Activity Display For Older Adults Living With Foot Drop:

Combine existing devices to create a system by Smart Phone App - WalkingGuardian

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Combine existing devices to create a system by Smart Phone App - WalkingGuardian

by

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ABSTRACT

With the rapid development speed of social and economic change, people are paying more and more attention to the health of themselves and their families. As a result, there is an increasing demand for health and rehabilitation services and technologies. Currently, the number of people living with foot drop caused by stroke is vast. These people have difficulties while walking, their quality of life is greatly affected due to foot drop disorders. How to make such people with foot drop to walk more steadily with the help of assistive devices to adapt to their daily lives while gradually getting rehabilitated is one of the focuses of compensation strategies in the field of rehabilitation.

This thesis proposes a compensate method for older adults living with foot drop to walk or even jog more steadily. Currently, there already exist many kinds of foot drop assistive devices. In this thesis project, orthotics, stimulators, and smart shoes are used to match up with my application design - the WalkingGuardian. For orthotics, Dynamic Ankle Foot Orthosis (DAFO) is designed to help a person maintain a functional position as well as improve stability for successful standing and walking. For stimulators, Dropped Foot Stimulator (DFS) can stimulate nerves to correct muscles to respond and form better circulation. For smart shoes, existing smart insoles can already collect a variety of foot data associated with foot drop condition and transmitted all the data to the smart phone immediately. Therefore, when the WalkingGuardian becomes the control center to integrate all the devices together into a system, individuals can select the most appropriate way to incorporate activities into daily lives not only achieve the purpose of rehabilitation but also improve their own physiological functions, facilitate the diagnosis and treatment, which can boosting efficiency and slashing costs. The WalkingGuardian is the operating system to control all the functions and gather all the information. All the physical data and using data are recorded in the application for analysis.

Nine older adults living with foot drop participated in the evaluation of the WalkingGuardian. Feedbacks were collected to determine the acceptability of the functions and the concepts. Suggestions for improving the concept and future research are recommended.

Keywords:
UX design; smart phone application; rehabilitation; foot drop; dynamic ankle foot orthosis; dropped foot stimulator

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Chapter 1

INTRODUCTION

According to United Nations' statistics, in 2017, there are an estimated 962 million people aged 60 or over in the world, comprising 13 percent of the global population. The population aged 60 or above is growing at a rate of about 3 percent per year, which is the largest growing population among all the ages. It is expected that the population over 60 will reach two billion by 2050. The growth is expected to come, in part, from the 47 least developed countries, where the fertility rate is around 4.3 births per woman, and whose population is expected to reach 1.9 billion people in 2050 from the current estimate of one billion. (UN,2017)

As the aging effects of society worsen, the number of empty-nest older adults is increasing, unfortunate events and injuries caused by falls are frequent. Due to aging, older adults are susceptible to various diseases. Among the older adults, foot drop accounts for a significant proportion.

Foot drop is a gait abnormality in which the dropping of the forefoot happens due to damage or paralysis of the common fibular (or peroneal) nerve, which branches from the sciatic nerve. This results in weakness or paralysis of the muscles in the anterior portion of the lower leg. Foot drop is characterized by an inability or impaired ability to raise the toes or raise the foot from the ankle (dorsiflexion). In walking, the raised leg is slightly bent at the knee to help prevent the foot from dragging along the ground. Foot drop makes people fall or trip more easily when walking on uneven ground or over obstacles. Individuals should take appropriate compensatory techniques to reach their rehabilitation goals as early as possible.

Foot drop can be caused by a variety of health issues such as stroke or traumatic brain injury. In most cases, the primary cause is stroke. China is the country with the largest number of people with stroke, according to China Cardiovascular Disease Report (2017), there are more than 12 million people with stroke in China and their incidence is still rising at a rate of 10% per year. Without any control, by 2030 there will be 31 million people with stroke in the country. Although the mortality rate of stroke has shown a declining trend year by year, about 75% of stroke survivors have varying degrees of disability such as foot drop. Foot drop symptoms brings great inconvenience to a person's life.

An inability to walk autonomously and freely affects a person's quality of life to a great extent. Due to the large number of people living with foot drop, there is a great need in society for rehabilitation intervention. Therefore, the research on the rehabilitation of foot drop is receiving more attention.

