European Stroke Association (EU)	http://www.eso-stroke.org/
American Stroke Foundation (US)	http://americanstroke.org/
Stroke Association (UK)	http://www.stroke.org.uk/
Chest Heart and Stroke (Scotland)	http://www.chss.org.uk/stroke/
Canadian Stroke Network (Canada)	http://www.canadianstrokenetwork.ca/

Table 6: Stroke-related institutions and websites

Stroke services	Methods
Nurses & Therapists Support Service	Therapists and nurses provide rehabilitation advice, information, and support via online platforms and emails to help stroke patients to make rapid adjustments and encouragements after returning home from the hospital.
Community Stroke Services	Through one-to-one volunteer visits, these are helping patients with daily life at home and accompany; There are also self-managed stroke groups, which support patients to participate and enjoy community activities with the aim to integrate them into society as quickly as possible.
Free Self-management Services	Selfhelp4stroke is a free self-management website that helps patients to set rehab goals in the form of video, audio, and interactive forms. There are plenty of resources available for free download, as well as many stroke patients sharing their stories and experiences.
Rahab & Health Information Services	This service is providing education and rehabilitation guidelines for stroke patients in various electronic PDF formats, including posters, booklets, newsletters, cards, and flyers.
Financial Support Services	By organizing offline activities, collecting donations online and recruiting volunteers, the association receives sponsorship from commercial organizations, charitable organizations, and individuals to support more stroke patients and creative projects.

Table 7: Stroke-related services provided by CHSS

However, challenges also exist in the operation of the remote rehabilitation system before its wide adoption. For instance, the acceptance of telerehabilitation by therapists and patients is not widespread enough. Some therapists worry that new technology will replace their status and lead to unemployment, or it might increase daily work intensity and duration. While some patients think that this form of treatment is not professional enough, and too many complicated wearing devices make patients feel dangerous and tiresome (Di Loreto et al., 2011; Vogiatzaki, 2016). Moreover, the data security and confidentiality of the patients on the remote rehabilitation platform must be protected (Di Loreto et al., 2011). Furthermore, business models and industry supply chains are complex. China needs to explore a set of business models that are suitable to the Chinese market.

Therefore, the remote rehabilitation system in this study is based on China's Level-Three rehabilitation model and refers to mature technologies and remote rehabilitation services in developed countries. In addition, the business model and service process that are suitable for China's actual conditions will be further developed in Chapter 5.

2.5.2 Upper limb rehabilitation product classification

This study aims to provide household and active mode of occupational therapy for mild stroke patients. Therefore, this section includes three classifications according to application scenarios, training types, and exercise modes. Based on different ways of classifications, upper limb rehabilitation products can be divided into medical and household, physical therapy and occupational therapy, passive mode and active mode.

(1). Classification according to application scenarios
Upper limb rehabilitation products can be divided into two types according to the application scenarios: medical and household. Medical rehabilitation equipment needs to meet the relevant standards and regulations formulated by the state. They have high quality and safety, but they are often complicated and require professional staff with practical knowledge and experience to operate (Du, 2017). Therefore, medical rehabilitation products are not suitable for patients to use at home alone. Nevertheless, there are very few home rehabilitation products on the market because of the limited development of remote rehabilitation systems and incomplete standards and regulations.

(2). Classification according to training types

Upper limb rehabilitation products can be mainly divided into two types: physical therapy and occupational therapy products. Physical therapy mostly includes range of motion training and muscle strength training through joint flexion and extension to prevent muscle atrophy and accelerate the recovery of limb function. While occupational therapy mainly includes fine skills and hand-eye coordination training. Occupational therapy refers to improving the flexibility of the upper limbs through some movements with a higher degree of precision to improve the daily living ability of patients. Table 8 presents a selection of the professional medical rehabilitation equipment provided by QianJing medical device company for general hospitals:

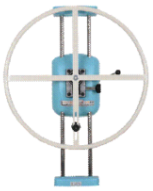
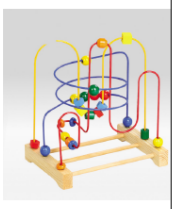
Physical therapy products		**Occupational therapy products**	
	**Name:** Upper and lower limbs bicycle **Purpose:** Suitable for active and passive training of upper and lower limbs with sitting posture		**Name:** Wooden board **Purpose:** To train the coordination of eyes and hands by inserting the sticks into the specified position accurately
	**Name:** Shoulder rehabilitation trainer **Purpose:** To improve the range of motion of shoulders' and elbows' joints		**Name:** Iron board **Purpose:** To train the coordination of eyes and hands by inserting the thin iron sticks into the specified position accurately
	**Name:** Shoulder rehabilitation trainer **Purpose:** To improve the range of motion and strength of shoulders' and elbows' joints		**Name:** 3D maze trainer **Purpose:** To train the stability of the upper limbs and brain cognition about colors and shapes
	**Name:** Wrist rehabilitation trainer **Purpose:** To improve the range of motion and muscle strength of wrists' joints		**Name:** 2D maze trainer **Purpose:** To improve the flexibility and consistency of hands and brain cognition about colors and shapes
	**Name:** Multi-function trainer **Purpose:** To improve the range of motion of all parts' joints		**Name:** Balls and sticks **Purpose:** To improve the range of motion and coordination of upper limbs by completing the tasks with balls and sticks

Table 8: A selected list of physical and occupational therapy products

By comparing these two types, it can be seen that most physical therapy products are made of steel with mechanical structure, which the patients must bind with a rope before using them, while most occupational therapy products are made of wood or cloth with bright colors, which focus more on the fine skills and can optimize the cognitive ability while training the upper limbs.

(3) Classification by exercise modes
Upper limb rehabilitation products can be divided into two types according to the exercise modes: passive mode and active mode. Passive mode is mainly used in early rehabilitation. The muscle strength of the patients at this stage is weak and unable to exert force actively. Therefore, patients must wear or use auxiliary rehabilitation equipment to do repeated flexion and extension in order to promote blood circulation and prevent muscle atrophy of the affected side. Active mode is suitable for the rehabilitation training of mild and moderate stroke patients. After a certain recovery of the upper limb muscle strength, the patient can complete the prescribed movement in a certain period without relying on external forces. At this time, muscle strength training and hand refinement training can be further carried out to speed up the recovery of the affected side and train the brain cognition.

2.5.3 Case Study

This section includes three case studies. As most remote rehabilitation products and services in China are still at the concept stage, the author chooses one domestic conceptual case and two foreign practical cases from Singapore and California to gain some further indications and synthesis for creation on the ideation part. Three case studies include "IKcare" provided by XunKang medical equipment company in China, "ArmMotus" provided by Fourier Intelligence Company in Singapore and "FitMi" provided by FlintRehab Company in California. The author first outlined the brief introduction of each case, then analyzed the innovations of the design outcome and the opportunities that can be improved.

(1). IKcare
Brief introduction: IKcare accurately captures limb changes by attaching sensors to the body, and then the user performs specified rehabilitation training by following 3D animated characters in the software application. The main components are shown in Figure 11 on the next page.

Figure 11: The scenario and main components of IKcare
(Source: http://www.ikcare.com/)

Innovations: IKcare's main innovation is the virtual three-dimensional character animation, which contains rich rehabilitation training movements. It solves the problem of limited rehabilitation guidance for users without the supervision of the therapist at home.

Opportunities: First, IKcare is still in the concept stage and its technical feasibility has yet to be verified through functional models. Secondly, this training mode is mainly aimed at range of joints' motion of different parts of the affected side. The last system is lacking strength training and fine movement training.

(2) ArmMotus

Brief introduction: ArmMotus is designed to promote neuroplasticity of upper limb function in patients with neurological brain injury. ArmMotus provides diversified task-oriented training to measure as well as improve the strength, speed and accuracy of the user's upper limb movements with an immersive interactive experience. The main components are shown in Figure 12.

Figure 12: The scenario and main components of ArmMotus
(Source: http://www.fftai.com/)

Innovations: ArmMotus has two main innovations. The first is through the X-Y two-dimensional orbit, a variety of training programs are provided for the complex movement of shoulder and elbow joints. Therapists can customize specific exercise prescriptions according to different situations of users to achieve multiple trajectory training in the plane. The second is providing comprehensive safety protection measures including hand elastics, emergency stop buttons, electronic fences, etc. These protection measures can provide multiple levels of safety for patients at home.

Opportunities: This product is more suitable for remote community rehabilitation places, because of the large size of the device, this cannot be easily placed and stored at home. Another limitation is that the X-Y orbit is not particularly flexible for curved movements and instantaneous movements from one point to another. In addition, the movements formed by the X-Y orbit are in the same horizontal plane and they lack vertical motion.

(3) FitMi

Brief introduction: FitMi is a simple rehabilitation device suitable for patients or the elderly at home to improve mobility for hands, arms, core, and legs. Through two blue and yellow disks with precise sensors and a tablet computer, forty full-body exercises, and ten difficulty levels designed by expert therapists, FitMi can help patients improve their motion ability. Training is divided into three simple steps: 1) choose which body part you want to exercise; 2) set parameters to customize the training program 3) start training and follow the visual instructions on the interface. The main components are shown in Figure 13.

Figure 13: The scenario and main components of FitMi
(Source: https://www.flintrehab.com/product/fitmi/)

Innovations: FitMi has one primary innovation. The device covers the whole body's movements with just two small disks to complete a large number of repetitive exercises of stroke patients. According to FitMi's experimental study, users performed twelve times more exercise repetitions than traditional therapies.

Opportunities: Although FitMi can perform whole-body movements by touching and moving two blue-yellow disks, the motion path is mainly a straight line formed by two points and lacks fine movements and hand grasp training. In addition, when performing foot training, the patient needs to step on the disks, and when performing hand training, the patient needs to touch the disks. Therefore, it is necessary to pay attention to the cleaning, to prevent bacterial infection.

Summary of chapter 2

To sum up some central findings of this literature review, the author describes the key points in Figure 14 below. One possibility for the remote rehabilitation system can include a rehabilitation product and a digital platform. Based on these two elements, task-oriented bilateral training with low-cost, high-precision sensors are quite feasible, and video calls with FMA can evaluate the training results. The next chapter will further introduce the field research in two hospitals in Shanghai to collect both the patients' and therapists' needs and opinions about rehabilitation after a stroke so that the main functions and characteristics of these two elements can be determined.

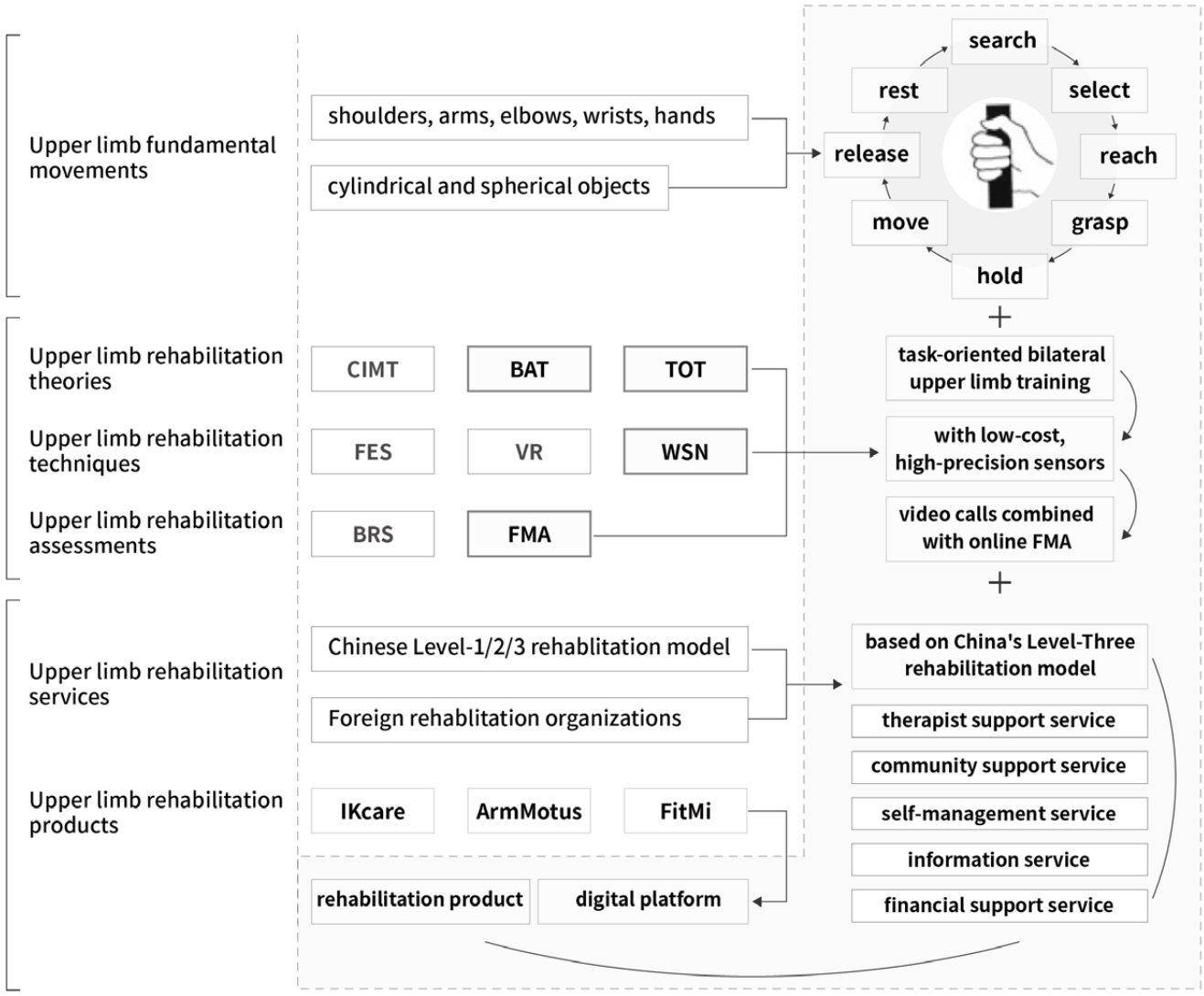


Figure 14: Key points of literature review

CHAPTER 3

METHODS AND DATA

METHODS AND DATA

In this chapter, the author describes qualitative field research of stroke rehabilitation service system, including mild stroke patients and professional therapists. Firstly, the author used observation methods to observe the patients who received upper limb rehabilitation in hospitals in Shanghai, to understand how the patients spend their days in the hospital and investigate the general physical and psychological needs of ten stroke patients. Secondly, interviews were conducted with patients and therapists to find more specific needs of patients during the process of rehabilitation after discharge, as well as summarize basic upper limb movements that were suitable for home rehabilitation training.

3.1 Preparation on field research

3.1.1 Objectives of the field research

The field research aimed to gather data concerning the four following themes:
(1). Understanding the stroke patients' issues as well as both physiological and psychological needs during the rehabilitation process through the observations and patients' interviews;
(2). Understanding the existing upper limb exercise methods, which are suitable for a home environment with the therapists' interviews;
(3). Understanding the relationship between stroke patients and other stakeholders in the entire rehabilitation service system;
(4). Exploring design opportunities and discussing their feasibility with targeted patients and therapists;
(5). Understanding how different elements can be connected in a sensitive and meaningful PSSD.

3.1.2 Procedures of the field research

The field research included four stages: observations, interviews, shadowing, and prototype testing. This field research was conducted in Shanghai and it was a

starting point for the future remote rehabilitation service system concept. The reason for this choice was that Shanghai implemented a new policy on January 1st, 2018, which states that patients who had been in the hospital for one year cannot continue their recovery in the hospital. This decision dramatically promotes the concept of remote home rehabilitation. In addition, the development of economy, technology, and education in Shanghai are much higher than those in remote cities, whose desire and acceptance of remote rehabilitation are at a much higher level. Table 9 shows the timeline and the detailed plan of the entire field research.

Date	Place	Objects	Methods
2019.01.05	Hospital A's rehabilitation department and wards	Therapists & stroke patients	Observations
2019.01.06	Hospital B's rehabilitation department and wards	Therapists & stroke patients	Observations
2019.01.09	Hospital A's rehabilitation department	Five representative stroke patients	Interviews
2019.01.11	Patient's home	One stroke patient	Shadowing
2019.01.15	Hospital A's rehabilitation department	Therapists	Interviews
2019.01.16	Hospital B's rehabilitation department	Therapists	Interviews
2019.07.09	Patient's home	Patients and families	Shadowing
2020.02.27	Patient's home	Patients and families	Prototype test
2020.02.28	Online	Therapists	Prototype test

Table 9: Date, place, objects and methods of the field research

Stage One: observations

The author had two-day observations in a rehabilitation department and wards in a general hospital (Hospital A) located in the suburbs of Shanghai, and a professional rehabilitation institution (Hospital B) in the center of Shanghai. The basic needs of stroke patients in the hospital were summarized by recording the surrounded environment, the behaviors and emotions of stroke patients during the treatment.

Stage Two: Interviews

The author has chosen five representative stroke patients and five therapists to conduct face-to-face interviews in the hospital in order to obtain the patients' real feelings and potential needs. In addition, through interviews with the therapists, the needs of patients from therapists' perspectives and their recommendations about

upper limb rehabilitation training that could be performed by patients at home were obtained.

Stage Three: Shadowing

The author has chosen one patient and spent two days in the hospital and at the patient's home respectively for shadowing to form a concrete user journey map. During the shadowing, the patient's behavior, touchpoints, emotions, and opinions of the preliminary concepts are shared with the author.

Stage Four: Prototype testing

The author turned design ideas and concepts into physical and virtual prototypes. Following the first stage, then the user feedback and experience were collected online and offline from both patients and therapists. Based on participants' suggestions, the solutions were updated and developed in order to meet all actors and stakeholders' expectations.

3.2 The observations

3.2.1 The process of observations

(1). Scenario One: Occupational treatment area in Hospital A's rehabilitation department

Environment: The Hospital A's rehabilitation department was a large room of about 100 square meters. All the upper limb and lower limb rehabilitation equipment were placed inside, and there was a small room dedicated to providing a quiet environment for speech therapy. The large room was divided into two main areas: the occupational therapy area and the physical therapy area. In different areas, there would be corresponding therapists to guide and treat patients.

Behavior:

a) Each patient must be accompanied by a family member or a caregiver.

b) For some passive-mode rehabilitation equipment, the therapist would ask the family members or nursing workers to continue supervising the training after the therapist had adjusted the training parameters (such as intensity, duration, tightness, etc.). Therefore, the therapist could save time to provide rehabilitation guidance for more patients.

c) Most therapists would give some positive feedback immediately after the end

of each rehabilitation training, such as "You look very well today", " This week's performance is better than last week's " and so on (see Figure 15).

Figure 15: Behavior in Hospital A's rehabilitation department

(2). Scenario Two: Wards of neurosurgery inpatient department in Hospital A

Environment: There were three beds in each ward with curtains, providing a private space. Patients with severe stroke were often unconscious, unable to speak, had no reaction with their limbs, and could only lie on the bed. In contrast, patients with mild stroke had varying degrees of slowness and weakness on one side of the limb and were commonly taken care of by one family member or caregiver. In the ward, most mild patients spend their time lying on the bed to rest, watching TV, or chatting with their families, while a small number of patients do rehabilitation exercises actively in the ward or the corridor.

Behavior:

a) When patients were recovering from static stretching, they would relieve the boring time by watching videos or chatting with other patients.

b) Under the guidance and supervision of the family members, some patients would conduct simple daily activities training on the affected upper limb, including dressing, washing, and writing, etc.

c) Accompanied by family members, some patients would conduct lower limb training, including squatting, stretching, and walking in the corridor or garden (see Figure 16).

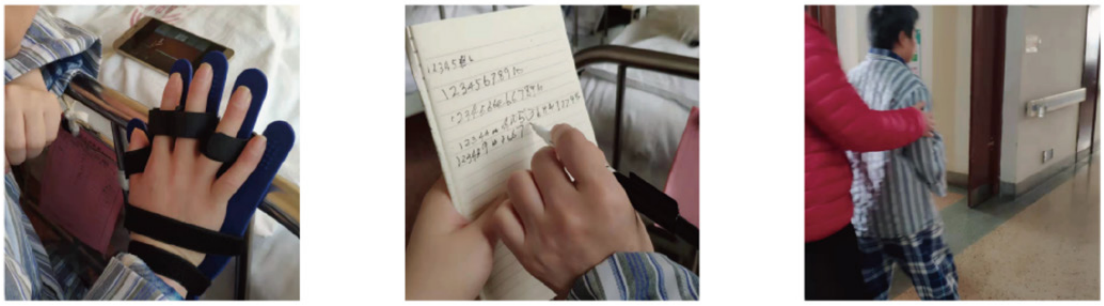


Figure 16: Behavior in Hospital A's neurosurgery inpatient department

(3). Scenario Three: Occupational treatment area in Hospital B's rehabilitation department

Environment: The Hospital B 's rehabilitation department was divided into different small rooms, and each room contained different rehabilitation exercises. There was a large long table in the occupational therapy room, which was full of various upper limb rehabilitation equipment. Each therapist arranged his or her working time and provided one-to-one rehabilitation guidance for the patient. Under normal circumstances, there were three to four groups of therapists and patients around the table, and the treatment time of each group was about half an hour.