There are many approaches to address foot drop. For my thesis work, I focus on two compensatory methods - orthotics and stimulators. For orthotics, a Dynamic Ankle Foot Orthosis (DAFO) is a brand name for some lower extremity braces that provide thin, flexible, external support to the foot, ankle and lower leg. Designed to help a person maintain a functional position, a DAFO can improve stability for successful standing and walking. (Bjornson, 2006) DAFO is characteristically thin, flexible and wraps around the individual's entire foot in order to provide improved sensation and alignment. The way DAFO generally corrects the ankle-foot alignment is balancing the power of the body system by exerting forces on the lower limb. Such forces are passively applied to the human body, also called passive orthotics. (Dawei Zhou, 2015)

With an understanding of the motor neurons, especially the neural conduction mechanism and muscle contraction of the human body under electrical stimulation, people derived the new form of orthosis - stimulators, such as Functional Electrical Stimulation (FES), Functional Neuromuscular Stimulation (FNS) and Neuro Prosthetics. The typical way of FES rehabilitation is to stimulate the corresponding nerve, contraction of muscle tissue so that the foot reverts to form a foot lift action to complete the normal walking. Meanwhile, by FES stimulation of the corresponding nerve, muscle tissue can maintain the function of nerves and muscle tissue, achieve the rehabilitation effect as soon as possible. Dropped Foot Stimulator (DFS) is one kind of functional electrical stimulation especially designed for people living with foot drop.

Besides orthotics and stimulators, smart shoes is an essential part that matched up with this thesis project. Using smart insoles (or other types of smart shoes according to personal preferences) through dynamic and static standing to record a variety of foot data associated with the condition of foot drop is particularly important. All the foot data can be transmitted to the application immediately for analysis and diagnosis. Besides, smart insoles are small and portable, which can be easily put in shoes.

As mentioned, the WalkingGuardian is a conceptual design to integrate all the existing foot drop assistive devices such as DAFO, DFS, and smart shoes together as a system. Both DAFO and DFS are playing therapeutic and rehabilitation roles as well as supporting individuals to walk more steadily. Moreover, all the three devices are lightweight and compact, which creates favorable conditions for the combination. Taking into account the factors that individuals will carry these assistive devices out during their daily activities, I designed the WalkingGuardian as a smart phone application. Individuals can self-regulate an appropriate amount and mode of the pulse trace current while walking and enjoy other ancillary functions also used by the general population. Personal information and physical data associated with the foot drop condition such as movement data and plantar pressure are recorded and can be presented as data graphs, which is convenient for individuals and health professionals to check the condition. Emergency contact information is included to deal with emergency circumstances.

This thesis is divided into seven chapters. Chapter 1 includes a general introduction to the research study. Chapter 2 describes the symptoms of foot drop in detail, which provides with a clearer understanding. The chapter also contains the background of general rehabilitation. Technologies that are most relevant to dynamic recover design are discussed. In Chapter 3, several existing products are analyzed to determine the design direction. Advantages and disadvantages are compared. Chapter 4 introduces assist design strategies and principles, which establishes a foundation for the application design. Chapter 5 describes the design and conceptualization of the WalkingGuardian for this thesis research project. Chapter 6 focuses on the evaluation and data collection of the WalkingGuardian through participants' reactions to the main components of the application and provides findings of the research. Finally, in Chapter 7, conclusions are made and opportunities for future research and development directions are proposed.

Chapter 2

FOOT DROP AND REHABILITATION

2.1 Symptoms and causes

Foot Drop is a condition where the individual has difficulties lifting the front part of the foot, causing the toes to drag while walking. (Figure 2.1-2 and Figure 2.1-2) An individual can raise the thigh when walking, as though climbing stairs (steppage gait), in order to help the foot clear the floor. When touching down, an individual with foo drop tends to slap the foot down onto the floor. In some cases, the skin on the top of the foot and toes is numb due to sensory impairment. Foot drop is a symptom of a neurological condition, not a disease. The condition can be temporary or permanent.

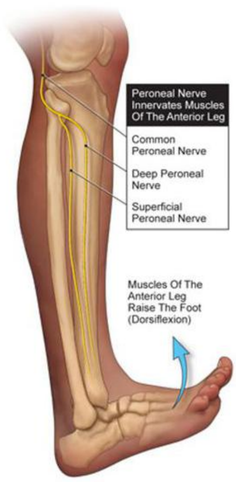

Figure 2.1-1 Normal Foot

Source: Robert H. Sheinberg, 2012

Figure 2.1-2 Foot Drop

Depending on the cause, either one or both feet can be affected at the same time. Besides, concurrent impairments may include paralysis or paresis of the upper extremity on the same side as the affected leg. There are many different causes for this condition and treatments will vary.

Foot drop is caused by weakness or paralysis of the muscles involved in lifting the front part of the foot. Causes of foot drop might include:

Nerve injury - The most common cause of foot drop is compression of a nerve in one's leg that controls the muscles involved in lifting the foot (peroneal nerve). This nerve can also be injured during hip or knee replacement surgery. A nerve root injury (pinched nerve) in the spine can also cause foot drop.

Muscle or nerve disorders - Various forms of muscular dystrophy, an inherited disease that causes progressive muscle weakness, can contribute to foot drop. So can other disorders, such as polio or Charcot-Marie-Tooth disease.

Brain and spinal cord disorders - Disorders that affect the spinal cord or brain such as amyotrophic lateral sclerosis (ALS), multiple sclerosis or stroke may cause foot drop. (Mayo Clinic)

As mentioned, in most cases, the primary cause of foot drop is the stroke. Foot drop is one of the common sequelae of stroke. Due to impaired function of the nervous system, people with stroke will reflexively cause sympathetic dystrophy and neurovascular atrophy. Most people will have foot drop within one week after the stroke, some accompanied by swelling pain, and the skin temperature increased, which affected the foot functions. (Wei Song, 2009) Therefore, the target population of this thesis project is older adults whose foot drop is caused by stroke.

2.2 Gait

2.2.1 Gait problems

Foot drop is characterized by what is known as steppage gait. While walking, people living with the condition drag their toes along the ground, to compensate they flex their hip and bend the knee on the affected side to lift their foot higher than usual to avoid the dragging. (MedicineNet, 2018) A person may also use a characteristic tiptoe walk on the opposite unaffected leg while letting the affected toe drop. Other gaits such as a wide outward leg swing (to avoid lifting the thigh excessively, or to turn corners in the opposite direction of the affected limb) may also indicate foot drop. (GPnotebook, 2018)

Some individuals who may have painful disorders of sensation (dysesthesia) of the soles of the feet may have a similar gait but do not have foot drop. Because of the extreme pain evoked by even the slightest pressure on the feet, such individuals may walk as if walking barefoot on hot sand.

2.2.2 Steppage gait

A person with a steppage gait lifts one or both feet higher than normal. This kind of high-stepping gait occurs under two very different circumstances. A person with severe foot drop cannot dorsiflex the foot. To permit the toes to clear during the stride phase and avoid tripping, the individual lifts the foot as high as possible by exaggerated flexion of the hip and knee, then throws the foot out as she puts it down. (See Figure 2.2-1) In normal walking, heel strike occurs first; with a foot drop, the toes fall to the floor first. The touching of toe then heel creates a characteristic "double tap."

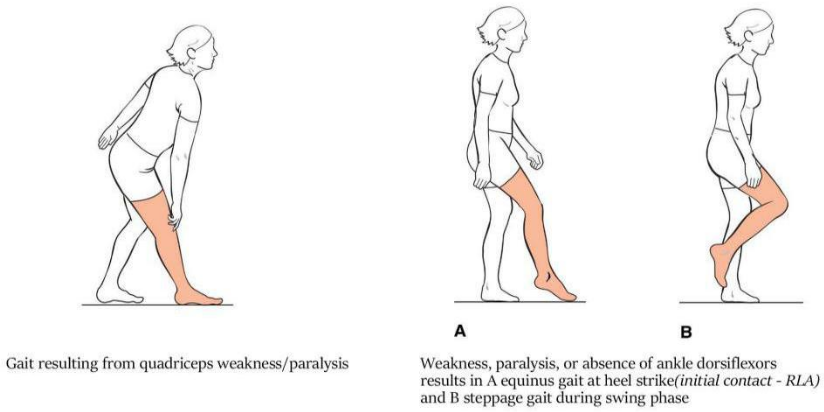

Figure 2.2-1 Steppage gait

Source: Studyblue, 2018

Sensory ataxia may also cause a steppage gait because an individual lifts the feet up high and then slaps or stamps them down to improve proprioceptive feedback. The gait of sensory ataxia may also cause a double tap, but in this case, the heel strikes first and smartly as the person stamps the foot to the ground to improve proprioceptive feedback. The sound of the two varieties of double tap is different. A pronounced steppage gait due to foot drop is much more common than a steppage gait from sensory ataxia. In severe polyneuropathies, the steppage gait may have components of both sensory ataxia and foot drop. (Wolters Kluwer Health, 2016)

2.2.3 Gait cycle

Foot drop describes an abnormal neuromuscular disorder that affects the person's ability to raise their foot at the ankle. Foot drop is further characterized by an inability to point the toes toward the body (dorsiflexion) or make a medial or lateral rotation.