Behavior:

a) There were usually three to four groups of therapists and patients training at the same time around the table, forming a good atmosphere, but sometimes they were easily distracted by the sounds or unexpected events by other groups.

b) During the speech therapy, the pictures on the cards are mainly about vegetables, fruits, and daily necessities, which are in rich colors and are familiar to patients.

c) During the training, therapists mainly used repetitive and encouraging words to guide the patient to complete the task independently and played a role of supervision. When the patient made a mistake or could not understand the instructions, the therapist would assist the patients training through hand-to-hand guidance.

d) Most rehabilitation devices on the table were made of wood and very colorful.

e) Most of the upper limb rehabilitation devices were in the form of thick or thin sticks, and the patient carried out rehabilitation training by holding and moving them.

f) At the end of the training, some patients were a bit pound because they completed the goals of the task, while some patients might end the upper limb rehabilitation early because of their physical conditions or the task was too challenging to complete (see Figure 17).

Figure 17: Behavior in Hospital B's rehabilitation department

(4). Scenario Four: Wards of neurosurgery inpatient department in Hospital B

Environment: In Hospital B, most therapists spent half a day in the rehabilitation room and the rest of the day in different wards in the inpatient department on bedside training for patients who could not reach the rehabilitation room. Each patient was given about 20 minutes to exercise with the help of the therapist. In addition, each ward usually had 3-6 patients who were quite familiar with each other and one caregiver to look after all the patients and be responsible for the cleaning of the ward.

Behavior:

a) The therapist's rehabilitation training in the ward was mainly divided into three steps. Firstly, the therapist helped the patient with ADL training such as dressing and putting on the patient's shoes. Then the therapist helped the patient with exercises such as squatting and stretching to improve joints' range of motion. Finally, the therapist used functional electrical stimulation (FES) to relax the muscle.

b) While instructing the patient to exercise, the therapist would chat with the patient about her physical condition, mood and thoughts. In addition, the therapist would talk about other patients' interesting stories if the patient felt anxious or depressed.

c) Therapists had tried to use more electronic equipment and corresponding software to arrange cognitive rehabilitation training for patients.

d) The five patients observed were not exclusive to the smart devices and they learned very quickly (see Figure 18).



Figure 18: Behavior in Hospital B's neurosurgery inpatient department

3.2.2 The results from the observations

Based on the observations of the above four scenarios, the author concluded the following general rehabilitation needs for most stroke patients in the hospital:

(1). A need for diversity of rehabilitation equipment: Each patient will use more than eight pieces of rehabilitation equipment on average every day, including at least four pieces of upper limb rehabilitation equipment. Therefore, there is the question of how to bring the functions of numerous upper limb-training devices back to the family, so that stroke patients can get comprehensive upper limb exercise. For the development of rehabilitation products design, this need should be fully considered and studied.

(2). A need for personalization of rehabilitation exercise: There is a great variety in the disabilities and physiological characteristics that stroke patients have. Therefore, even they use the same equipment, the therapist will adjust the parameters of the equipment before each patient is trained, such as training duration, frequency, intensity, and difficulty.

(3). A need for professional guidance: During the rehabilitation, clear instructions from the therapist will make the training more organized and the patient's attention more concentrated (Ostwald et al.,2008). Sometimes, the patient does not understand the therapist's instructions, and the therapist needs to repeat the instructions patiently until the patient follows.

(4). A need for straightforward & understandable information: In the process of guiding patients, the therapist should avoid the use of medical or technical terms. Instead, simple and understandable sentences and instructions are expected.

(5). A need for safety: Most patients lose their abilities to take care of themselves after stroke, and they need family members or caregivers to look after them instead. Patients should be given more attention and supervision, and accompanied by family members if necessary, to avoid falling or other accidents in the daily life and rehabilitation exercising.

(6). A need for psychological intervention: Due to the lack of psychological preparation for the disease, patients often have psychological problems such as depression and anxiety. Furthermore, the long and tedious rehabilitation training can also easy to generate negative emotions for patients. During this time, stroke patients need to carry out corresponding psychological treatments, such as appropriate psychological treatment, family encouragement, social support, and incentives for rehabilitation progress.

3.3 The interviews

3.3.1 Interviews with the mild stroke patients

Although the target group is stroke patients, not all stroke patients have the ability to continue the rehabilitation at home. As shown in Table 10, the author firstly summaries inclusion criteria and exclusion criteria for patients suitable for remote upper limb rehabilitation based on literature research (Franceschini, 2020; Lin & Yan, 2011) and professional suggestions.

Inclusion criteria
More than 6 months post stroke
Mild upper limb impairment (FMA's upper limb scores between 18~56 or in 5~7 Brunnstrom Recovery Stages)
Ability to understand and follow simple instructions
Ability to maintain a sitting position

Exclusion criteria
Severe bilateral impairment
Refusal or inability to provide informed consent
Have other severe medical conditions or problems

Table 10: Inclusion and exclusion criteria

Furthermore, according to the criteria, five target users were selected from the above four scenarios. Table 11 summaries participants' personal information, including their ages, main symptoms, place of rehabilitation and other diseases that they had.

Name	Age	Main Symptoms	Place of Rehabilitation	Other Diseases
Patient A	50	Mobility problem (right side affected) Speech and communication problems Memory problem	In Hospital A (go home soon)	None
Patient B	71	Mobility problem (left side affected) Speech and communication problems	At home	Hypertension
Patient C	42	Mobility problem (left side affected) Speech and communication problems	In Hospital A	None
Patient D	70	Mobility problem (right side affected) Speech and communication problems Memory problem	In Hospital B (go home soon)	Hypertension
Patient E	53	Mobility problem (left side affected)	In Hospital B	Diabetes

Table 11: Five target patients to be interviewed

The content of the interview was recorded using notes and taking photos. In consideration of the sensitivity of stroke patients to their conditions, the interview was mainly conducted by chatting to create a relaxed atmosphere. The general outline of the interview of stroke patients with prop questions is in the appendix.

During the interviews with the five participants, most of them were able to answer the questions. In some cases, for example, when the patients didn't know how to answer, or the physical condition became worse, the family members responded instead. In addition to the differences in patients' ages, symptoms, and family conditions, there were also significant differences in patients' rehabilitation models and daily lives. The following Table 12 summarizes patients' responses in terms of rehabilitation hours, habits and interests, self-care ability as well as their issues.

Name	Rehabilitation hours	Habits/ Interests	Self-care Ability	Issues
Patient A (50)	-3 hours in the morning -2 hours in the afternoon	-Go to bed and get up early -Eat more vegetables and fruits -Stand for a while after eating -Video chatting with daughter and friends -Have a daily timetable -Used to clean the room or do the laundry every day	No (Taken care of by one caregiver)	-Eager to make progress, but cannot see it -Daily life makes her feel bored -The memory is not so good
Patient B (71)	-1 hour in the morning -1 hour in the afternoon -1 hour at night	-Watching news on TV -Drinks water very often -Doing grocery shopping in the morning (Likes to compare food prices)	No (Taken care of by his wife)	-No clear instructions and supervision when exercising at home -There is not many training equipment to exercise with at home compared to in the hospital
Patient C (42)	-3 hours in the morning -1 hour in the afternoon	-Listen to some music and radio -Watch TV series by iPhone -Used to play games on the mobile phone or iPad	No (Taken care of by his mom)	-Feel disappointed with himself due to the failure of reaching certain goals -Feel bored about repetitive and mechanized training
Patient D (70)	-2 hours in the morning -1 hour in the afternoon -1 hour at night	-Planting -Shopping online -Have a timetable -Play chess/cards with others -Used to play table tennis -Used to travel around the world	Yes	-Some high-tech rehabilitation devices which have difficult interactions and complex instruction -Fear of feeling lonely after returning home
Patient E (53)	-3 hours in the morning -2 hours in the afternoon	-Go to bed and get up early -Walk for a while after eating -Eat more vegetables and fruits -Used to travel in other cities -Have a daily timetable	No (Taken care of by one caregiver)	-Sometimes have no motivations to rehab -Feel bored about repetitive and mechanized training -The atmosphere is too quiet sometimes

Table 12: Summary of interviewed patients' response

Summary of interview results

Firstly, most of the patients lost self-care ability due to the loss of motor function and language function caused by stroke. They needed at least one caregiver to accompany them for 24 hours. In addition, many patients' original lifestyles were utterly changed. Their time for work, housework, and social interaction were replaced by medication and rehabilitation training. However, some interests and hobbies were still retained, such as planting, playing cards, watching TV shows, etc. In order to better restore physical health, most patients would develop better lifestyle habits, such as specifying a daily schedule, going to bed and getting up early, paying attention to diet and so on. From this perspective, most patients had a strong need for organized care and rehabilitation.

Secondly, stroke patients were prone to anxiety, loneliness, depression, fear, pessimism, and other negative emotions because it was difficult for them to accept the sudden hemiplegia and loss of self-care ability. Furthermore, in the process of rehabilitation, a long time of repetitive rehabilitation training tends to make patients feel bored and ineffective. A small number of patients feel frustrated for not completing the goals of rehabilitation training or not seeing the progress. Therefore, positive psychological intervention and counseling were also one of the important needs of stroke patients.

As a result, meeting the physiological and psychological needs of patients was complementary and indispensable. For example, the progress at the physiological level will bring a sense of pleasure and pride at the psychological level, and the psychological intervention of patients can also alleviate the anxiety after the disease, thus significantly improving the patients' recovery enthusiasm and initiative. During the design of the upper limb rehabilitation treatment system, the relationship between the two should be fully considered and combined to obtain better rehabilitation results for stroke patients.

3.3.2 Interviews with the therapists

The author interviewed five therapists including three occupational therapists, one physical therapist and one speech therapist. The purpose of these interviews was to find out patients' potential needs after returning home, therapists' needs, as well as the rehabilitation training methods that could be implemented at home.

There were three kinds of therapists interviewed: physical therapists, occupational therapists, and speech therapists. Physical therapists helped patients to regain their strength and balance, increase range of motion, and decrease pain. While occupational therapists helped patients to safely and independently perform activities of daily living and improve working abilities. Finally, speech therapists helped patients to conquer communication problems, memory loss, and swallowing dysfunction. Table 13 represents the basic information about the interviewed therapists:

Therapists	Age	Employment Length	Types
Therapist A	24 years old	5 years	occupational therapist
Therapist B	24 years old	2 years	occupational therapist
Therapist C	33 years old	12 years	occupational therapist
Therapist D	30 years old	10 years	physical therapist
Therapist E	26 years old	2 years	speech therapist

Table 13: The basic information about interviewed therapists

Figure 19: Interviews and discussions with therapists

The main interview contents are shown in the following Table 14:

Q1：What parts of the body of most patients are affected by the stroke?
Therapist A：Half side of limbs, speech ability, swallowing control center.
Therapist B：Upper and lower limbs.
Therapist C：Parts which are controlled by the brain that are affected by stroke.
Therapist D：Half side of upper and lower limbs.
Therapist E：The upper and lower limbs.
Q2：What are the best expected results after rehabilitation?
Therapist A：First restore a certain motor function, and then can live independently.
Therapist B：Based on the patient's own condition and duration of rehabilitation.
Therapist C：Can take care of himself in daily life and back to the society.
Therapist D：Can take care of himself and do some simple work like ordinary people.
Therapist E：There must be a gap in life before and after stroke, and the patient need to maintain a peaceful mood every day.
Q3：What do patients and family members need to pay attention to when they return to home?
Therapist A：At the beginning, there must be a plan with goals, which can be achievable. Self-management is very important without the therapist's supervision.
Therapist B：Rehabilitation is not like ordinary people's fitness program. Rehabilitation can be lifelong and step-by-step functional exercises. If you don't practice for a week, you may lose the previous three months of rehabilitation results, including muscle stiffness, cognitive decline, etc.
Therapist C：Encourage effective exercise and socializing in safe conditions.
Therapist D：While persisting in rehabilitation, patients should also pay attention to their daily health, such as balanced diet, no smoking and drinking, taking medicine on time, regular work and rest to avoid other diseases. In addition, patients need to have regular follow-ups to adjust their treatment.
Therapist E：It is important to pay attention to patients' emotion and try to keep them in a happy and relaxed state. The company and encouragement of family members are very important.
Q4：Do you have any recommended exercise methods or equipment for upper limb rehabilitation at home?
Therapist A：Get involved in daily activities, or use a recovery machine that has both active and passive mode.
Therapist B：With the assistance of family members, the patient can exercise shoulders, elbows, wrists and hands to maintain muscle strength and joints' range of motion. In addition, the patient needs to independently complete daily activities such as washing, dressing, eating at home, which is also a kind of training.
Therapist C：Practice daily movements and postures that are close to life.

Therapist D： With the help of family members, patients can perform exercises such as flat lifting, raising, and stretching of the affected side to improve blood circulation and eliminate edema.
Therapist E： The patient can use some simple objects at home such as bottles, chopsticks, pens and towels to complete more daily activities .
Q5： What is the most difficult part of the patient's upper limb rehabilitation at home?
Therapist A： The nervous system need to be rebuilt . This process takes time and the right method, but not everyone can compensate for the system.
Therapist B： Rehabilitation assessments. Very subjective and often depend on the experience of the rehabilitation therapists.
Therapist C： If the patient cannot see the progress, he or she will give up halfway.
Therapist D： Evaluation scales such as Brunnstrom are relatively rough. The evaluation results do not accurately reflect the process and details of rehabilitation. In addition, current rehabilitation assessments rely on manual inspections and observations by doctors. It is even more difficult to evaluate at home.
Therapist E： Rehabilitation training is a long process and will not work in a short period of time. Patients and their families need to enhance their confidence and patience in rehabilitation training.
Q6: How do you define progress in recovery?
Therapist A： Ability to complete certain daily activities independently.
Therapist B： Motor function is restored.
Therapist C： By Fugl-Meyer Assessment Scale.
Therapist D： Fugl-Meyer Assessment Scale.
Therapist E： The patients' ability to take care of themselves.
Q7： When does the patient exercise with the most (least) motivation every day?
Therapist A： More motivated in the morning.
Therapist B： More motivated when the patient finds that he has made progress.
Therapist C： More motivated at about 10 am and less motivated at about 3 pm.
Therapist D： More motivated when gets the therapist’s praise.
Therapist E： More motivated after the target is completed.
Q8： Is there any way to improve the motivation of patients to exercise?
Therapist A： Add some daily-life or gamified scenarios.
Therapist B： If the patient can earn something from exercises.
Therapist C： Real progress and appropriate encouragement.
Therapist D： Correct education and guidance.
Therapist E： Set targets which can be achieved by effort.

Q9： What do you think of the remote rehabilitation system? (e.g. Who is important in this system? What is your role in this system? What kinds of technology and information are necessary to support the entire system?)
Therapist A： Nowadays, there are more and more online consultation platforms and extending the hospital's rehabilitation services to the family or the community is an important trend. However, how to allocate responsibilities and risks requires new policies and laws, so it is estimated that it will take another five years to really implement.
Therapist B： Remote rehabilitation will be more convenient for patients, but for doctors and therapists, however, how to measure and supervise, how to reasonably arrange our workload online and offline without making mistakes related issues need to be taken into account.
Therapist C： Remote rehabilitation is a good concept, especially for patients.
Therapist D： It can be properly promoted, but cannot completely replace the traditional rehabilitation because the first 6 months are the golden rehabilitation period which should be more effective under the guidance and supervision of a therapist.
Therapist E： Rehabilitation is a team-based work and any role is important. I will complete the work requirements and instructions given to me, but I think the whole system needs some time for everyone to understand and learn, it is impossible to master all at once.

Table 14: Interviews content with five therapists

3.3.3 The results from the interviews

According to the interviews with patients and therapists, the author summarized them into three aspects: 1). the added patients' needs, 2). the therapists' needs, 3). home rehabilitation training methods suggested by therapists.

1). Patients' needs

In the analysis of observation results, the author summarized the basic needs of patients in the hospital. While based on in-depth interviews with patients and therapists, the following needs are added to meet patients' potential requirements when they return home:

(1). A need for professional rehabilitation goals: Patients might be disappointed or even want to give up rehabilitation when they cannot complete the goals. According to Rehman's "SMART GOALS" standard, rehabilitation goals should be Specific, Measurable, Attainable, Realistic, and Time-based (Rehman,2014). This standard

means that treatment activities should be task-specific, with assessment methods to give feedbacks on exercise results. In addition, patients can achieve their goals through a certain period of effort and be graded quickly. Furthermore, the tasks should always be updated according to the situation of the individual.

(2). A need for miniaturized rehabilitation devices: The patient's living environment is not like the hospital, with an ample space for different types of rehabilitation equipment. Therefore, most patients prefer small and portable rehabilitation devices that can be used in different areas at home.

(3). A need for straightforward and easy-to-use physical interaction: Although most patients have a high acceptance of electronic devices such as mobile phones and computers, they prefer simple physical interactions with real objects which cost a little time to learn.

(4). A need for multi-sensory information feedback: Multi-sensory information feedback means that patients can receive signals from the outside world through vision, hearing, and touch and then take action. For example, bright colors and sudden sounds attracted stroke patients easily.

(5). A need for an effective incentive mechanism: During the rehabilitation process, long-term repetitive rehabilitation training and no progress might make patients feel bored and want to give up halfway. An effective incentive mechanism can arouse the continuous attention and interest of patients to participate in remote rehabilitation actively.

(6). A need for medication reminders and monitoring: Most stroke patients also suffer from chronic diseases such as hypertension and diabetes, which are also easy to cause the recurrence of stroke. Therefore, it is necessary to take medicine and monitor health conditions regularly.

2). Therapists' needs

Although stroke patients are the primary beneficiaries, therapists, as the service providers who are intimately in contact with patients, play an important role in the system and their needs also should be considered. Through interviews with five therapists, the following requirements are collected:

a) Therapists need to be reasonably qualified to work online and offline without increasing their workload.

b) Therapists also need to be trained and taught how to use the products and services.
c) Therapists need a methodology that allows for remote rehabilitation assessment.
d) Electronic medical records need to be better integrated with the rehabilitation system so that therapists can have a more comprehensive and detailed picture of patients.
e) Personal information and data about the therapists and the patients they are responsible for must be kept strictly confidential.

3). Home rehabilitation training methods

Based on the FMA assessment and further communication with the therapists, several basic movements suitable for rehabilitation training at home were initially identified in three levels: basic, intermediate, and advanced level. The basic level movements keep the affected muscle groups active and reduce spasticity, which is the starting point to add flexibility and mobility to the affected arm after a stroke. The intermediate level movements focus on a full range of motion for joints and prevent painful contractures, while the advanced level movements aim to strengthen the muscles and dexterity. Each level's movements are divided into shoulders, arms, and hands parts. The patient only needs a large area board (like a towel), a thick stick (such as a water bottle), a tied stick (such as a pen), and a ball (such as tennis) to complete these movements. The above movements are summarized and illustrated, as shown in Figure 20 on the next page.

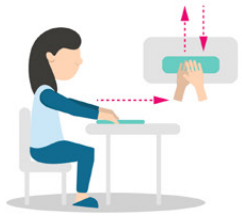
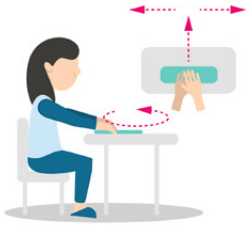
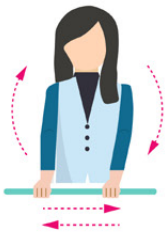
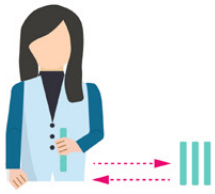
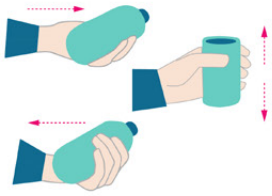
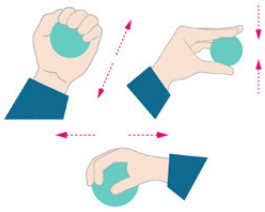
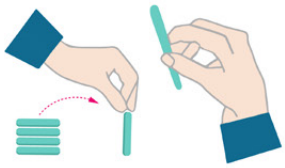
	BASIC LEVEL	INTERMEDIATE LEVEL	ADVANCED LEVEL
SHOULDER	 Shoulder retraction Apply enough pressure to keep your hands together, then use your hand to slide the towel away from you, toward the middle of the table.	 +Shoulder abduction≥90° Use your hand to slide the towel away from you, follow this movement by sliding it from side to side. Finally, incorporate all of these movements into a series of circular motions.	 +Shoulder elevation +External/internal rotation Hold the stick with both hands in front of your body with your arms bent at a 90–degree angle at your sides. Next, push the stick outward to your left and right without dropping your arms.
ARM	 Wrist Circumduction Elbow flexion/extension Hold the arm at a comfortable position, then carefully bend and straighten the elbows as if you are doing a dumbbell curl.	 +Arm strength Hold a small weight in your hand. Gently bend and straighten the elbow. Repeat to your endurance point. Over time, increase repetitions as the elbow strengthens.	 +Wrist and arm stability Elbow flexion/extension Use the weaker hand, take each stick and place it in the cup. And then use the weaker hand, take out each stick one at a time.
HAND	 Cylinder grasp cylinder shaped object (small can) tug upward, opposition of thumb and fingers Place a water bottle in the affected hand. Keep the affected hand and fingers relaxed. Curl the fingers in and grasp the water bottle then release. Then move the bottle from A to B.	 Spherical grasp fingers in abduction/flexion, thumb opposed, tennis ball, tug away Hold ball tightly in palm of hand. Squeeze the ball, hold, and relax. Repeat ten times, for two sets. Then move the ball from A to B.	 Pen grasp pulpa of the thumb against the pulpa of 2–nd finger, pencil, tug upward Place a coin or pen to the side of the table and then gently grip it with the affected fingers. Slide the pen across the table, and then release. Repeat ten times, for two sets.

Figure 20: The basic movements suitable for upper limb rehabilitation training at home

However, these training methods are not enough to keep the patients motivated to complete exercises every day due to lack of training guidance, feedback, records, and assessments. For example, one patient went home with oral advice from his therapist to use bottles and chopsticks for upper limb exercise. After two weeks, he gave up due to a lack of supervision and motivation. Some patients may even cause muscle and joint injuries due to improper exercise methods or unscientific control of training intensity and duration. Therefore, when it comes to the design concept of the home rehabilitation device and digital system platform, the solutions should be based on the above home upper limb rehabilitation training methods but considered more systemically.

Summary of chapter 3

In a nutshell, this chapter described the process of observations and interviews to have insight into stroke patients' and therapists' needs. In addition, the author visualized the home rehabilitation training methods suggested by therapists to further develop them in chapter 5. In the next chapter, the author will apply service design principles and tools to analyze and summarize information and insights from this chapter in order to transform user needs into specific design concepts.

CHAPTER 4

ANALYSIS AND KEY FINDINGS

ANALYSIS AND KEY FINDINGS

In this chapter, the author applied service design tools to analyze and summarize the findings of patients and medical workers in the remote rehabilitation service system based on the field research. For example, persona, user journey map, and stakeholder map were used to define typical users from basic information, physical condition, goals, behaviors, and relationships with others. Finally, the design opportunities and concepts were developed according to the conclusions from each chapter before.

4.1 Findings

4.1.1 Summary of patients' needs

In the process of designing remote upper limb rehabilitation services for stroke patients, the accurate positioning of user needs can help the designer to clarify the design direction in the later stage. Based on the results of observation and interview research, the author divides all the needs of patients in remote home rehabilitation into three categories: rehabilitation needs, information needs, and emotional needs. See Table 15 for details:

Rehabilitation needs	Information needs	Emotional needs
Professional & achievable rehabilitation goals	Straightforward & understandable information	Encouragement and praise
Multi-functional & small-sized rehabilitation devices	Multi-sensory & immediate feedback	Effective incentive mechanism
Simple interactions	Visual display of data and information	Effective companionship of the family
Effective rehab training methods	Multi-dimensional data reporting	Support and social contact with peers
Personalized rehab training content	Medication Reminder	Social support and financial help
Professional rehabilitation assessment	Confidentiality of patient data	

Table 15: The stroke patients' needs

The core needs in which service design can intervene and play a leading role are multi-functional and small-sized rehabilitation devices with simple interactions, visual display of data and information, effective incentive mechanism. Other patients' needs, such as professional rehab goals and rehab assessments, are dominated by the medical field, while data confidentiality and multi-dimensional data reporting are driven by technology.

4.1.2 Persona of stroke patients and therapists

Personas are fictional profiles of a particular group of people based on their shared characteristics, behavior, needs, interests, and issues, built after an exhaustive observation of the potential users (Stickdorn & Schneider, 2011). Among all the stakeholders, patients and therapists are two main stakeholders in the remote rehabilitation system. Through the observation and interview of patients and therapists, the author created two virtual personas (see Figure 21 & Figure 22) as typical users to guide the subsequent design.

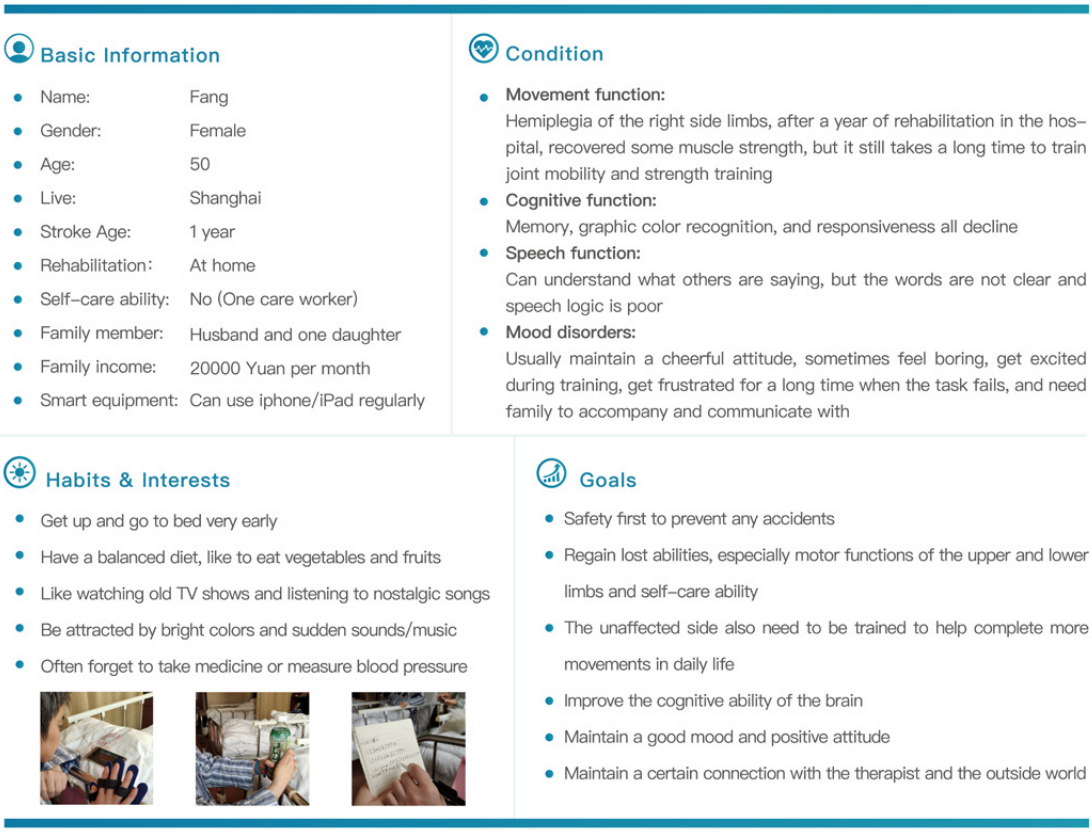


Figure 21: The stroke patients' persona

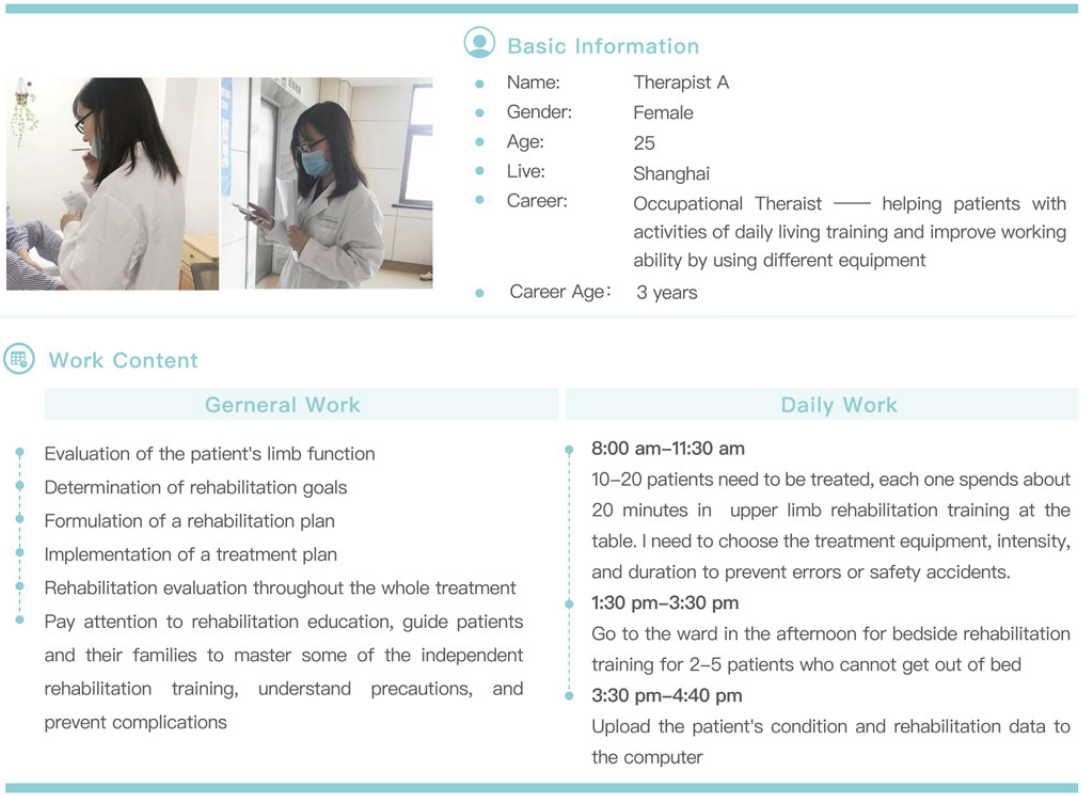


Figure 22: The therapists' persona

4.1.3 Stakeholders

In addition to stroke patients and therapists, many other stakeholders are in various ways involved in the remote rehabilitation service system. With the stakeholder map Figure 23(on the next page), complicated relationships between different stakeholder groups in the remote rehabilitation service system are visualized and listed, to help the author to identify opportunities for optimizing service processes later.

Stroke patients and their family members are end-users in the home rehabilitation system. They are the main stakeholders who may benefit or suffer due to the changes in the system. In general, they have a strong interest but very little power to influence it. Designers need to anticipate their needs and keep these stakeholders informed to ensure their continued attention.

Administrators in the hospitals and medical device companies are key stakeholders who have the authority to make the decisions and changes by organizing and arranging projects and workload. Therapists and staff in the medical device

companies are the service providers responsible for finishing the working plan according to the department's index.

Other secondary stakeholders such as care workers, stroke survivors, researchers, investors provide different kinds of supports, including care, emotion, knowledge, and finance support respectively. Although they may not be so active in the system at first, their relevance may change over time and contribute a considerable boost in the process.

Service designers need to comprehensively consider all stakeholders and strive to enable most stakeholders to play an effective and enjoyable role in the service process, but the needs and interests of main stakeholders should be met first to ensure the basic engagement and support.

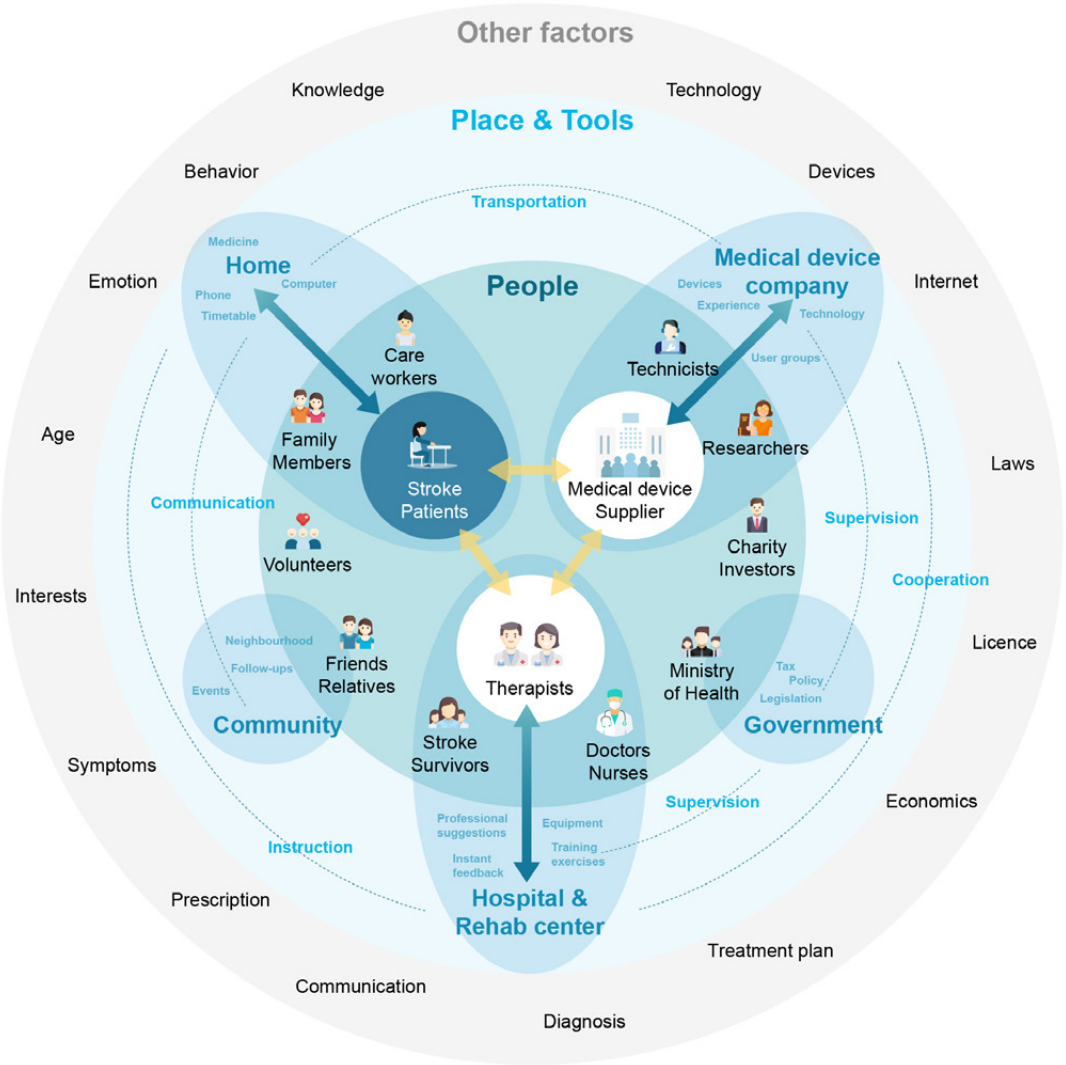


Figure 23: The stakeholder map

4.2 Findings of the stroke patients' service journey

4.2.1 Touchpoints in the stroke patients' service journey

The service journey map describes the journey of a user by representing the different touchpoints that characterize their interaction with the service (Stickdorn & Schneider, 2011). Based on the persona of the targeted patients, the designer draws one service journey map which is divided into three stages: 1) the early stage including diagnosis, treatment and rehab and care in the hospital; 2) the mid-stage including discharge and rehab and care at home; 3) the later stage including follow-up and review. Each stage is vividly structured by the author into touchpoints, user behavior, psychological activities, and emotional ups and downs in order to find pain points and opportunities (see Figure 24).

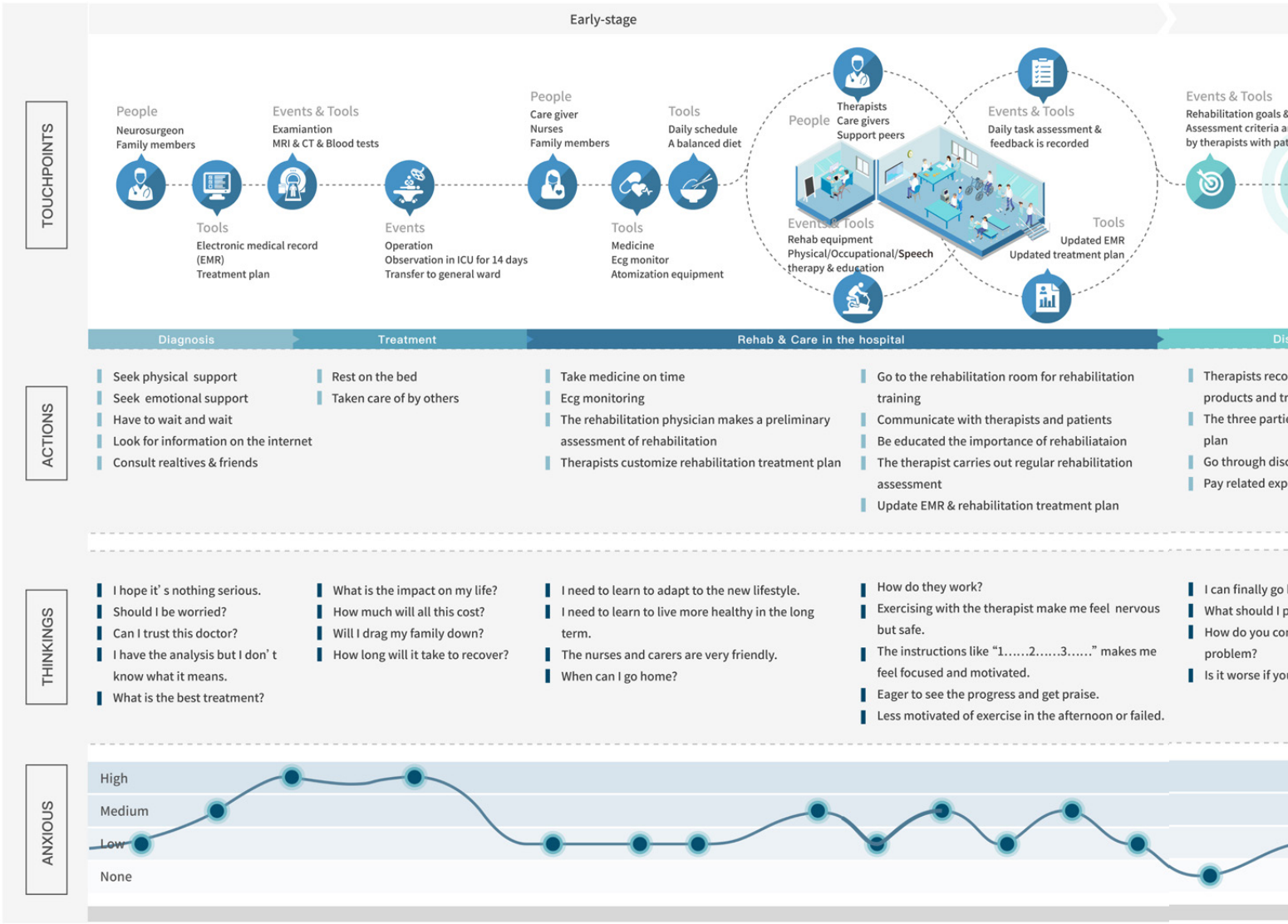
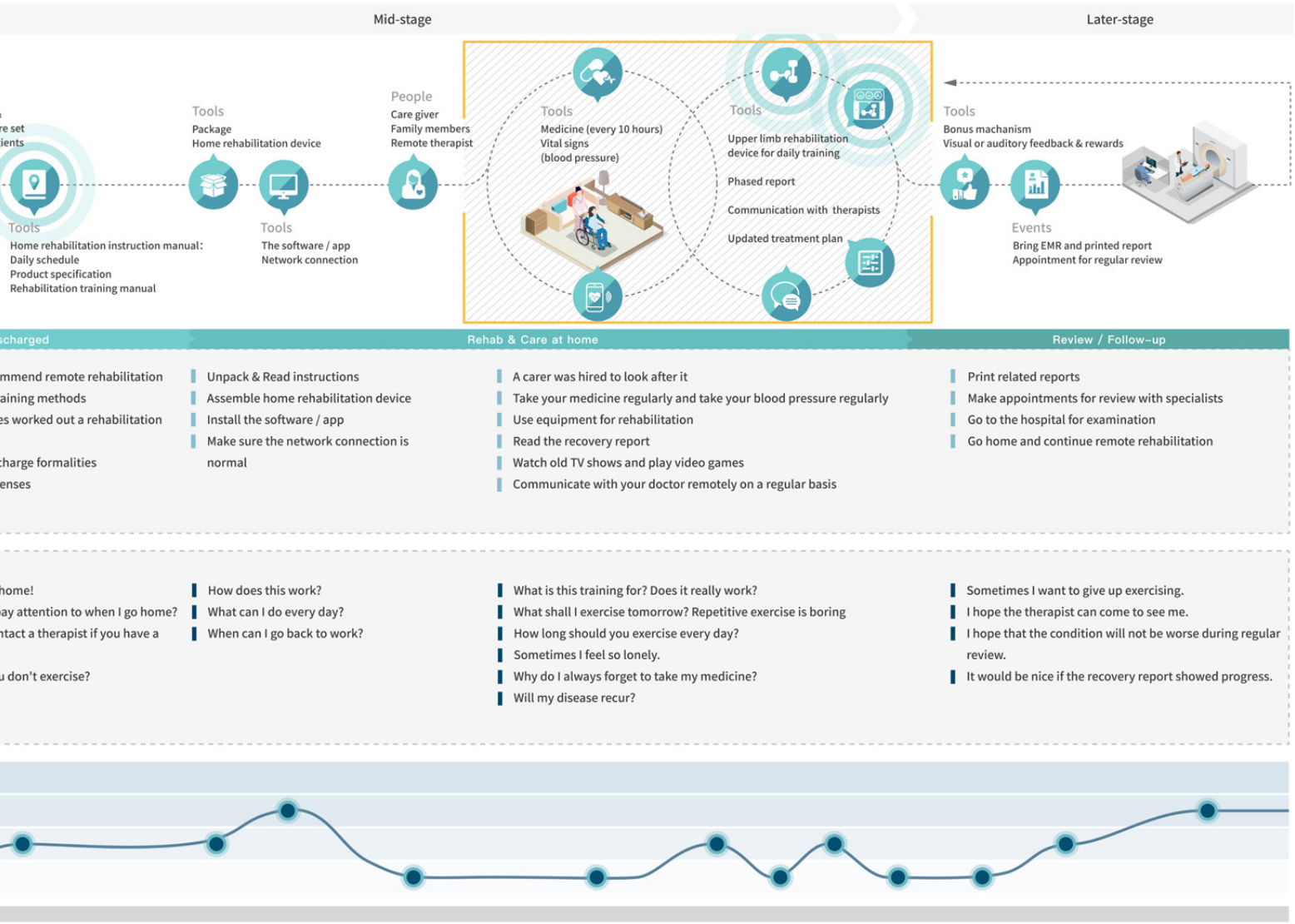


Figure 24: The user journey map



4.2.2 Characteristics of main touchpoints

There are three main touchpoints in this user journey, which include the instruction manual, the upper limb rehabilitation device, and the online platform.