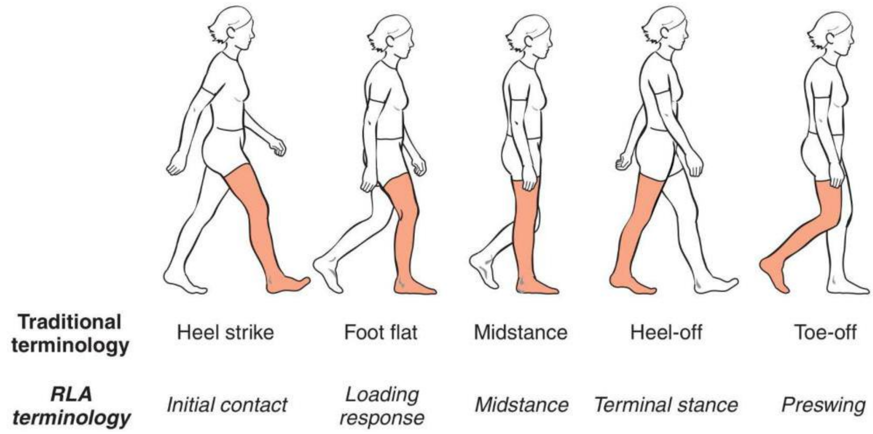

Figure 2.2-2 Five components of stance phase

Source: Studyblue, 2018

Foot drop is the inability to dorsiflex, evert, or invert the foot. So when looking at the gait cycle (Figure 2.2-2), the part of the gait cycle that involves most dorsiflexion action would be heel contact of the foot at 10% of the gait cycle, and the entire swing phase, or 60-100% of the gait cycle. This is also known as gait abnormalities, which refers to a deviation from normal walking.

2.3 Rehabilitation theories and treatment

2.3.1 Rehabilitation theories

Rehabilitation refers to the application of various measures to eliminate or reduce the physical and mental health and social dysfunction of individuals, in order to change individuals' life and enhance their independence. The ultimate goal is letting individuals reintegrate into society and improve their quality of life.

According to different symptoms, the purpose of rehabilitation may vary, such as increasing the degree of joint motion, strength and endurance, inhibit abnormal muscle tone, improve neuromuscular function and activities of daily living (ADL) as well as treatment of various complications. While in this thesis project, the rehabilitation goal for older adults living with foot drop is to improve walking and functional mobility.

The scope of conditions that receive rehabilitation include:
neurological diseases - stroke, traumatic brain injury, brain tumor surgery, pediatric cerebral palsy, spinal cord injury, peripheral neuropathy, Parkinson's disease, acute infectious multiple nerve root inflammation, poliomyelitis,

multiple sclerosis.

skeletal muscle system diseases - fracture and dislocation, amputation and prostheses, arthritis, frozen shoulder, cervical spondylosis, lumbar disc herniation, artificial joint replacement.

internal organs diseases - heart disease, chronic obstructive pulmonary disease, diabetes, hypertension, chest disease postoperative.

2.3.2 Rehabilitation measures of foot drop

2.3.2-1 Functional electrical stimulation (FES)

Functional electrical stimulation (FES) is a technique that uses low energy electrical pulses to artificially generate body movements in individuals who have been paralyzed due to injury to the central nervous system and peripheral. More specifically, FES can be used to generate muscle contraction in otherwise paralyzed limbs to produce functions such as grasping, walking, bladder voiding, and standing. (Figure 2.3-1)