Characteristics of the instruction manual:

(1) The content of the instruction manual can include the daily timetable, rehabilitation goals, treatment plans, and self-assessment forms.

(2) It could have both paper and electronic versions.

(3) It needs to be easy to read and understand. For example, there should be more visual graphics instead of many medical terms.

Characteristics of the upper limb rehabilitation device:

(1) It' s better if the device can be recommended by therapists and tested by patients before discharge.

(2) The device needs to be portable and easily carried back home.

(3) The device needs to have first time use instructions and easily set up for elderly.

(4) It's better if the device can fit into the home interior environment.

(5) The device needs to be multifunctional so that stroke patients can use it to complete different exercises.

(6) The exercises provided by the device need to be personalized by setting parameters such as training duration and repetitions times.

(7) The device needs to have accessible forms of interaction so that patients can operate it with less effort.

(8) Solutions are required to deal with patients giving up or losing interest in the device. For example, providing visual and auditory rewards or positive feedback, like displaying small improvements and gratifying messages in real-time, can improve patients' motivation for exercise.

Characteristics of the digital platform:

(1) Information overload should be avoided by classifying and integrating the information and placing the main content and services in a prominent place with clear instructions.

(2) The logic level should be straightforward and unified, and the user's operation steps should be minimized.

(3) The platform's interface needs to remove unnecessary decorative elements. Using simple elements and graphic are more intuitive and easier to understand than lots of texts.

(4) Reasonable navigation and information feedback are needed to help users to take the next step and avoid mistakes.

(5) When it comes to data transmission, the high confidentiality of patient information should be ensured.

4.3 The development of concept ideas

4.3.1 Patients' pain points

Based on the results of the above desktop and field research, although remote rehabilitation is an inevitable trend in the future, patients will still encounter some pain points when they return home. As shown in Figure 25, one of the main pain points is that the patients need a simple rehabilitation device with clear instructions to complete different kinds of upper limb exercises. Furthermore, with this simple device, patients may have some other pain points during the whole remote rehabilitation system. For example, in the early stage (discharged from the hospital), they need to have basic knowledge of how to operate and train at home. In the mid-term stage (during training at home), they need to have a self-assessment and professional assessment from remote therapists of rehabilitation outcomes. While in the later stage, there needs to be a reward mechanism or incentives to help keep the training up instead of giving up halfway.

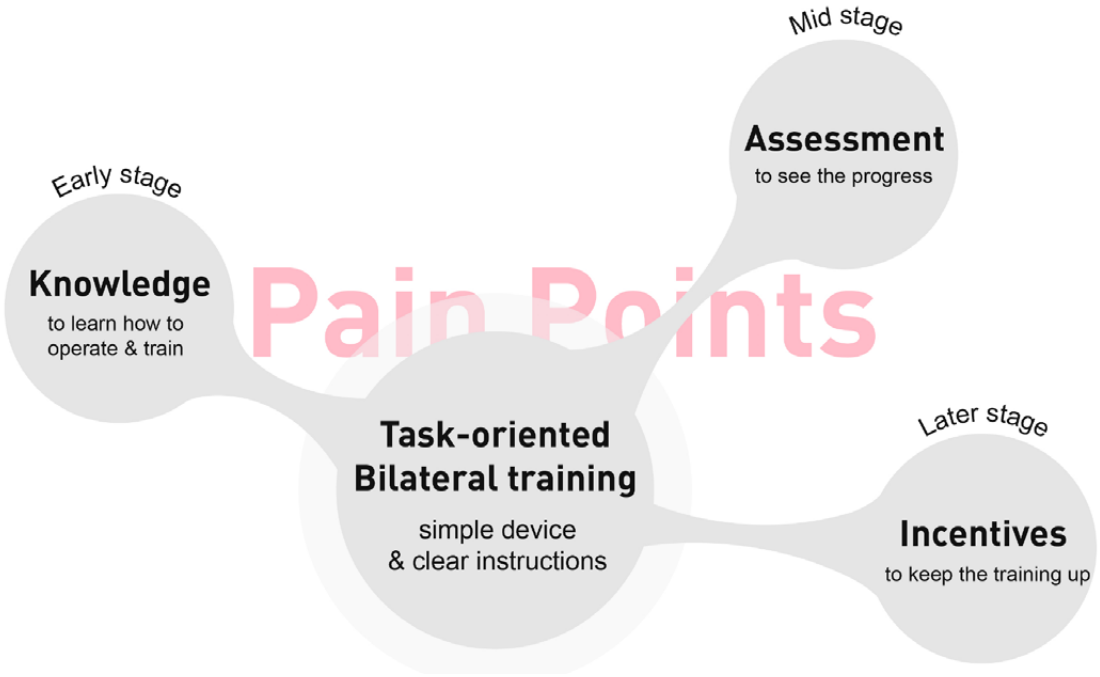


Figure 25: The pain points at home

4.3.2 The design opportunities

The designer made some conclusions through the research and analysis in each chapter. As shown in Table 16, the findings of each part contributed to the design opportunities and guided the following development of remote rehabilitation product and service system design.

Chapter	Research Conclusion	Design opportunities
Chapter 1 Background Research	In China, the population of stroke patients are increasing while the space and resources in the hospitals are limited.	Personalized remote home rehabilitation service system will be promoted in the future.
	75% of stroke survivors have upper limb problems, which cause a decrease in ability and quality of daily life (Lawrence, 2001)	Upper limb rehabilitation can be a starting point for remote home rehabilitation.
	The Chinese government has made great efforts to develop and promote the third-level rehabilitation service model.	The development of remote home rehabilitation can be promoted based on the existing third-level rehabilitation model in China and the role of community therapists can be added.
	The main stakeholders in the remote home upper limb rehabilitation service system usually include hospitals and medical device companies, therapists, patients and family members.	The remote rehabilitation system can be established by the cooperation between the hospital and the medical device company with different management rights. As the users of the platform, the therapists and the patients have different user entrances.
Chapter 2 Theoretical Research	Compared with CIMT, bilateral arm training (BAT) and task-oriented training (TOT) have been proved to be effective in clinical practice and more suitable for patients with mild stroke.	Upper limb exercises with specific tasks can guide patients to actively participate in both upper limbs' motor function training.
	The development of desktop virtual reality technology and wireless sensor network (WSN) technology	Tabletop scene adds immersion and patients' interest.

	are becoming more and more mature and popular.	Sensors can capture human movements and bioelectrical signals from the body.
	Compared with the Brunnstrom assessment, the Fugl-Meyer assessment scale is more specific and quantified, which facilitates the therapist to generate personalized and refined rehabilitation treatment plans.	The simplified online version of the Fugl-Meyer assessment and video assessment are the two efficient and reliable remote assessment methods intended for the therapists.
	Upper limb rehabilitation devices are relatively vacant in China. Foreign rehabilitation systems mainly provide different services through the combination of hardware and software products.	The remote home upper limb rehabilitation service system can be divided into two main parts: the home rehabilitation device and the digital system platform.
Chapter 3 & Chapter 4 User Research	The household rehabilitation devices need to be intelligent, miniaturized, multifunctional and require simple and easy-to-operate physical interaction.	The home rehabilitation device includes a variety of hand grasp modes by means of modularization and a variety of upper limb movement modes by means of point-to-line.
	The purpose of upper limb rehabilitation training includes improving the joints' range of motion, muscle strength, hand-eye coordination and brain cognition.	The home rehabilitation device includes simple, intermediate and advanced upper limb training exercises for shoulder, elbow, wrist and finger joints.
	In addition to rehabilitation needs, most patients also need basic self-health management and good psychological intervention.	In addition to the rehabilitation training function, the platform also needs to add health management functions.
	As the patient's recovery time increases, more exercise data and medical records will be generated.	The digital platform uses data cloud to form patient electronic medical record files, which can be used to store, analyze, and transmit user rehabilitation data.
	Long-term repetitive rehabilitation training can easily cause patients to feel bored and negative, as well as give up training halfway.	Incentives or reward mechanism should be established to improve patients' motivations and enthusiasm.

Table 16: A summary of the research conclusions and design opportunities

4.3.3 The design concepts

The home rehabilitation device is an essential touchpoint in the remote rehabilitation service system. The target users are patients with mild stroke who have the ability to understand and follow simple instructions. According to the stroke patients' user journey and pain points, it is concluded that in the environment of home rehabilitation, patients' needs for a home rehabilitation device include multi-function, portability, understandability, safety, and feasibility. Therefore, the author carried out three preliminary design concepts and compared them based on the evaluation standard in the following Table 17. Finally, the author selected one concept for further development.

Patients' needs	Evaluation standard	Explanation
Multi-function	5 points	Combine a variety of grasping and upper limb movements into one product
Portability	5 points	Small size, easy to install and store
Understandability	5 points	Simple interaction and immediate feedback
Safety	5 points	Round appearance, strong affinity, light material
Feasibility	5 points	Technically feasible and inexpensive to implement

Table 17: An evaluation standard of three concepts

The concept one

Components: a foldable plate with holes, LED lights, sensors, and sticks
Training methods: The lighting mode of LED lights on the foldable plate generates different upper limb movements. The user grasps and holds the stick and traces different paths along the light to exercise the upper limb mobility. In addition, the brain can also be cognitively trained through different lighting modes. For example, by turning on several lights at the same time and immediately turning them off, the user needs to recall the position where the light was just turned on, and then move the upper limb to touch the corresponding light to train the instant memory (see Figure 26 on the next page).

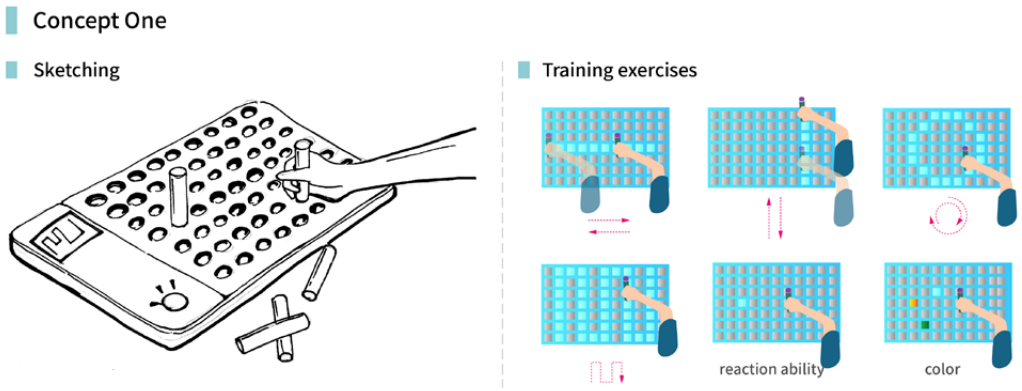


Figure 26: Visualization of the concept one of the home rehabilitation device design

The concept two

Components: smart monitoring bracelet and bracelet holder containing sensors.
Training methods: Firstly, the functions of the bracelet include displaying the time, measuring the user's heart rate and blood pressure, reminding the user to take medicine every day and so on. Different functions can be switched by tapping the screen. Secondly, when the user starts the upper limb rehabilitation training, it is necessary to open the bracelet bracket, and the internal sensor is used to receive the position and movement direction of the bracelet, so as to train the joint movement of the upper limb (see Figure 27).

Figure 27: Visualization of the concept two of the home rehabilitation device design

The concept three

Components: a dumbbell, which can be divided into two grasping modules and one targeted module, sensors

Training methods: Firstly, the dumbbell can be used for strength training and range of motion training for each joint. Secondly, the dumbbell can be divided into two grasping modules, which integrate cylinder-shaped and ball-shaped grasping forms, and one targeted module, which integrates a variety of upper limb movements. In addition, it can be combined with software interface guidance for brain cognitive ability training (see Figure 28).

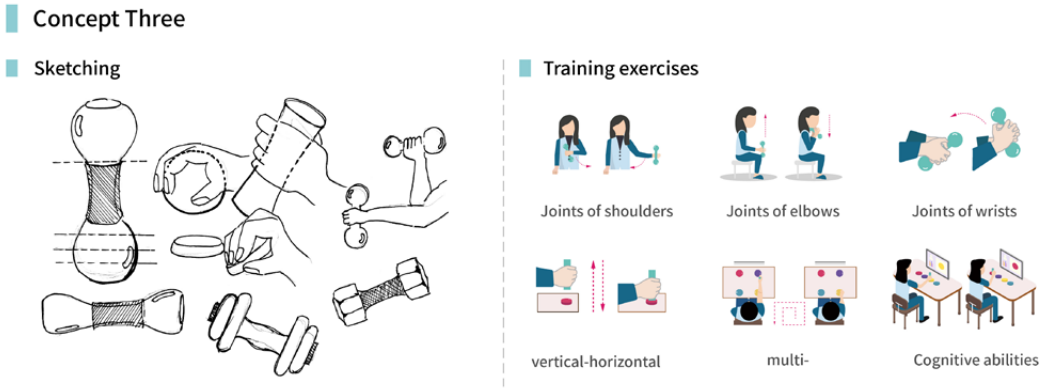


Figure 28: Visualization of the concept three of the home rehabilitation device design

The author introduced these three concepts to the three therapists in the interview and asked them to rate each concept according to the evaluation standard. The score of each factor is from 1 point to 5 points (see Table 18 below).

Evaluation standard	Concept One			Concept Two			Concept Three		
Multi-function——5	4	4	4	3	4	3	5	5	5
Portability——5	3	3	4	5	5	5	5	5	5
Understandability—5	5	3	4	3	3	4	4	5	3
Safety——5	4	5	4	4	5	4	4	5	4
Feasibility——5	4	4	4	3	4	3	4	3	3
Total scores——25	20	19	20	18	21	19	22	23	20
Average	19.6			19.3			21.6		

Table 18: The scores of three evaluated concepts

The score of the concept three was slightly higher than that of concept one and two. In addition, the concept three's two evaluation factors: multi-function and portability were both 5 points, meeting the primary needs of patients' rehabilitation at home. According to the feedback from the therapists, the size of concept one was a bit larger, while the upper limb training methods of concept two was relatively insufficient. And the technical feasibility of all the concepts needs to be proved by medical clinical trials and iterations in the future. Therefore, the author chose concept three as the final solution of a home rehabilitation device design and added pencil-shaped grasping part in addition to cylinder-shaped and ball-shaped grasping parts to train more fine upper limb movements based on therapists' opinions.

Summary of chapter 4

In this chapter, the author divided patients' needs into three aspects: rehabilitation needs, information needs, and emotional needs. In addition, service design tools were made use of to visually sort out the relationship between main stakeholders and characteristics of main touchpoints in the remote rehabilitation system. Moreover, based on the research results of each chapter, design opportunities and three concepts were proposed and evaluated by three therapists. In the next chapter, the author will introduce more about the final remote rehabilitation product and service design concept.

CHAPTER 5

THE PRODUCT AND SERVICE DESIGN CONCEPT

THE PRODUCT AND SERVICE DESIGN CONCEPT

This chapter first applies the service design tools to visualize and describe the whole system framework and business model of remote upper limb rehabilitation service. The target users of the service system are positioned as patients with mild stroke who need to continue to recover at home after discharge. Secondly, the concept of a home rehabilitation device and a digital platform is further designed to improve the upper limbs' strength and skills by completing different tasks every day.

5.1 Home Upper Limb-rehabilitation Service System Design

5.1.1 Service offering

As China pays more attention to stroke and actively promotes remote rehabilitation policies, many stakeholders in the rehabilitation system are also working together to build an implementable and sustainable future distance rehabilitation service system.

The home upper limb rehabilitation service system is the starting point of the future remote rehabilitation system. Its core is that patients use simple smart devices at home to improve both upper limbs' movement and skills by completing different specific tasks with visual guidance. In addition, patients can receive professional reports and regular communication with therapists through video calls. In addition, the remote rehabilitation service can also be expanded to connect the relationship between patients and patients, patients and therapists, therapists and hospitals, as well as hospitals and medical device suppliers. Ultimately, all stakeholders work together to form a platform for information collection, storage, analysis, and transmission.

Through the research and analysis in the previous chapters, the main stakeholders of the system include patients, therapists, and managers. Patients with mild stroke who

can understand and follow simple rules after six months' rehabilitation in the hospital are the ultimate beneficiaries. Therapists using the system for remote treatment are the executors. The medical device company cooperated with the hospital are the administrators, mainly managing the storage of information and data, maintenance and update of equipment, system promotion, etc.

5.1.2 A service system map

Based on the government policies and financial support, the interaction and resource flow among various stakeholders in the whole rehabilitation process can be better reflected with the help of a service system map. Figure 29 shows the current traditional home rehabilitation mode. In the present scenario, the therapist will give verbal rehabilitation advice when the patient is discharged from the hospital. When the patient returns home, the family members will be responsible for daily care and help to do some simple rehabilitation training, such as walking, squatting, regular communication, etc. Some family members will buy appropriate rehab devices online for passive-mode training, for example, electric bicycles for upper and lower limbs, air wave pressure massage equipment for varicose veins, etc. In addition, most family members will also pay attention to some rehabilitation application software to understand more detailed stroke knowledge and information. However, this traditional model lacks data recording as well as professional guidance and supervision, so many patients will give up rehab training halfway.

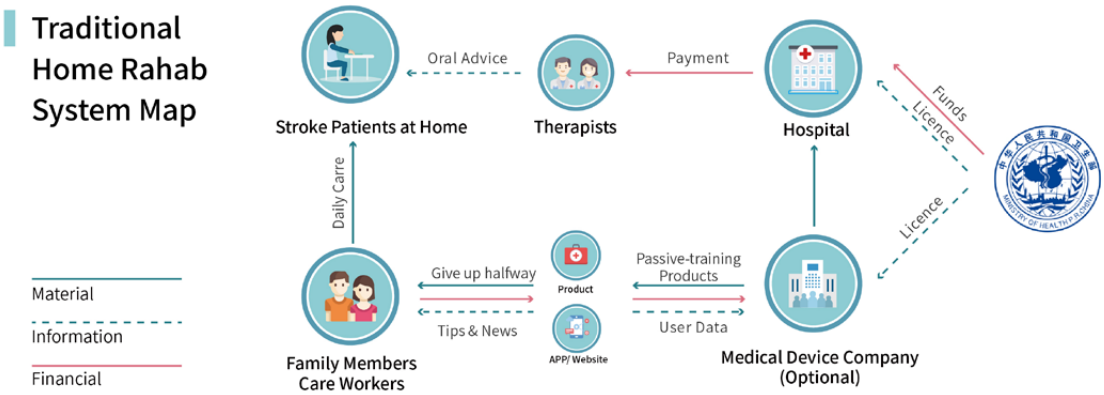


Figure 29: The traditional home rehab system map

Compared with the current traditional form of home rehabilitation, the author has added more additional potential stakeholders such as smart medical device companies, stroke rehabilitation survivors, scientific research institutions, social media, charity investors and so on. In addition, the author has added additional available resources such as platforms built by hospitals and medical companies, rehabilitation manuals, smart rehabilitation devices. The future home rehab system map is explained in detail through the analysis of material flow, information flow, and financial flow, as shown in Figure 30.

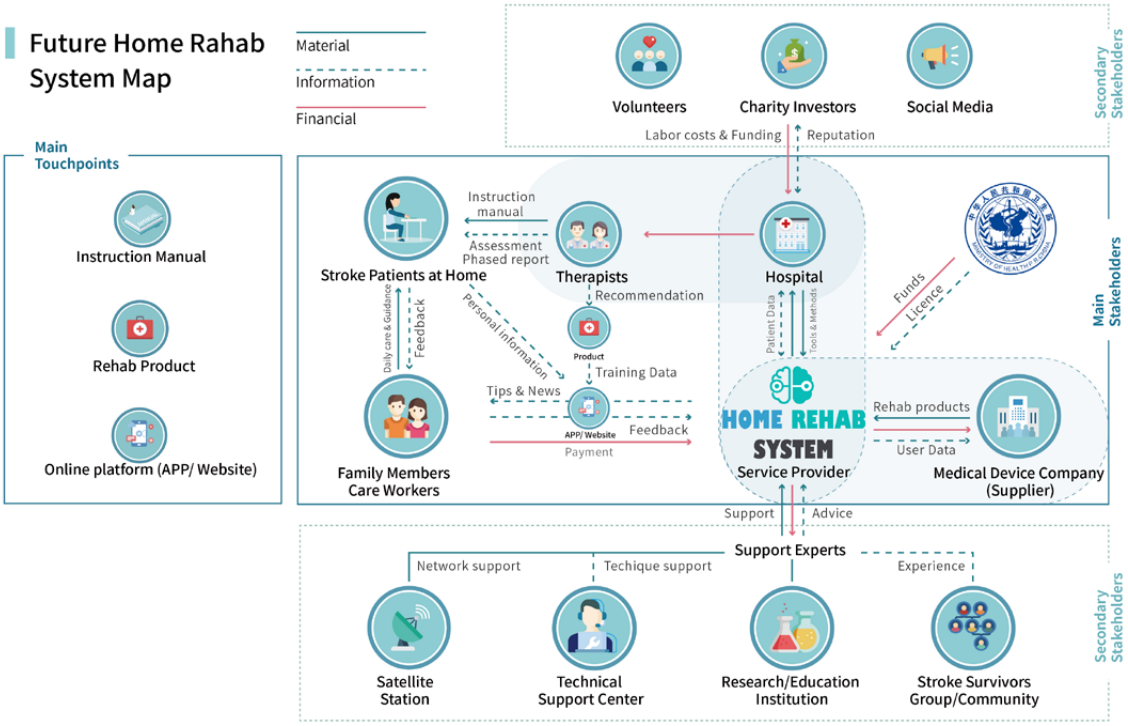


Figure 30: The future home rehab system map

(1). Financial flow scenario:

Financial flow is the flow of money between various stakeholders to ensure the design of an orderly and sustainable service ecosystem. The government 's Ministry of Health plans to invest funds into the home rehabilitation system established by the cooperation between hospitals and medical equipment suppliers, which is the primary source of funding for the platform. In addition, some charity investors, such as the Red Cross of China and enterprises like Philips and J&J will invest funds in order to improve their social reputation and public awareness. At the same time, the home rehabilitation system will charge patients for certain rehabilitation products and follow-up services. All the funds obtained are mainly spent on the initial software and hardware development and production, hiring experts and consultants, and

subsequent maintenance costs.

(2). Material flow scenario:

Material flow refers to meeting the needs of different stakeholders in various visible and invisible material forms. a) Hospitals and medical device companies. Medical device companies will provide remote rehabilitation devices and platform for partner hospitals, while the hospitals will provide professional human resources and suitable patients' information for companies. b) Therapists and patients. When the patient is in the hospital, the therapist in the hospital will recommend the remote rehabilitation system and its device to the patient, which will increase the user's trust and acceptance of the system. When the patient is discharged from the hospital, the therapist will provide a piece of instruction manual, including one suggested daily schedule, one rehabilitation training schedule, and one self-assessment form. Furthermore, the therapist will provide remote rehabilitation counseling and regular rehabilitation video assessments for the patient. c) Secondary stakeholders. The secondary stakeholders can provide different support materials. For example, research institutions like the Chinese Academy of Sciences can provide more suitable home rehabilitation exercises. Stroke patients' peers can offer their experience and emotional support. Technical support centers can help maintain and develop technical problems encountered in data storage, analysis and management of the platform.

(3). Information flow scenario:

Information flow refers to the dissemination and flow of information among different stakeholders. The patient uploads basic personal information and the home rehabilitation treatment plan formulated by the therapist to the digital platform. Then through the home rehabilitation devices, the training results collected during daily exercise will be automatically uploaded to the system. All information will be transmitted to the hospital, which acts as a transfer station for information screening and monitoring, and then the hospital manager redistributes the patient's data to the appropriate therapist. The therapist is responsible for regularly checking the staged report, adjusting the patient's rehabilitation treatment plans, and communicates with the patient remotely. In addition, the patient and family members can provide feedback and ask questions on the home rehabilitation system platform. Furthermore, hospitals, medical device companies, experts, and other stakeholders can promote their products and share information on the remote rehabilitation system platform.

5.1.3 Circular business model

In order to analyze the business model of the remote rehabilitation system, the author chooses “circular business canvas” created by a French company Circulab (https://circulab.com/home/). With this toolkit, we can consider the viability of the system not only in terms of cost and revenue but also value creation through social and environmental impacts. The “circular business canvas” is divided into eleven modules: users, key partners, key activities, key resources, value proposition, distribution, next use, revenues, costs, positive impacts, and negative impacts.

Figure 31: Circular business canvas

Users: The primary users are patients with mild stroke who need upper limb rehabilitation training after one year of hospital rehabilitation.

Key partners: 1). The hospital (rehabilitation center) and its medical teams. 2). Medical device companies and their R&D teams.

Key activities: Hospitals, as the administrators of patient information, they can upload the basic information and condition of the patient to the platform to form an electronic medical record. Therapists, as the executors, they make the personalized

treatment plan and upper limb rehabilitation training after downloading the basic information of the patients. Patients, as end-users, go home for rehabilitation exercise through the device, and all the data is automatically uploaded to the platform and fed back to the administrators, helping therapists to conduct remote assessments to formulate a new round of treatment plans and goals.

Key resources: Hospitals or rehabilitation centers provide professional human resource support such as experts and therapists. Medical device companies provide resources for product development, production and maintenance. Stroke survivors group/community can share their experiences and emotional support.

Value proposition: 1). Build a remote upper limb-rehabilitation system by promoting cooperation between hospitals and medical device companies. 2). Integrate multiple upper limb exercises into one modularized product with high precision sensors, which accurately capture changes in upper limb movements. 3). Explore a new pattern of work for therapists in the future and meanwhile provide remote rehab assessments and communication for patients.

Distribution: At the early stage of the system, the remote rehabilitation products are recommended and educated to the patients through medical institutions or rehabilitation centers when patients are still recovering in hospitals, which can increase the trust and acceptance of the platform of patients. In the later stage, it can be promoted through the medical device company's official website, mobile platform, and social media.

Next use: The collected data can be used for the government, hospitals, or institutions to create better home training exercises and user experience. In addition, design concepts can expand future possibilities and markets for remote rehabilitation.

Cost structure: It consists of the costs of licenses, development, production, advertisements, and maintenance of hardware devices and software platforms, as well as the cost of payment for therapists and other experts.

Revenue streams: Government subsidies, third-party company partnerships, funding from charity organizations, and expenses generated by patients' purchase of device and service form the entire revenue stream of the platform.

Positive impacts: 1). More cooperation between hospitals and medical device

companies are promoted. 2). Practical remote training can help more stroke patients and attract more potential users. 3). Various stakeholders are involved in the implementation of the remote rehabilitation system, which promotes multidisciplinary communication. 4). Public awareness and more care for stroke patients in society are raised.

Negative impacts: 1). The confidentiality of patients' personal information may be affected. 2). The reputation of hospitals or companies may decline if accidents or conflicts happen. 3). Patients' acceptance of new services and technologies may not be high at the beginning, and knowledge about how to use is required.

5.1.4 A service blueprint

A service blueprint is a tool for visualizing the entire service system process and various links, helping designers to understand the interrelationships of the early, middle, and late stages of the service. The service blueprint includes five elements: physical evidence, customer journey, front stage interactions, backstage interactions, and support processes.

Physical evidence, also called touchpoints, can be tangible or intangible. Touchpoints are mostly physical products, equipment, or main events in the system. Customer journey is based on the previous user journey map, including user behavior and selections performed by patients to achieve a specific goal. Front stage interactions refer to the activities directed at the patient. These activities can be human-to-human or human-computer interaction (such as mobile phones or ATMs). Backstage interactions refer to other stakeholders' interactions that are invisible to the patient. The support processes are an internal activity that supports the basic operation of the whole system, such as database, payment system, data transmission module, data calculation module, etc.

The complete service system is composed of multiple service stages and touchpoints. Based on the analysis in chapter four, there are three main touchpoints, which are the rehabilitation instruction manual, the upper limb home rehabilitation device, and the digital platform. Through the interaction of these touchpoints, the intangible service is tangibly embodied, and the entire service experience can also be improved by optimizing the design of these touchpoints, as shown in Figure 32 (on the next page).

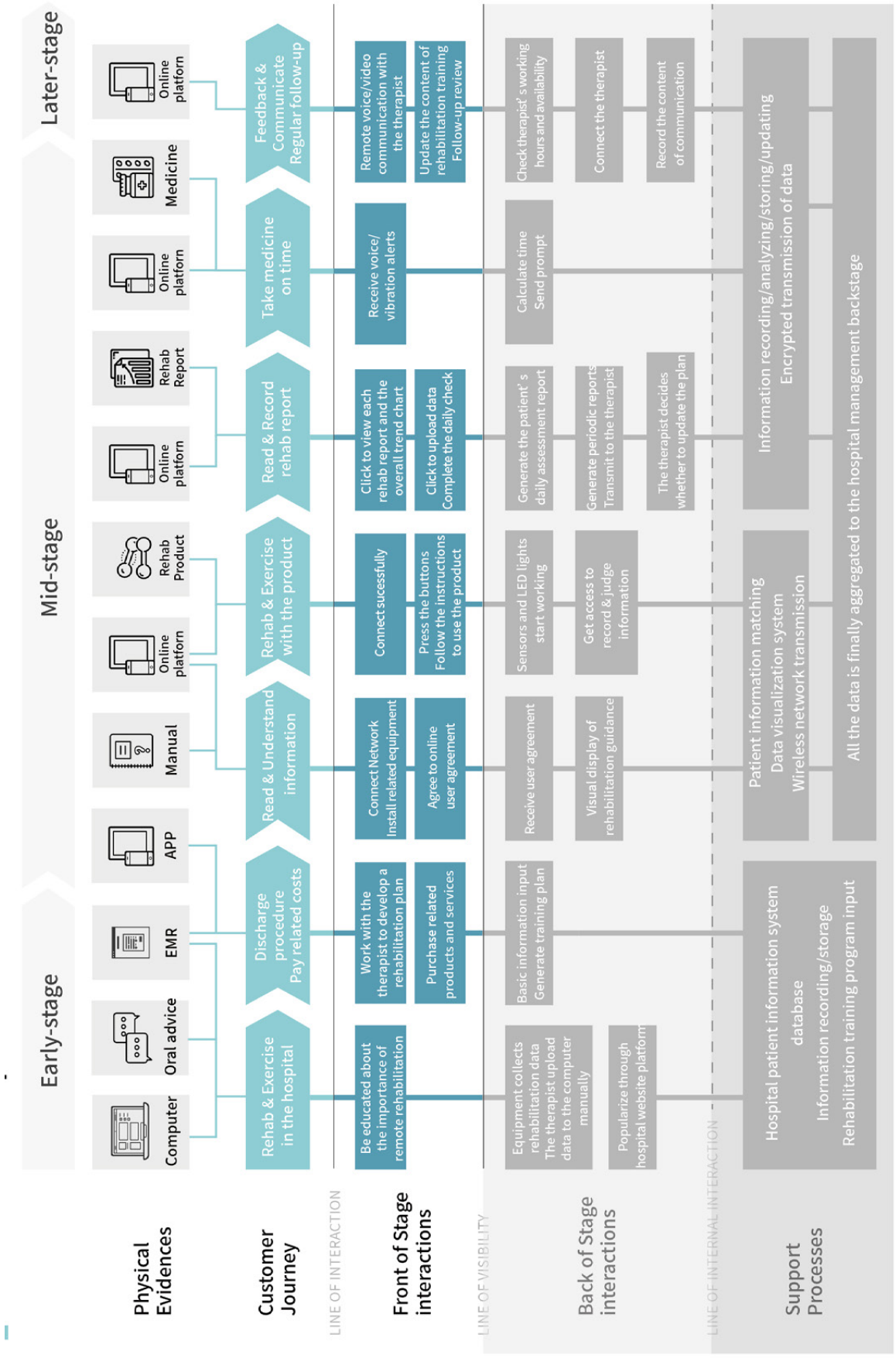


Figure 32: The service blueprint

5.2 Hardware part: A home rehabilitation device design concept

5.2.1 Brief introduction

'LimBro' means the limb's best companion, which is a household upper limb-rehabilitation device for mild stroke patients (see Figure 33 on the next page). This device aims to help more and more stroke patients get personalized, high-quality, low-cost, and sustainable upper limbs' rehab training at home, combined with the intervention of remote participation of therapists.

'LimBro' is based on the theory of bilateral arm training, task-oriented training, and wireless sensor network technology. By setting parameters such as repetitions, training duration, and motion path, patients can easily, repeatedly, and actively complete upper limbs' movement training (including muscle strength, joint range, and coordination) to induce active muscle movement and prevent joint contractures. In addition, with the continuous improvement of patients' condition, LimBro can adjust the training content through the change of grasping shape and interaction modes to increase patients' compliance. Furthermore, LimBro can improve the patients' confidence and motivation through multi-sensory feedback, visual guidance, and professional rehab reports, as patients may become bored or negative due to long-time training.

Figure 33: The rendering of LimBro home rehabilitation device design concept

5.2.2 Product details

Product details mainly include three aspects: appearance, functions, and training methods.

(1) The appearance of the LimBro home rehabilitation device design concept

Shape: The overall shape of the LimBro hardware part uses the symbol of "dumbbell", intending to give patients the feeling of daily fitness exercises. The device is divided into two parts: the grasp part and the target part. Both parts use the geometric visual language and the round shape to ensure safety and avoid complexity.

Color: The color of the LimBro is blue, green, and white. According to the therapists in the interview, blue and green, which are the primary colors of nature are one of the favorite colors for middle-aged and older people. These two colors have not any stimulating effect on people's psychology so that people may feel peaceful and comfortable during treatment. Moreover, green and blue are the most suitable for human optic nerves, that is why the environment and clothing masks in the diagnosis room and operating room are often green and blue, which can relieve doctors' eyes. The four-targeted disks use two sets of contrasting colors: a set of red-green and a set of blue-yellow. A small area of bright colors can attract the patient's attention and improve the brain's color recognition ability.

Material: LimBro is made of ABS plastic that is light, easy to clean, and has strong plasticity and various colors. In addition, some textures can be easily added on the surface to increase the friction.

Size: LimBro's size mainly depends on the adults' average hand size. The author referred to GB/T 16252-1996 National Standards and measured the size of the dumbbells at the gym, and then preliminarily determined the basic size. See Figure 34 (on the next page) for the three views of the device.

(2) Functions of the home rehabilitation device design concept

There are three kinds of shapes for patients to grasp: cylinder-shaped, ball-shaped, and pen-shaped, which are all necessary hand skills. Firstly, the cylinder shape is the simplest and most common shape in daily life, such as door handles, handles of various tools, water bottles and so on, which is an elementary form of training, focusing on muscle strength and range of motion. Secondly, the ball shape is an intermediate grasp form, which requires each finger abducting at a certain angle to grasp the object. Eventually, a pen-shaped cylinder, challenging more delicate skills to improve hand flexibility and coordination, will replace the ball.

The target part is composed of four disks with sensors and LED lights. By placing the position of the four disks and setting the order of touching the disks, various upper limb movement paths can be formed. In addition, the LED lights can give the patients timely feedback on each movement to train the patient's cognitive ability (see Figure 35).

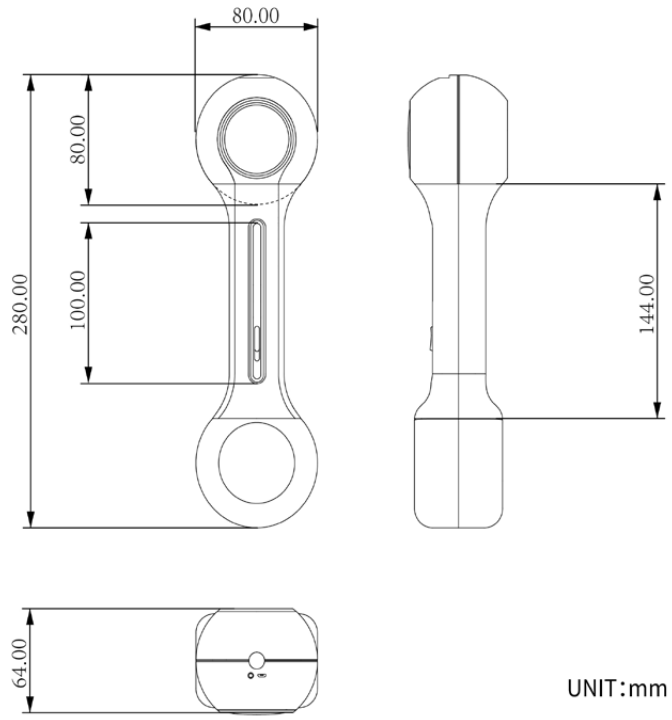


Figure 34: The three views of LimBro home rehabilitation device design concept

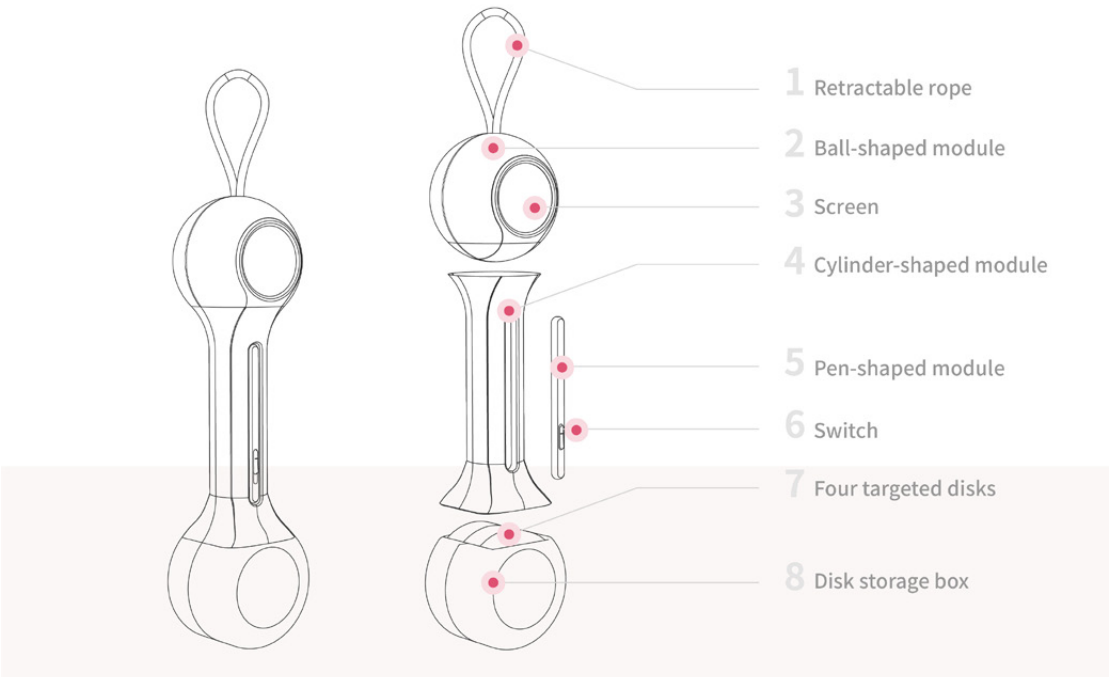


Figure 35: Different parts of LimBro home rehabilitation device design concept

(3) Training methods of the LimBro home rehabilitation device

As is shown in Figure 36 (on the next page), the author summarized the following upper limb rehabilitation training methods that LimBro could provide, based on previous desktop research on the types of upper limb movements and the therapists' recommendations for home rehab training methods. Users can choose to buy single or double LimBro. Generally, one single LimBro is enough to complete effective rehabilitation training.