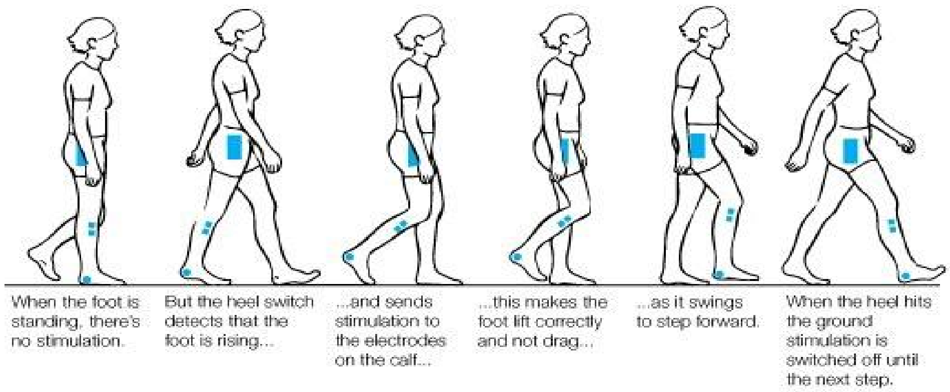

Figure 2.3-1 How FES works

Source: MsTrust, 2018

This technology was originally used to develop neuroprostheses that were implemented to permanently substitute impaired functions in individuals with spinal cord injury (SCI), head injury, stroke, and other neurological disorders. A consumer would use the device (See Figure 2.3-2) each time he or she wants to generate the desired function. (M.R.Popovic, 2015) FES is sometimes also referred to as neuromuscular electrical stimulation. (M. Claudia et al, 2000)

Figure 2.3-2 Existing Functional Stimulation Unit
Source: Foot-drop.blogspot.ca, 2018

In recent years FES technology has been used to deliver therapies to retrain voluntary motor functions such as grasping, reaching and walking. In this case, FES is used as a short-term therapy, the objective of which is the restoration of voluntary function and not lifelong dependence on the FES device, hence the name functional electrical stimulation therapy, FES therapy (FET or FEST). The FEST is used as a short-term intervention to help the central nervous system of the use to re-learn how to execute impaired functions, instead of making the use dependent on neuroprostheses for the rest of her/his life. (M.K. Nagai, 2016)

2.3.2-2 Ankle foot orthosis (AFO)

An ankle-foot orthosis (AFO) is a support intended to control the position and motion of the ankle, compensate for weakness, or correct deformities. AFOs can be used to support weak limbs or to position a limb with contracted muscles into a more functional position. In addition, AFOs are used to control foot drop caused by a variety of neurologic and musculoskeletal disorders. Due to the common use for addressing foot drop, AFO has become synonymous with the term "foot-drop brace". (Whiteside, S., 2007)

The goal of AFO use is to stabilize the foot and ankle and provide toe clearance during the swing phase of gait. This helps decrease the risk of catching the toe and tripping or falling.

A typical AFO creates an L-shaped frame around the foot and ankle, extending from just below the knee to the metatarsal heads of the foot. AFO's can be purchased off the shelf or can be custom molded to an individual wearer, and can be fabricated using a variety of materials, including low temperature (moldable) thermoplastics, metal, leather and carbon composite. AFOs are the most commonly used orthoses, making up about 26% of all orthoses provided in the United States. Different types of AFOs meet specific needs including:

Carbon Fiber AFOs - Lightweight, modern, low-profile design provides added strength and stability while avoiding contact at critical pressure points and facilitating a normal walking pattern. Ideal for active users.

Swedish AFOs - Deliver moderate lateral stability and static dorsiflexion assistance in a streamlined design for an easy, comfortable fit. Open calf and heel offer cool comfort and better shoe fit than a traditional plastic AFO. Trimmable footplate helps fit to any shoe. Ideal for a moderately active user.

Traditional Plastic AFOs - Reliable, economical options to meet a variety of needs. Can be applied in minutes, and easily modified by heat-molding or trimming for optimal customization. An ideal solution for short-term use.

2.3.2-3 Rehabilitation training exercises

Specific exercises that strengthen the muscles in the foot, ankle and lower leg can help improve the symptoms of foot drop in some cases. Exercises are important for improving range of motion, preventing injury, improving balance and gait, and preventing muscle stiffness. For people with foot drop that still have certain activity ability, these exercises could be used.

Towel Stretch - Sit on the floor with both legs straight out in the front. Loop a towel or exercise band around the affected foot and hold onto the ends with hands. Pull the towel or band towards the person's body. Hold for 30 seconds. Then relax for 30 seconds. Repeat 3 times.

Toe to Heel Rocks - Stand in front of a table, chair, wall, or another sturdy object the person can hold onto for support. Rock the person's weight forward and rise up onto toes. Hold this position for 5 seconds. Next, rock the person's weight backward onto heels and lift toes off the ground. Hold for 5 seconds. Repeat the sequence 6 times.

Marble Pickup - Sit in a chair with both feet flat on the floor. Place 20 marbles and a bowl on the floor in front of the person. Using the toes of the affected foot, pick up each marble and place it in the bowl. Repeat until the person has picked up all the marbles.

Ankle Dorsiflexion - Sit on the floor with both legs straight out in the front. Take a resistance band and anchor it to a stable chair or table leg. Wrap the loop of the band around the top of the affected foot. Slowly pull toes towards the person then return to the starting position. Repeat 10 times.