For patients with moderate stroke, they can first use the integrated LimBro, with the assistance of the unaffected side, to complete the motion of joints training listed on the left side in Figure 36. There are about ten exercises, including shoulder abduction and adduction, shoulder flexion and extension, elbow pronation and supination, wrist abduction and adduction and so on. In addition, variable parameters mainly include the range of motion of joints, the number of repetitions, and the training duration.

For patients with mild stroke, they can directly use the modular LimBro, with the assistance of the unaffected side, to complete the skills and strength training listed on the right side in Figure 36. Exercises include grasp training, hold training, reach to target, and cognitive training. Furthermore, variable parameters mainly include position of the disks, the distance between the disks, the completion time (speed) of each path and the number of repetitions. The difficulty of training is controlled through the setting of parameters to meet the individual needs of patients.

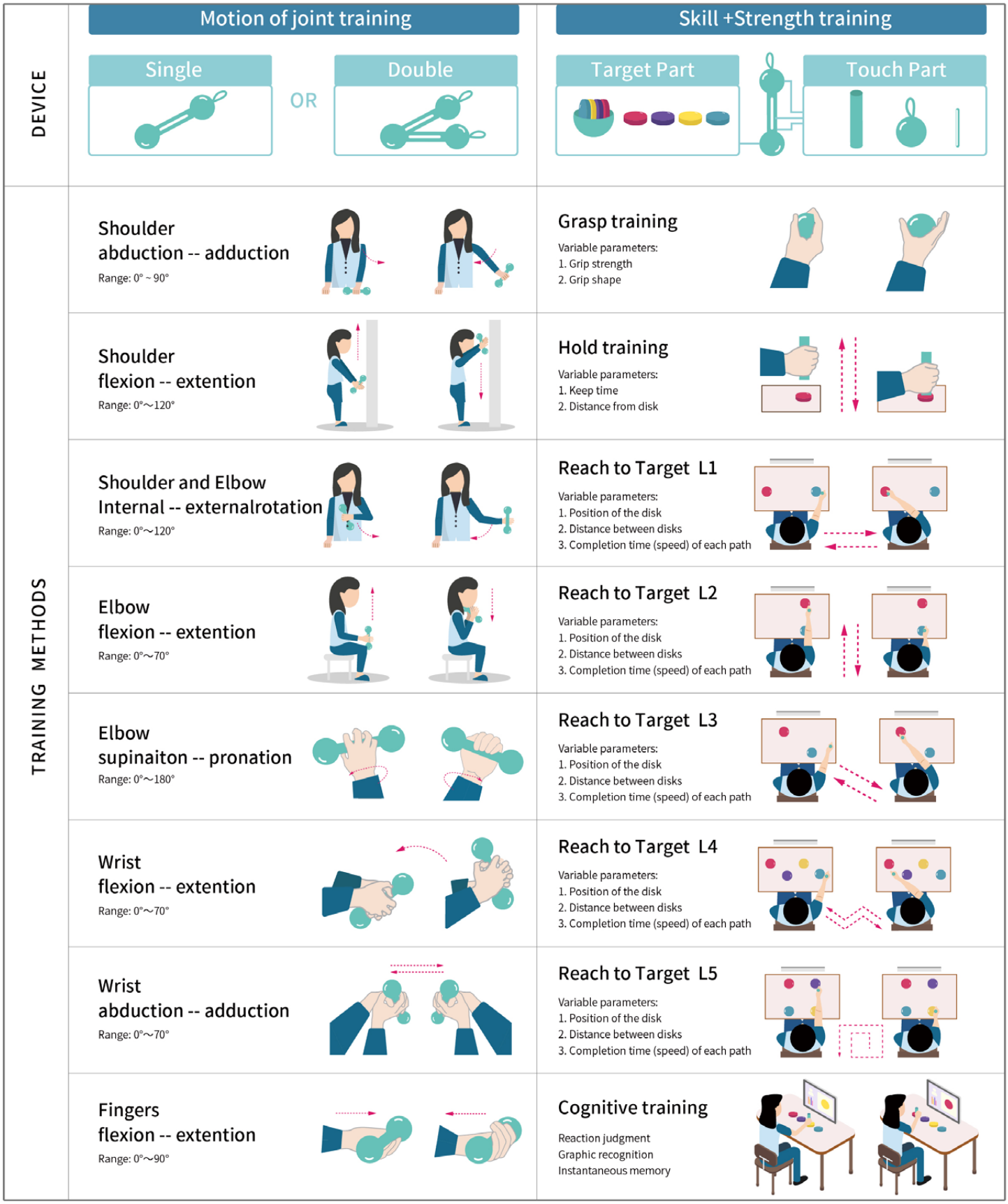


Figure 36: The training methods of LimBro home rehabilitation device design concept

5.2.3 User scenarios

Figure 37: Scenario one

During the treatment in the hospital, the patient is educated about the importance of remote rehabilitation and how to operate the home rehab device and digital platform. When the patient is discharged from the hospital, the therapist provides a new device and instruction manuals for the patient to use at home. In the meantime, the patient's electronic medical records are always updated in the background management system (see Figure 37).

Objectives for the service design solution

- To increase the patients' acceptance and trust in remote services
- To educate patients and increase familiarity with the device when they are in the hospital
- To stay updated

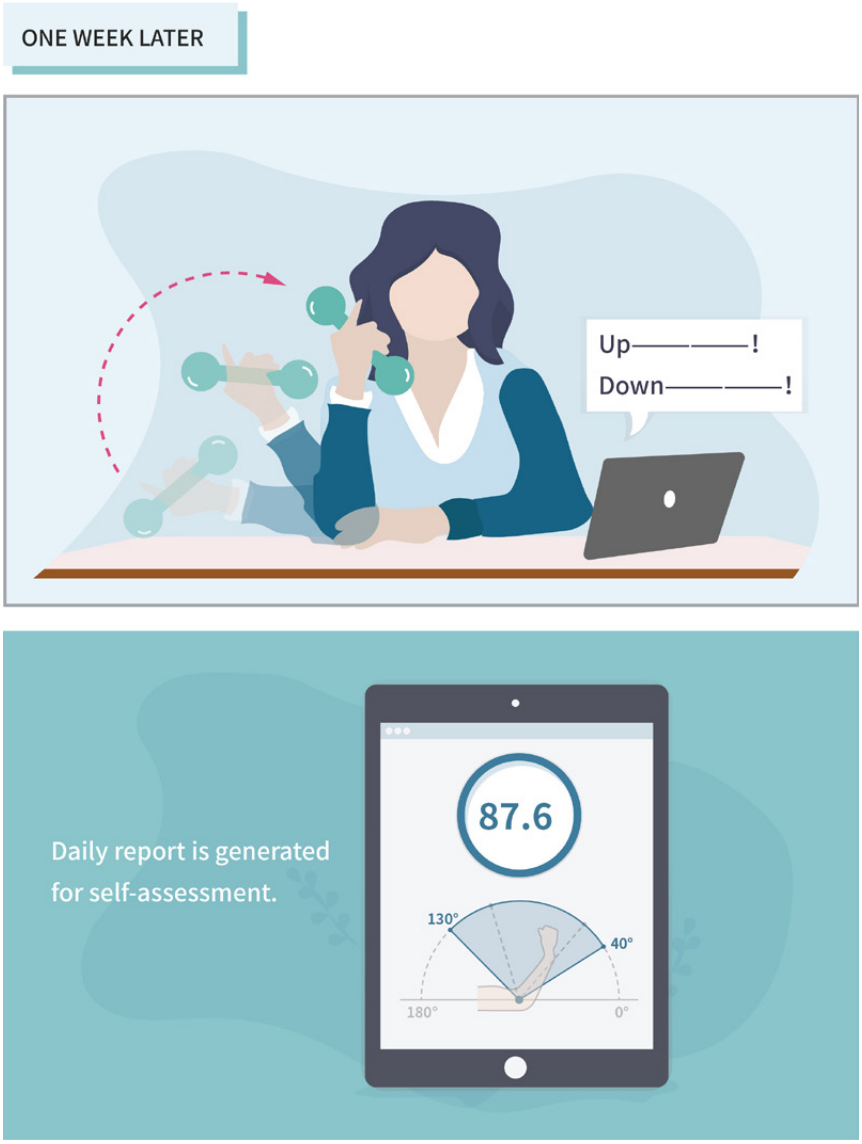


Figure 38: Scenario two

When the patient has just returned home, upper limb movements that focus on a full range of motion are performed every day via the device and visual training guidance on the digital platform. After each training, the background support system will calculate the scores and generate the report (see Figure 38).

Objectives for the service design solution

- To keep the affected muscle groups and joints active
- To reduce spasticity
- For self-assessment

Figure 39: Scenario three

The patient sets the alarm by uploading the name and time of the medicine they need to take into the platform in advance, and the mobile phone will ring at the exact time (see Figure 39).

Objectives for the service design solution

- To prevent patients from forgetting to take medication
- To prevent complications
- For self-health management

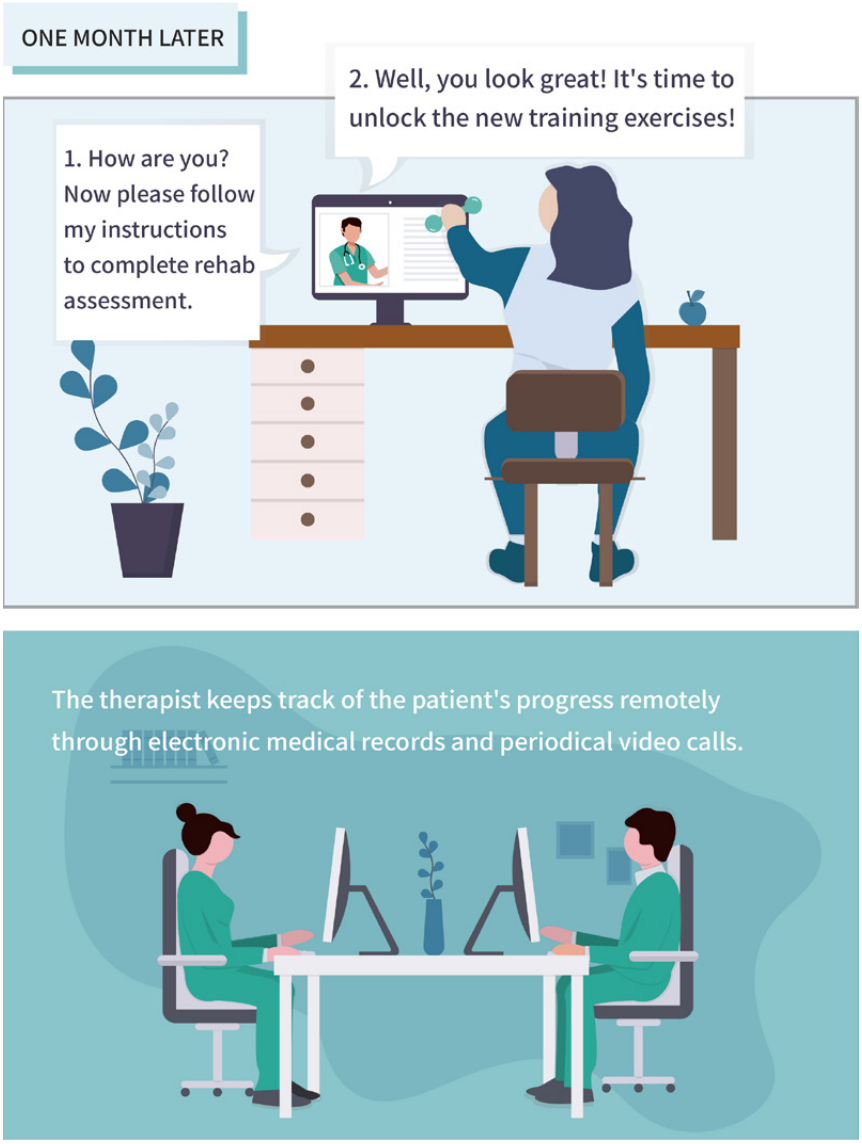


Figure 40: Scenario four

The therapist tracks the progress of each patient's rehab training during their online working hours. At the end of each month, the therapist will conduct rehabilitation assessment and guidance by a video call and decide whether to update the rehabilitation plan and start new training exercises according to the patient's situation (see Figure 40).

Objectives for the service design solution

- To provide professional rehab assessment
- To strength the relationship between patients and therapists
- To supervise and encourage the patient to insist on training
- To keep the exercises updated and challenging

Figure 41: Scenario five

After some time, more challenging upper limb movements that focus on more precise skill training and cognitive training are performed by the patient. In addition, the background support system will generate periodic report trend charts and corresponding task rewards (see Figure 41).

Objectives for the service design solution

- To keep exercises comprehensive and challenging
- To keep patients motivated by new tasks and rewards
- To see the tiny progress by periodic reports

5.3 Software part: A digital system platform interface design

5.3.1 Brief introduction

LimBro online platform solves the pain point of patients' lack of rehabilitation guidance and supervision without the direct intervention of therapists, which leads to the midway give up of rehabilitation. The LimBro online system platform has three entrances for patients, therapists, and administrators respectively.

Functions of the patients' platform:

(1). Rehabilitation training guidance: Combined with LimBro home rehabilitation devices, the platform provides real-time instructions for upper limb training exercises through the visualized interface. The system contains different kinds of tasks for each part of upper limb, and some tasks can only be unlocked after the patient has exercised for a certain period and obtained permission from the therapist remotely.

(2). Interpretation of rehab assessment reports: The reports are divided into daily training reports and periodic rehabilitation reports. The daily training report is used for the regular self-assessment of the patient. The score of each training is made up of training difficulty, duration, and completion degree, helping the patient and family members to see small changes and progress every day. While the periodic rehabilitation report is used for the monthly professional assessment of the therapist, which is presented in the form of a simplified version of the FMA assessment scale through the monthly video call. In addition, the rehabilitation knowledge and terms in the report will be translated into easy-to-understand words and visualized figures for patients and their families to read.

(3). The Personal health management: After the patient binds the electronic medical record, the medication reminder will be generated to help the patient take medicine in time. In addition, the patient can manually input health data such as blood pressure, blood glucose, or weight to find whether it is within the standard range or not to prevent recurrence and other diseases.

(4). Professional remote consultation: When the patient and their family members are using devices or services, if they encounter technical problems, they can give feedback on the platform. Then the staff of medical device companies will receive

the issues in real-time and provide an immediate reply and provide follow-up on-site maintenance services as required. While if the patient and family members have rehabilitation problems, they can ask the therapist questions online by texts, and the therapist will reply during their online working hours.

(5). Online sharing and communication: By binding WeChat, the patient can share their rehabilitation condition and progress, as well as their daily emotions with their family members, friends, and other stroke patients. They can also receive encouragement and support from them.

Functions of therapists' platform:

(1). Remote supervision by electronic medical record file: The remote rehabilitation section is added to the existing electronic medical record file. Through this section, the therapist can view the data and trend of the patient's recovery reports. If there are obvious problems in the report, the therapist can contact the patient in time, thus playing the role of remote supervision.

(2). Online rehabilitation guidance: The therapist can use the platform to provide online rehabilitation guidance by the forms of texts, voice, or video, which depend on the needs of the patient, while all the consultation and guidance will be recorded to the cloud for management.

(3). Update of the rehabilitation plan: The patient's initial rehabilitation plan is prepared before the patient is discharged from the hospital and uploaded to the electronic medical record. With the progress of remote rehabilitation at home, the patient's condition is continuously improving. So the therapist can remotely unlock new rehabilitation training exercises to update the rehabilitation plan and goals based on the rehab assessments.

Functions of administrators' platform:

(1). The hospital management system platform is mainly responsible for storing and managing the medical information of patients and therapists, including patients' electronic medical records, rehabilitation data from the hospital to the home, and online consultation data to evaluate the work results and attitudes of therapists.

(2). The management system platform of medical equipment company is mainly responsible for storing and managing personal information of patients, including name, gender, address, etc., but no medical information.

5.3.2 The information frame

Since this study mainly focuses on providing home rehabilitation for patients, the interface of patients' platform is designed in detail at first to ensure the coordination with the LimBro home rehabilitation devices. The therapists' and administrators' platforms will be further designed and implemented in the future.

According to the analysis of patient needs, the patients' platform is divided into three major functional modules: **rehabilitation training module, rehabilitation community module, and personal center module**. As shown in Figure 42, the author detailed each module to make the specific information frame. Firstly, the rehabilitation training module includes the rehabilitation goals set by the therapist, instructions for starting everyday upper limb training and rehabilitation reports (daily training reports and periodic rehabilitation assessments). Secondly, the rehabilitation community module aims to provide comprehensive rehab management needs, including online consultation with therapists, knowledge about rehabilitation, and self-health management. The personal center module is responsible for recording the patient's data and information including EMR, reports, rehab medals, collections, news, and general setting.

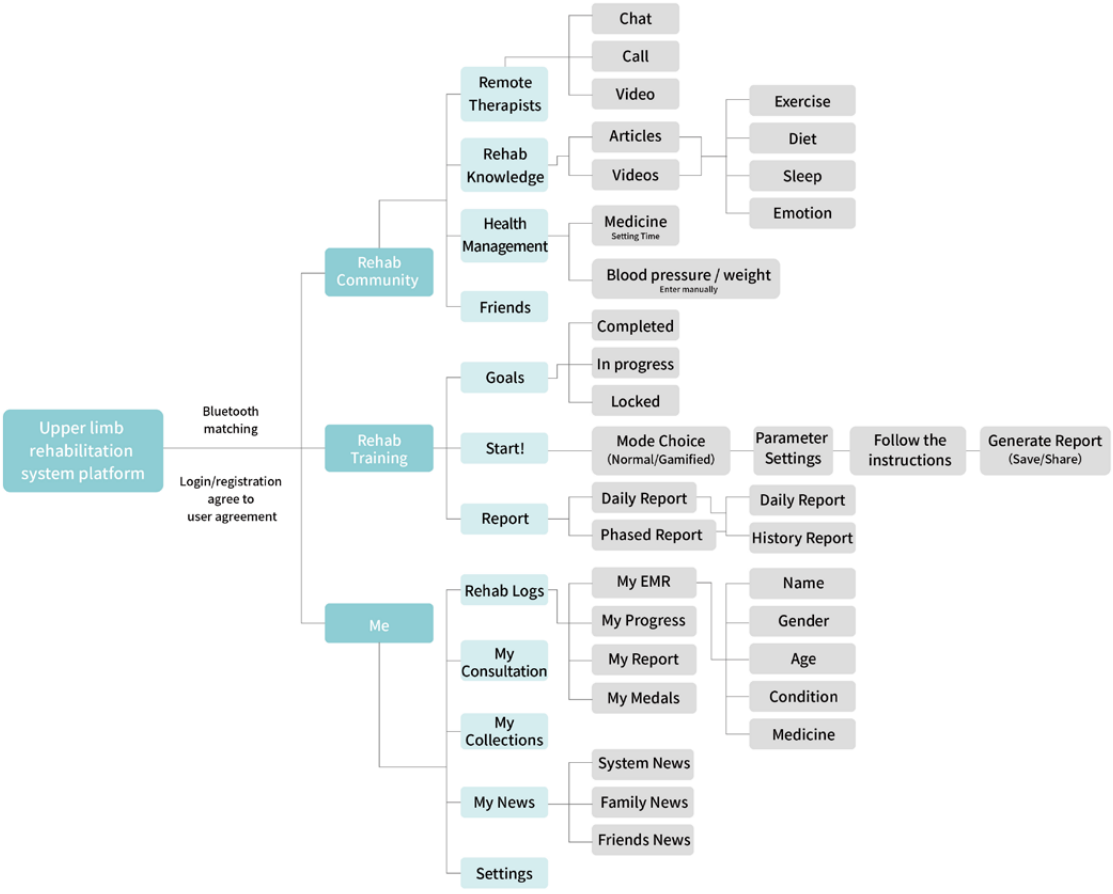


Figure 42: The information frame of LimBro patients' platform

5.3.3 Main function flow

(1). First login

When the patient logins for the first time, the critical information on the electronic medical records are synchronized to the cloud platform, which includes

- basic information (name, gender, patient identification number, date of birth, address, nationality, marital status);
- medical information (consultation records, clinical diagnosis, the therapist);
- rehabilitation information (rehab goals set by the therapist before discharge, rehabilitation training exercises, and related assessment scale results);
- medicine information (prescribed medicine, dosage, usage, history of drug allergy).

In addition, patients also need to fill out other personal information, such as setting the initial password of the platform, setting the contact phone number for an emergency, and uploading personal head portrait. All the information will be ensured confidentiality (see Figure 43).

Figure 43: The interface of first login

(2). Set rehabilitation parameters

After the patient has logged in, the interface jumps to the homepage, including three buttons of rehabilitation training module, rehabilitation community module, and personal center module. The rehabilitation-training module is located in the most prominent position. When the patient clicks “Start Training”, the patient can first select the default training parameters or customize the training parameters (see Figure 44).

There are three steps to customizing training parameters. The first step is to select the training content that is divided into joint range of motion training and skill/ strength training. The second step is to select the interface mode, which is divided

into ordinary instruction mode and gamified scenario game mode. The third step is to choose specific training exercises, which are listed in Figure 5-13 and set the difficulty level and training duration. After three steps are completed, the interface jumps to how to place the four disks' positions, and the patient starts training according to the guidance in the form of visualized pictures and voice.

Figure 44: The interface of setting rehabilitation parameters

(3). Start rehabilitation training

During the training process, the patient holds and manipulates the hardware parts to improve the upper limb's mobility and hand-eye coordination, mainly following visual instructions on the interface in the form of visualized pictures and voice. For example, if the patient chooses two targeted disks to complete a left-right motion path, the corresponding two disks will be displayed on the interface. When the patient touches the left disk, the interface will guide the patient to reach the right disc next (repeat like this again and again) (see Figure 45).

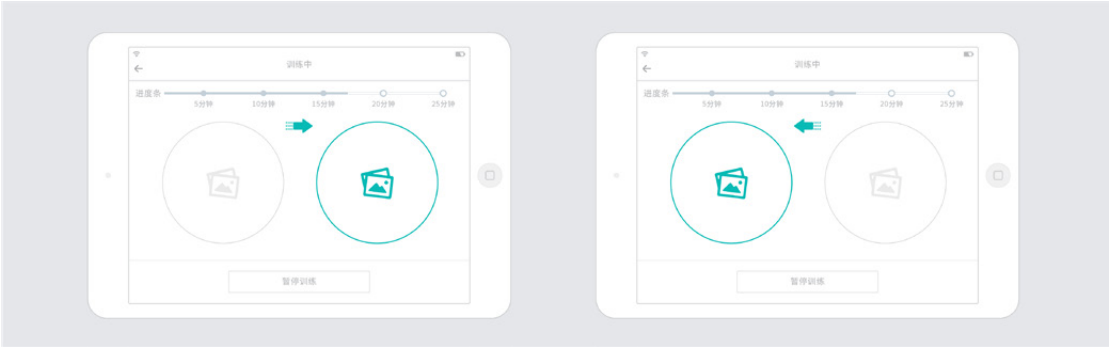


Figure 45: The interface of starting rehabilitation training

(4). Get training report

The daily training report is for patients' regular self-assessment. When the patient has completed the daily rehab training, the background support system will calculate the scores and generate the report, which includes the total training score, the joint range of motion, and the default therapist's comments. The total rehabilitation score is 100 points. If the patient does not complete the path movement within the specified time or touches the target incorrectly, the points will be deducted accordingly. Furthermore, the patient can view the overall trend through the historical training report and future treatment plan (see Figure 46).

Figure 46: The interface of getting training report

(5). Remote rehabilitation assessment

Monthly rehabilitation assessment reports will be produced remotely by the therapist. Firstly, the therapist reads the patient's EMR and historical training report at the end of every month. Secondly, the therapist makes a video call with the patient to observe the patient's upper limb mobility through the camera, completes the online simplified FMA rehabilitation assessment. Then the therapist further judges whether it is time to update the rehabilitation plan or not. Furthermore, if a patient encounters a problem and wants to conduct an online video consultation, he or she could make an appointment with the therapist for online working hours and then pay for the consultation (see Figure 47).

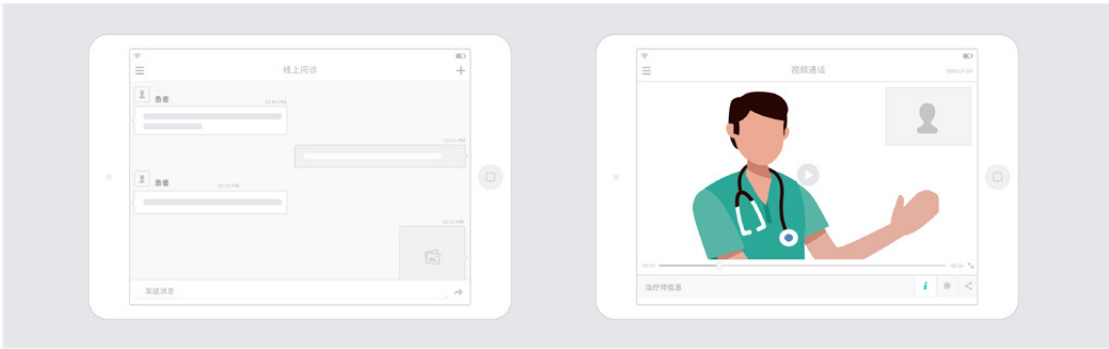


Figure 47: The interface of remote rehabilitation assessment

(6). A daily medication reminder

By binding the electronic medical record, the patient's medication information and time can be synchronized to the calendar, and then the patient can be reminded daily to take the medication on time to prevent other complications such as epilepsy (see Figure 48).

Figure 48: The interface of a daily medication reminder

(7) Exchange of rehabilitation achievements

After completing each upper limb rehabilitation training, the patient can receive corresponding stars, while a different total number of stars are equivalent to different badges of honor. In addition, stars are also in exchange for personal health care products in the online rehabilitation mall. The designer aims to use this reward mechanism that includes both honor (spiritual) and material levels to encourage patients to keep training instead of giving up halfway (see Figure 49).

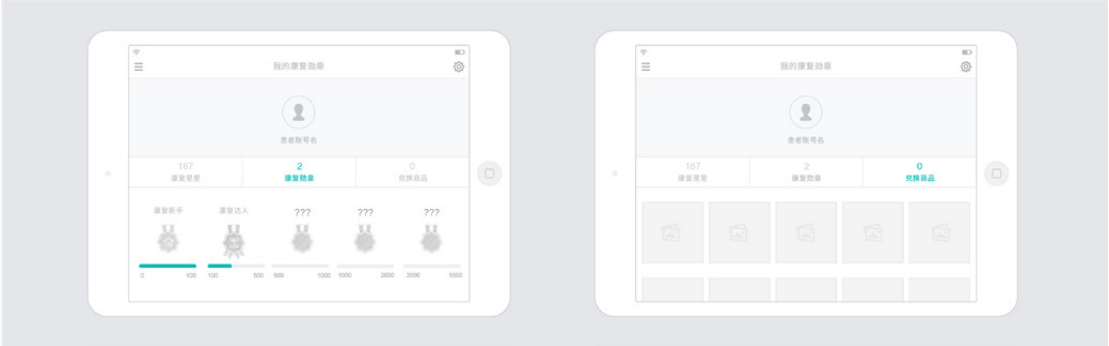


Figure 49: The interface of exchange of rehabilitation achievements

5.3.4 Interface design of the platform

The visual style of the platform interface for the stroke patients is the same as that of the LimBro home rehabilitation devices, with blue, green, and white as the primary colors to keep patients calm and positive. The interface is a combination of simplified visual graphics and straightforward texts in large sizes, which is convenient for the middle-aged and elderly to read and understand. In addition, the main functions are in a prominent position and provide direct instructions. At the same time, each interface of the training is also equipped with voice prompts, so that patients with poor vision can also operate without obstacles.

Figure 50: A high fidelity interface of patients' platform

Summary of chapter 5

To sum up, based on the literature review and field research, the author developed a concept of remote upper limb rehabilitation product-service system. The products included a home rehabilitation device and a digital platform, while the services included rehabilitation training service, information service, and emotional service. In the next chapter, user feedback will be collected by the prototypes of the LimBro device and platform made by the author for design iterations.

CHAPTER 6

Discussions

Discussions

In this chapter, the prototypes of the LimBro device and platform were made by the author for user test and feedback. The objectives of this chapter include:
(1). Simulate real application scenarios of future remote rehabilitation at home, and reflect possible problems and hidden dangers of products, so as to avoid potential risks.
(2). Test whether the characteristics and training methods of the LimBro home rehabilitation devices and digital platform meet the physical and psychological needs of patients, further understand their additional requirements and expectations of this whole service system.
(3). Collect user experience and user-friendliness of the LimBro home rehabilitation devices and digital platform, then summarize which details or interfaces can be improved and optimized.

6.1 User test and feedback

Steps:
(1). The author used the 3D printer to make a simple prototype of the LimBro home rehabilitation device, as shown in Figure 51. In addition, the feedback form was prepared to compare the present home rehabilitation and LimBro remote rehabilitation. The form was divided into patients' rehabilitation needs, information needs, and emotional needs in each user journey stage. A score of 5 indicated that the demand was satisfied fully, while a score of 1 meant that the need was not satisfied at all.
(2). The author went to two stroke patients' homes. The project background and design concept were briefly introduced to the patients and their families.
(3). The patients were asked to use LimBro home rehabilitation device to carry out range of joints' motion training and grasping movement training independently (See Figure 52). The author manually controlled the visual training instructions on the software interface and observed the behaviors of the patients during the training.
(4). After using the prototype, the patient was asked to fill out the feedback form and shared their user experience during the training. The patients and their family

members provided suggestions about how to improve this remote rehabilitation system.

Figure 51: Prototype of the LimBro home rehabilitation device

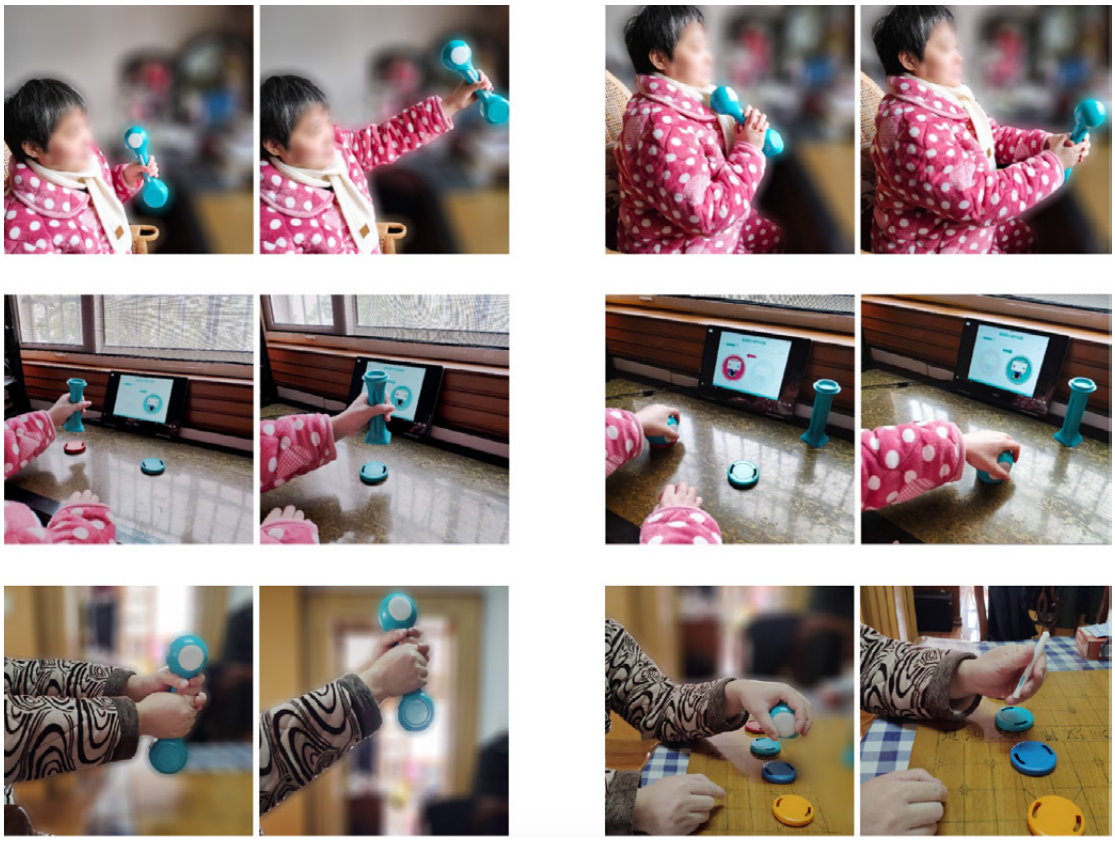


Figure 52: User test scenarios

Feedback:

The user test feedback mainly includes the patient's feedback forms and professional suggestions from therapists online. As is shown in Figure 53, both two stroke patients were quite satisfied with the LimBro remote rehabilitation system, which met their rehabilitation needs to a great extent. Speaking of information needs, they felt it very helpful to have rehabilitation instruction manuals, medicine reminders, and remote professional consultation, but they were a bit worried about the confidentiality of personal information. In addition, the idea of incentive mechanism (exchange of rehabilitation achievements) attracted the patients while they expected more financial support from the government and innovative ways of socializing when it comes to emotional needs.

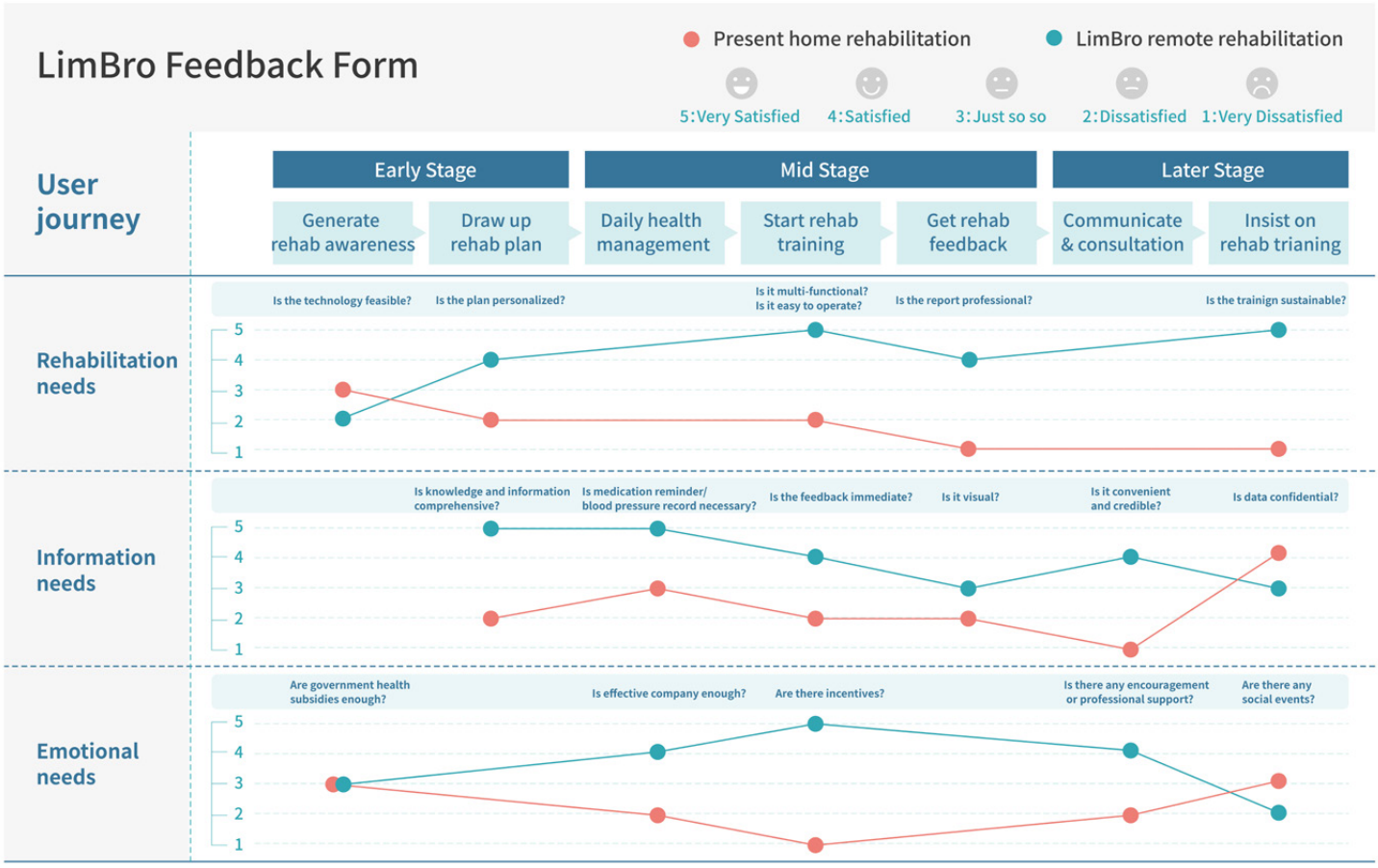


Figure 53: Patient A s' feedback form

Furthermore, professional suggestions from therapists are included as follows:

(1). The surface of the ball-shaped grasping module is too smooth. Some textures can be appropriately added to improve friction.

(2). The comfort and scale of the pen-shaped grasping module can be improved by adjusting its shape and size like a real pen.
(3). It is quite interesting to use four disks to form a variety of movement paths. And it is recommended to visualize the lines between points for users to see and follow the paths.
(4). Before the training starts, animation or video guidance can be added to the interface to perform an action demonstration, so that users can understand more clearly.
(5). The digital platform can not only be used on tablet computers but also be displayed on other smart devices such as TV sets and mobile phones to increase its adaptability and provide more possibilities for users.
(6). The LimBro digital platform for therapists can be added to the existing platform as an additional function so that in addition to the patient's recovery records, other information, such as visit records, hospitalization records, and medicine records can be integrated.

6.2 Design update & optimization

In response to the above first, second, and third suggestions, the author improved the design of LimBro home rehabilitation device from three aspects. 1). Increase the surface friction of the ball-shaped grasping module. 2). Adjust the appearance of the pen-shaped grasping module and add a soft silicone sleeve at the lower part to improve comfort. 3). Add an infrared laser transmitter to the four disks to make the upper limb movement paths visible, as shown in Figure 54. Moreover, the fourth, fifth, sixth suggestions would be taken into consideration for further development for the design of the digital platform.

Figure 54: Improvements of LimBro home rehabilitation device

CHAPTER 7

Conclusions

7.1 Research Summary

With the continuous growth of stroke patients in China and the trend of longer rehab duration, the Chinese government aims to promote the Level-Three rehabilitation service with the assistance of the Internet and high technologies. In this research, the author has treated the remote upper limb rehabilitation as a starting point. With the approaches and tools of product-service system design, the author established a support system to help the post-stroke patients at home exercise effectively and improve their upper limbs' function with the remote supervision from therapists.

The results of this research are as follows:
(1). The theoretical framework of stroke rehabilitation was summarized, which included the basic human upper limb movements, upper limb rehabilitation methods, high technologies, and assessments. All the researches laid the foundation for the future practice of remote rehabilitation systems and also helped subsequent designers to quickly understand the professional knowledge about stroke and rehabilitation in the medical field.

(2). The patients' and therapist's needs were collected by the field research and further subdivided into three categories: the rehabilitation needs, the information needs, and the emotional needs. Based on these needs, the author identified primary pain points and established the inclusion criteria as well as exclusion criteria of stroke patients who were suitable for remote rehabilitation.

(3). The author proposed the concept design of the remote upper limb rehabilitation service system for stroke patients. The hardware part integrated suitable upper limb training methods, theories, and technologies into one modular smart hardware device. In addition, the software part, an online digital platform, was established that allowed patients to keep in touch with therapists while recovering at home and recorded patients' daily conditions and progress.