Plantar Flexion - Sit on the floor with both legs straight out in the front. Take a resistance band and wrap it around the bottom of the foot. Hold both ends in hands. Slowly point toes then return to the starting position. Repeat 10 times.

Ball Lift - Sit in a chair with both feet flat on the floor. Place a small round object on the floor in front of the person (about the size of a tennis ball). Hold the object between feet and slowly lift it by extending legs. Hold for 5 seconds then slowly lower. Repeat 10 times.

2.3.2-4 Physical therapy

Common interventions in the treatment of Foot Drop include (Twinboro, 2017): Manual Therapeutic Technique (MTT) - hands on care including soft tissue massage, deep friction massage, manual stretching and joint mobilization by a physical therapist to regain mobility and range of motion of the foot and ankle therapeutic exercises including stretching and strengthening exercises to regain range of motion and strengthen the foot and affected muscle.

Neuromuscular Re-education (NMR) - restore stability, retrain the lower extremity, and improve movement technique and mechanics (for example, walking, stairs, gait training, or stepping) in daily use of the involved lower extremity.

Modalities - include the use of EMS (electrical muscle stimulation) ultrasound, electrical stimulation, ice, cold laser, and others to decrease pain and inflammation in the foot and affected area.

Home program - includes strengthening, stretching and stabilization exercises and instructions to help the person perform daily tasks.

2.4 DAFO and DFS

There are a variety of treatments for people living with foot drop. According to their different characteristics, I choose to use mainly DAFO and DFS in this thesis project.

A Dynamic Ankle Foot Orthosis (DAFO) is a brand name for some lower extremity braces that provide thin, flexible, external support to the foot, ankle and/or lower leg. Designed to help a person maintain a functional position, a DAFO can improve stability for successful standing and walking. (Bjornson,

2006) Though being one kind of Ankle Foot Orthosis (AFO), DAFO is different from a traditional AFO, which is typically stiff and rigid. A DAFO is characteristically thin, flexible and wraps around the person's entire foot in order to provide improved sensation and alignment (Figure 2.4-1).

Figure 2.4-1 Components of DAFO

Source: Jd.com, 2018

The concept for the original DAFO was developed in 1985 as the collaboration between Don Buethorn, CPO, and Nancy M. Hylton, PT, LO. (Journal of Prosthetics and Orthotics, 1989) The two collaborated to create a thin, flexible brace that would meet the needs of pediatric individuals with neurodevelopment challenges and the result was the creation of a Washington state-based company, Cascade Dafo, Inc.

The working principle of Dropped Foot Stimulator (DFS) is to generate pulsed micro current artificially and transmit to the peripheral nerves through the electrodes placed on the skin to stimulate the central nervous system-controlled skeletal muscle. The obstruction of the electrical signal transduction pathways caused by the high central nervous disorders and to make the muscles produce contraction and drive joints in accordance with certain ways of activities, to complete the corresponding motor function. DFS works mainly through the peroneal nerve root surface below the fibula. Electrical stimulation signals flow into the peroneal nerve, thereby controlling the contraction of the tibialis anterior muscle, this causes the ankle dorsiflexion and knee valgus movement (Figure 2.4-2).

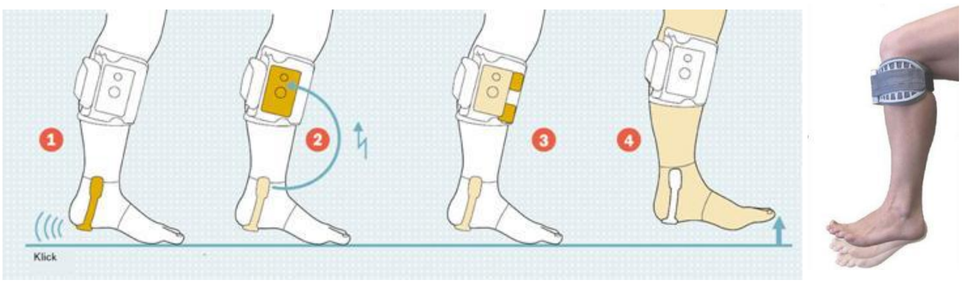

Figure 2.4-2 Working principle of DFS

Source: Disabled-world.com, 2018

Active muscle contraction can improve muscle strength and endurance. Through these muscles contracts ankles and tendons become more stabilized with the possibility of an increase in bone density which can make the entire skeletal system more stable. More importantly, the DFS is smaller in size and easier for users to hide with clothing. The increase in the user's range of movement can permit a more active lifestyle and enhance his or her quality of life and sense well-being. However, DFS also has some disadvantages and is not suitable for all the foot drop clients. It is not suitable for individuals who have other physical conditions. Some individuals have sensitive skin and may have acupuncture-like sensations to electrode-conduction. In addition, this system of the orthosis is problematic in water, and environments with high humidity. (Dawei Zhou, 2016)