(4). The author applied the product-service system design tools such as the system map, the user journey map, and the service blueprint in the analysis of research findings and visualization of design results. In addition, service prototyping was applied to iterate the design of two main touchpoints according to the user test and feedback.

Furthermore, the author concluded this thesis with the answers to the research questions in the following sections.

Research question:

How to build a support system to help the post-stroke patients at home exercise effectively and improve their upper limbs' function by adopting service design approaches and tools?

Answers are divided into two parts.

1. How service design approaches and tools can be integrated into finding stroke patients' issues and potential needs when it comes to remote rehabilitation?

The author played the role of a facilitator to promote the participation and communication of patients and therapists during the observations and interviews. With stroke patients willing to share their stories and experience, the author was able to have a deep understanding and empathy with them. In addition, service design tools visualized the research findings to provide better interpretation and design delivery. For instance, the user journey map concluded patients' behavior, thinking, and touchpoints during the remote rehabilitation, while the system map and service blueprint created a vivid picture of the whole service system. Therefore, the author could verify whether the needs of stroke patients were satisfied or not by service prototyping and brought in the patient-centered perspective into the development process.

2. What kinds of products, services, and system can be provided for the stroke patients at home with the remote intervention of therapists?

During the process of building this support system, two main issues were found in this study: (1) In the home rehabilitation environment, patients lack multi-functional and small-sized upper limb rehabilitation devices to perform rich and effective exercises. (2) Without the intervention of the therapist, patients are lack of rehabilitation guidance and supervision, which may lead to giving up halfway. Therefore, the design concept of a Products-Service-System was provided by the author.

- Products: a home rehabilitation device and a digital platform.
- Services: rehabilitation training service, information service and emotional support service.
- System: a remote household upper limb rehabilitation system cooperated by hospitals and medical device companies.

The next section will introduce the values and innovations about these three elements.

7.2 Values and innovations

The innovations and values of **LimBro remote upper limb rehabilitation system** are:
(1). Build a remote upper limb-rehabilitation system connecting multiple stakeholders, clarify the flow of material, information, and finance in this system, and provide suggestions for the specific implementation of this remote platform in the future;
(2). Realize its social and commercial value by promoting cooperation between hospitals and third-party medical device companies to provide intelligent and comprehensive remote rehabilitation support services.

The innovations and values of the **LimBro home rehabilitation device** are:
(1). Combine three types of hand grasping forms into one small product by modularization;
(2). Integrate multiple upper limb movements by drawing different lines made up of dots;
(3). Accurately capture changes in upper limb movements and provide instant feedback through smart motion sensors.

The innovations and values of the **LimBro digital platform** are:
(1). Provide easy-to-understand upper limb rehabilitation training guidance by the visualized interface in coordination with the LimBro home rehabilitation device;
(2). Conduct regular remote rehabilitation assessment and remote communication with patients by reasonably scheduling online working hours of therapists;
(3). Promote patients to adhere to long-term sustainable rehabilitation training through the design of material and spiritual incentive mechanisms.

7.3 Limitations and future possibilities

For the entire remote rehabilitation system, its final implementation requires the high involvement of multiple stakeholders. In addition to stroke patients, therapists, hospitals, and medical device companies, the Chinese government's attention and permission are particularly important. Also, the target users of this study are now patients with mild stroke. In the future, with the development of the technology and more clinical experiments, the target users can be extended to patients or the elderly who have mobility and cognitive problems caused by other diseases.

For the LimBro home rehabilitation device, the WSN technology and interaction modes need to be continuously tested and improved to not only ensure the accuracy and safety but also reduce the cost as much as possible. In addition, it is necessary to meet the relevant national standards and regulations for rehabilitation products before they can be put into the market for sale. Furthermore, the categories of remote rehabilitation products can be enriched by adding lower limb rehabilitation products, cognitive rehabilitation products, and speech rehabilitation products to form a more comprehensive set of rehabilitation training tools.

In this study, the digital platform mainly focuses on the interface design of the patient side to ensure the cooperation with the LimBro home rehabilitation device. The interface and information architecture of the therapist side and background management system will be further designed and implemented in the future to form a comprehensive information system and data platform.

To sum up, the implementation of a remote rehabilitation system requires more professional knowledge, time, clinical experiments, and the participation of various stakeholders. This study and concept design results can be used as a starting point to provide more possibilities for future rehabilitation services.

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APPENDICES

CONTENT

1. Information Sheet

College of Design and Innovation,Tongji University,
No.281 FuXin Road, YangPu District, China
and
Aalto University School of Arts Design and Architecture,
Department of Design, Creative Sustainability, Otakaari
1, Espoo, Finland

同济大学 TONGJI UNIVERSITY

Aalto University
School of Art and Design

Information Sheet

The study title: Upper Limb-rehabilitation Service System for Chinese Post-stroke Patients at Home
Research method: Observation and Interviews
Researcher in charge: Shen LiangYan
Designated researcher: Shen LiangYan

I am a graduate student from Tongji University and Aalto University. My graduation design and thesis are about remote rehabilitation system for Chinese stroke patients.

The rehabilitation of stroke is a very long process. After the early rehabilitation in the hospital, most of patients choose to be discharged from the hospital for home rehabilitation. This project is mainly about how to build a system to help the post-stroke patients exercise and improve their limbs' function, especially the upper limb at home, and at the same time how to increase patients' confidence, give them the feeling that they are still integrated into life and society are the aims of this project.

The interview is part of the first stage concerning collecting data. These interviews will be carried out in two hospitals in Shanghai.

The aim of observation and interview is to gather data concerning four different themes. And the interview questions focus on the following themes 1) Understanding of both physical and psychological needs of stroke patients; 2) Understanding of patients' behavior, habits, interests and expectations; 3) Understanding of the relationship between patients and therapists; and 4) Understanding of both patients and therapists' opinions on the remote rehabilitation service system. Designated researcher will ask you questions related to these themes with the printed colorful pictures.

Each entire interview will last about 20 minutes and will be audio recorded.

Your participation at this interview is voluntary nature; you have right to discontinue participation at any time without obligation to disclose specific reasons. This study does not present any possible risks to the participants.

Your participation is very valuable to this project.

Thank you for your participation.

If you have any further questions related to study, do not hesitate to contact designated researcher at 1542810965@qq.com or liangyan.shen@aalto.fi

Researcher in charge
Shen LiangYan

Designated researcher
Shen LiangYan

Helsinki, _____

2. Consent Form

College of Design and Innovation,Tongji University,
No.281 FuXin Road, YangPu District, China
and
Aalto University School of Arts Design and Architecture,
Department of Design, Creative Sustainability, Otakaari
1, Espoo, Finland

同濟大學 TONGJI UNIVERSITY

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Consent Form

The study title: Upper Limb-rehabilitation Service System for Chinese Post-stroke Patients at Home
Research method: Observation and Interviews
Researcher in charge: Shen LiangYan
Designated researcher: Shen LiangYan

General ethic concerns
I understand that the purpose of the interview is to gather information about the current state of rehabilitation exercise methods, patients' condition, feelings and expectations. The findings are used to generate knowledge and ideas in general of the development of the remote rehabilitation system for stroke patients in China and to contribute to a Master Thesis.

I understand that my participation in the study is completely voluntary and that I have the right to discontinue my participation at any stage without any consequences.

I have understood that the personal records, interview material and pictures are only for the use of Shen's research in its efforts to build a successful research proposal and for academic research in the thesis. Designated researcher reserves the right to use detached, unidentifiable quotations and data in some publications.

The research results related to me are only available to designated researcher and the researcher in charge and they will not be presented to a third party without my written consent. Designated researcher of the study may, however, give permission to his/her other cooperation partners to analyze the research results for scientific purposes or ask for a professional consultation on possible unexpected incidental findings without separate consent. The anonymity of the results has been ensured. And any type of commercial exploitation of the results is prohibited.

I understand that any information I provide is confidential, and that no information that could lead to the identification of any individual will be disclosed in any reports on the project, or to any other party. No identifiable personal data will be published. The identifiable data will not be shared with any other organization. The collected data will be storage at the secure Aalto on-line server and it will be kept there for the time being of the project. Data will be destroyed after the retention period.

By my signature, I confirm my participation in this study and agree to volunteer as a study subject. If I need any additional information regarding interview, I will contact Designated researcher.

Signature_____ Name _____

Date _____

I give consent to be audio-recorded and photographed during the study.
Please indicate:_____Yes _____No

I give my consent for the use of recordings resulting from this study to be used for scientific publications, presentations to other researchers.
Please indicate:_____Yes _____No

* All personal names will be removed and faces masked.

3. Fugl-Meyer Assessment upper limb part (FMA)

FUGL-MEYER ASSESSMENT **ID:**
UPPER EXTREMITY (FMA-UE) **Date:**
Assessment of sensorimotor function **Examiner:**

Fugl-Meyer AR, Jaasko L, Leyman I, Olsson S, Steglind S: The post-stroke hemiplegic patient. A method for evaluation of physical performance. Scand J Rehabil Med 1975, 7:13-31.

A. UPPER EXTREMITY, sitting position					
I. Reflex activity				**none**	**can be elicited**
Flexors: biceps and finger flexors (at least one) **Extensors**: triceps				0 0	2 2
			Subtotal I (max 4)		
II. Volitional movement within synergies, without gravitational help				**none**	**partial**	**full**
Flexor synergy: Hand from contralateral knee to ipsilateral ear. From extensor synergy (shoulder adduction/ internal rotation, elbow extension, forearm pronation) to flexor synergy (shoulder abduction/ external rotation, elbow flexion, forearm supination). **Extensor synergy:** Hand from ipsilateral ear to the contralateral knee	Shoulder Elbow Forearm	retraction elevation abduction (90°) external rotation flexion supination		0 0 0 0 0 0	1 1 1 1 1 1	2 2 2 2 2 2
	Shoulder Elbow Forearm	adduction/internal rotation extension pronation		0 0 0	1 1 1	2 2 2
			Subtotal II (max 18)			
III. Volitional movement mixing synergies, without compensation				**none**	**partial**	**full**
Hand to lumbar spine hand on lap	cannot perform or hand in front of ant-sup iliac spine hand behind ant-sup iliac spine (without compensation) hand to lumbar spine (without compensation)			0	1	2
Shoulder flexion 0°- 90° elbow at 0° pronation-supination 0°	immediate abduction or elbow flexion abduction or elbow flexion during movement flexion 90°, no shoulder abduction or elbow flexion			0	1	2
Pronation-supination elbow at 90° shoulder at 0°	no pronation/supination, starting position impossible limited pronation/supination, maintains starting position full pronation/supination, maintains starting position			0	1	2
			Subtotal III (max 6)			
IV. Volitional movement with little or no synergy				**none**	**partial**	**full**
Shoulder abduction 0 - 90° elbow at 0° forearm neutral	immediate supination or elbow flexion supination or elbow flexion during movement abduction 90°, maintains extension and pronation			0	1	2
Shoulder flexion 90° - 180° elbow at 0° pronation-supination 0°	immediate abduction or elbow flexion abduction or elbow flexion during movement flexion 180°, no shoulder abduction or elbow flexion			0	1	2
Pronation/supination elbow at 0° shoulder at 30°- 90° flexion	no pronation/supination, starting position impossible limited pronation/supination, maintains start position full pronation/supination, maintains starting position			0	1	2
			Subtotal IV (max 6)			
V. Normal reflex activity assessed only if full score of 6 points is achieved in part IV; compare with the unaffected side				**hyper**	**lively**	**normal**
Biceps, triceps, finger flexors	2 of 3 reflexes markedly hyperactive 1 reflex markedly hyperactive or at least 2 reflexes lively maximum of 1 reflex lively, none hyperactive			0	1	2
			Subtotal V (max 2)			
			Total A (max 36)			

B. WRIST support may be provided at the elbow to take or hold the starting position, no support at wrist, check the passive range of motion prior testing		none	partial	full
Stability at 15° dorsiflexion elbow at 90°, forearm pronated shoulder at 0°	less than 15° active dorsiflexion dorsiflexion 15°, no resistance tolerated maintains dorsiflexion against resistance	0	1	2
Repeated dorsifexion / volar flexion elbow at 90°, forearm pronated shoulder at 0°, slight finger flexion	cannot perform volitionally limited active range of motion full active range of motion, smoothly	0	1	2
Stability at 15° dorsiflexion elbow at 0°, forearm pronated slight shoulder flexion/abduction	less than 15° active dorsiflexion dorsiflexion 15°, no resistance tolerated maintains dorsiflexion against resistance	0	1	2
Repeated dorsifexion / volar flexion elbow at 0°, forearm pronated slight shoulder flexion/abduction	cannot perform volitionally limited active range of motion full active range of motion, smoothly	0	1	2
Circumduction elbow at 90°, forearm pronated shoulder at 0°	cannot perform volitionally jerky movement or incomplete complete and smooth circumduction	0	1	2
	Total B (max 10)			

C. HAND support may be provided at the elbow to keep 90° flexion, no support at the wrist, compare with unaffected hand, the objects are interposed, active grasp		none	partial	full
Mass flexion from full active or passive extension		0	1	2
Mass extension from full active or passive flexion		0	1	2
GRASP				
a. Hook grasp flexion in PIP and DIP (digits II-V), extension in MCP II-V	cannot be performed can hold position but weak maintains position against resistance	0	1	2
b. Thumb adduction 1-st CMC, MCP, IP at 0°, scrap of paper between thumb and 2-nd MCP joint	cannot be performed can hold paper but not against tug can hold paper against a tug	0	1	2
c. Pincer grasp, opposition pulpa of the thumb against the pulpa of 2-nd finger, pencil, tug upward	cannot be performed can hold pencil but not against tug can hold pencil against a tug	0	1	2
d. Cylinder grasp cylinder shaped object (small can) tug upward, opposition of thumb and fingers	cannot be performed can hold cylinder but not against tug can hold cylinder against a tug	0	1	2
e. Spherical grasp fingers in abduction/flexion, thumb opposed, tennis ball, tug away	cannot be performed can hold ball but not against tug can hold ball against a tug	0	1	2
	Total C (max 14)			

D. COORDINATION/SPEED, sitting, after one trial with both arms, eyes closed, tip of the index finger from knee to nose, 5 times as fast as possible		marked	slight	none
Tremor	at least 1 completed movement	0	1	2
Dysmetria	pronounced or unsystematic slight and systematic no dysmetria	0	1	2
		≥ 6s	**2 - 5s**	**< 2s**
Time start and end with the hand on the knee	6 or more seconds slower than unaffected side 2-5 seconds slower than unaffected side less than 2 seconds difference	0	1	2
	Total D (max 6)			

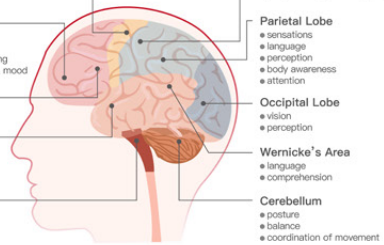
TOTAL A-D (max 66)	

4. General outline of the interview to stroke patients

1. How do you feel today?
2. How long have you been recovering from the hospital?
3. Can you tell me a bit about what do you do every day from the moment you get up to the moment you go to sleep? *(Let the patient tell his or her story. Allow the patient to talk for as long as he or she wishes.)*
4. What are some of the things you enjoy doing? *(Possible follow-ups: How often do you get to do that these exercises? What would make it easier for you to do this more often? What is your best memory of doing that? What do you usually do on weekends?)*
5. Which parts of your body have been affected? The current rehabilitation exercise is mainly in which part?
6. What kind of exercise methods do you have right now? *(Dependently / Independently; Most effective / Least effective; Most interesting / Most boring)* *(Possible follow-ups: Why do you think it is very effective /interesting?)*
7. How much time do you spend on exercise every day?
8. How do you feel after everyday exercise?
9. Can you tell me about some of your good and bad experiences with the health care system? *(Possible follow-up: What could have made that experience (even) better?)*
10. When you are going to recover at home, what's your plan? *(Possible follow-ups: Who is going to take care of you? What kind of exercise will you continue to do? What are you going to do every day? What's your expectation about the future? What's the difference between treatment in the hospital and at home?)*

WHAT IS STROKE

Brain Structure and Their Functions



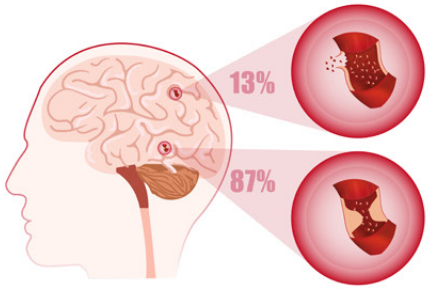
WHAT IS STROKE

A stroke is a "brain attack". It can happen to anyone at any time. It occurs when blood flow to an area of brain is cut off. When this happens, brain cells are deprived of oxygen and begin to die. When brain cells die during a stroke, abilities controlled by that area of the brain such as memory and muscle control are lost.
(https://www.stroke.org)

In China, the annual stroke mortality rate is approximately **1600000**, approximately 157 per 100 000, which has exceeded heart disease to become the leading cause of death and adult disability.
Being the third cause of mortality and the first one of handicap in adults, we can say that stroke is one of the main health problems in our era. (World Health Organization, http://www.who.int/en/)

China has **2500000** new stroke cases each year and 7500000 stroke survivors.

The type of stroke



Hemorrhagic Stroke
• A brain aneurysm burst or a weakened blood vessel leak (hemorrhagic) is one of two types of stroke. While the least common of the two types of stroke it most often results in death.

Ischemic Stroke
• Ischemic stroke occurs when a blood vessel carrying blood to the brain is blocked by a blood clot. This causes blood not to reach the brain. High blood pressure is the most important risk factor for this type of stroke. Ischemic strokes account for about 87% of all strokes.

COMMON CONSEQUENCES

Mobility problems	Visual problems	Speech and communication problems	Difficulty in swallowing	Loss of bladder/bowel control	Neuropathic pain	Emotional difficulties (depression and anxiety)	Fatigue and extreme tiredness

Physical therapy
This can help a person relearn movement and co-ordination. It is important to stay active, even if it is difficult at first.

Occupational therapy
This is used to help a person to improve their ability to carry out routine daily activities, such as bathing, cooking, dressing, eating, reading, and writing.

Speech therapy
This helps with any problems producing or understanding speech. Practice, relaxation, and changing communication style can all help.

Mental Health therapy
These help with common mental health problems such as depression that can occur after a stroke.

How stroke can affect upper limb

Solutions Methods

Hemiparesis — weakness

Your arm may be paralysed completely, or your shoulder, elbow, wrist or hand may be weak. Paralysis on one side is called hemiplegia. Weakness on one side of the body is called hemiparesis.

- Constraint-induced movement therapy. This involves using a mitt or sling on your unaffected hand or arm to encourage you to use your affected limb. Increased use of your affected hand or arm will promote improvement.
- Video games to help you practise using your arm.
- Low-level electrical current to stimulate a weak muscle.
- Mirror therapy (put a mirror between your arms on a table.)

Apraxia — coordinating problems

You may have difficulty planning arm movements. This is called apraxia. You may also have difficulty coordinating arm movements, which makes them feel slow or clumsy.

- Talk about, rehearse and practise the steps that make up that movement.
- Therapist may also do the movement with you.
- If your muscles have high tone, an injection of botulinum toxin A (botox) may help.
- Electrical simulation may also be used.

Spasticity or Hypotonia — changes in the muscles

You may have high tone which makes your muscles stiff and tight. This is called hypertonia or spasticity. Alternatively, your muscles may be floppy or loose. This is called low tone or hypotonia.

- Stretching and strengthening exercises
- Temporary braces or casts, limb positioning
- Application of cold packs
- Electrical stimulation and biofeedback.

Subluxation

Changes in the muscle may cause your arm bone to sit slightly lower in your shoulder socket.

- Electrical stimulation
- A sling or strapping
- You will also need to learn the best ways to move and protect your arm. If the pain does not improve, you may need a specialist pain management doctor or clinic.

Contracture — joint fixed in one position

If your muscles are tight or weak, they can become shorter. This can result in the joint becoming fixed in one position.

- Begin to loosen up your contractures with daily stretching and passive exercise

Changes in sensation — lose feeling

You might lose feeling, have pins and needles or have increased feeling (hypersensitivity).

- Retrain your senses by feeling different materials, objects and textures to re-learn what they feel like.

Swelling

If your hand or arm does not move as well as it used to, fluid may build up (oedema).

- Exercises, electrical stimulation, massage or pressure garments.
- Supporting your arm in a raised position when resting can also help.

6. Renderings of the LimBro home rehabilitation device