In this thesis project, the assistive application - WalkingGuardian integrated all the existing devices including DAFO and DFS together into a rehabilitation system to improve the walking functions of the older adults living with foot drop. Detailed about how DAFO and DFS adapt with the WalkingGuardian will be introduced in Chapter 5.

2.5 Chapter 2 Summary

In this chapter, the condition of foot drop is introduced. The causes of foot drop and rehabilitation approaches are described. For clients who have foot drop, wearing ankle foot orthosis is a compensatory rehabilitation approach and helps maintain the functional position during walking. Two orthosis - DAFO and DFS are described. These will be discussed in the following chapters as the focus of the design.

In the next chapter, physiological data associated with foot drop are discussed. Existing products and applications related to foot drop are presented along with their advantages and disadvantages for rehabilitation.

Chapter 3

CURRENT RESEARCH AND DEVICES AND APPLICATIONS

3.1 Physiological data associated with foot drop

Research conducted by Shengjing Hospital Rehabilitation Center (affiliated with China Medical University) has explored the effect of the functional electrical stimulation on the foot pressure of people with stroke in walking mode. (Xiangnan Yuan, 2014) Subjects with foot drop (caused by stroke) were examined, participants walked unassisted on a plantar pressure measuring mat and walked with the affected limbs using electromyographic biofeedback. Participants were asked to walk barefoot on the foot pressure measurement mat, collecting walking data at least 5 times to provide average walking results. Plantar data was divided into different regions, the research analyzed the characteristics and comparison of walking foot pressure with and without electromyographic biofeedback. Comparisons of the center of gravity, pressure points, initial touchdown time, touchdown time ratio, peak pressure, touchdown area, impulse, and other indicators were recorded.

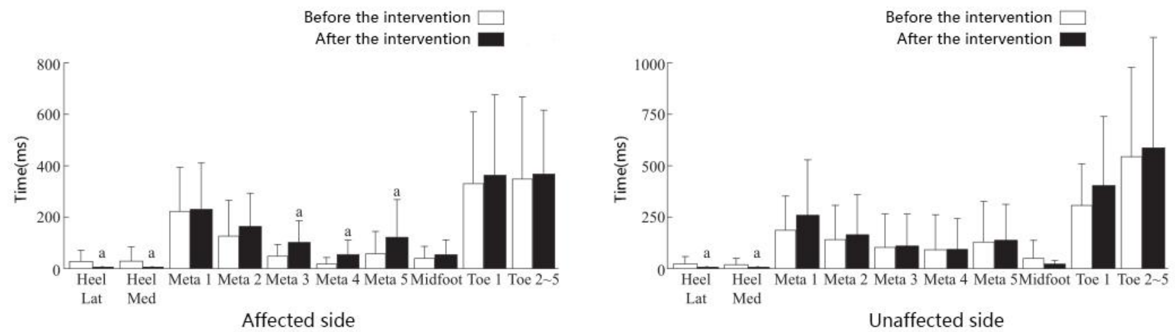

Figure 3.1 The initial touchdown time for each part of the foot

Source: Xiangnan Yuan, 2015

Results showed, after the intervention, the track of center gravity pressure became smoother, the initial touchdown location moved from outside of the foot to the heel or middle of the foot. Touchdown time significantly delayed. (Figure 3.1) Touchdown area of the heel and the inside area of the foot increased while outside area of the foot decreased. Comparison of touch time accounted for the proportion of the total support phase, heel medial and lateral can be seen to increase. Compared with peak value, the first metatarsal area, and the lateral area can be seen to have improved.

The conclusion is, for people with foot drop, the functional stimulation of myoelectric biofeedback can improve the touchdown area and pressure inside the heel and foot, and delay the contact time outside the foot as well as reduce the touchdown area outside the foot. Therefore, data such as touchdown area and plantar pressure could be collected and analyzed to help with the rehabilitation.

3.2 Related smart shoes and applications

As mentioned before, same as orthotics and stimulators, smart shoes is an essential part of the rehabilitation system that matched up with the WalkingGuardian. Existing smart shoes can already collect a variety of foot data such as plantar pressure and ground contact time, which are all necessary physical data associated with the condition of foot drop. All the data can be transmitted to the related smart phone application immediately. Currently, there are many types of forms for smart shoes, includes anklet, insoles, and socks.

3.2.1 Sensoria Socks

Sensoria Smart Socks are infused with 100% textile pressure sensors to inform individuals in real-time when they are striking with the heel or the ball of the foot.

Figure 3.2-1 Sensoria socks and application

Source: Gadgets and wearables, 2018

The smart garment connects to a lightweight anklet that wirelessly relays data during a person’s run to the related smart phone application (Figure 3.2-1). The person then gets information in real-time such as the cadence and foot landing technique.

The smart phone application monitors individuals’ run in much more detail and provides the user with a foot heat-map as well as information on the foot landing, contact time on the ground, cadence, pace, heart rate (when connected with the Sensoria HRM or other devices), speed, distance, altitude gains, GPS track and many other parameters. The app also allows the user to tailor goals and track progress.

The Redmond-based startup, announced at the Consumer Electronics Show (CES) 2017 the second generation of its fitness sock. “Sock 2.0”, the upgraded garment improves on the above metrics and provides actionable information from Sensoria’s AI coach on how to run farther, faster and healthier.

The company also announced a partnership with the running barefoot shoemakers. Powering the shoes are two removable sensoria cores, each connected to four pressure sensors in the sole. (Gadgets & Wearable, 2018)

3.2.2 Digitsole Warm Series

Figure 3.2-2 Digitsole warm series and application
Source: Gadgets and wearables, 2018

With a single tap on the screen, the heating function can be activated and the temperature adjusted for each insole separately. (Figure 3.2-2) Because of the built-in thermostat, individuals can control the temperature inside shoes as one would do in a house or car.

There are also more standard functions. The built-in accelerometer keeps a count of the number of steps, distance walked and calories burned thus turning the insole in a reliable pedometer. Individuals can track steps, log the distance walked and measure the calories burned.

The company - Digitsole also has other connected footwear in its product range. One can opt for the Warmin' sneaker or Smartshoe 001, both of which allow shoes to reach a pre-determined set temperature via smart technology. These shoes are defined as the first connected, interactive, heated, shock-absorbent shoes with automatic tightening that can be controlled via smartphone.

Finally, there is also the run profiler. These are digital insoles which analyze the 3D position of a user's feet and the characteristics of a user's strides. They will detect and measure one's fatigue to prevent injury, analyze gait to show how to spend less energy, and give audio coaching advice in a real time. (Gadgets & Wearable, 2018)

3.2.3 Kinematix TUNE

Kinematix TUNE is a product that applies in-shoe monitoring to both feet at the same time. (Figure 3.2-3) The tracker builds personal runner profile and continues to evolve it with each run. (Figure 3.2-4) This allows the users to evaluate their performance, for individual runs or even segments of runs, so they can understand where they performed best and where they need more work. The profile is built using running data from the insoles, GPS as well as personal information the uses provide such as age, height, weight, among others.

Figure 3.2-3 Kinematix TUNE

Source: Gadgets and wearables, 2018

Because each foot is monitored separately, this allows the tracker to detect and visualize asymmetries between the left and right foot and heel and ground contact times - all of which can be corrected with the proper training. TUNE will then recommends specific activities, and shows how to do them via video demonstrations. (Gadgets & Wearable, 2018)

Figure 3.2-4 Kinematix TUNE application

Source: Gadgets and wearables, 2018

3.2.4 Stridalizer

These sensor-packed insoles (Figure 3.2-5) tell the users exactly what's going on with their runs. If users carry their smart phones during their runs, they can access real-time tracking, stress-maps, and alerts. Or, leave phones behind, sync data and review running form and performance afterward. Data provided by the app includes pace, distance, time, stride length, stride rate and ground contact time.

Figure 3.2-5 Stridalizer

Source: Gadgets and wearables, 2018

The app shows a stress map or the pressure experienced on the feet and knees. This is important if the users want to avoid injury. Knee injuries account for about 42% of all running injuries. Stridalizer will help correct this by pinpointing areas on which the users need to focus.

The users also get real-time notifications on the stress experienced on feet and knees, overpronation and overstriding. Should they overstride or overexert themselves too much during a run, the app will send out an immediate alert. (Gadgets & Wearable, 2018)

3.3 Individual rehabilitation application

With the penetration of mobile Internet in various industries, the mobile Internet technology that focuses on the field of medical and health care has been highly concerned with its rapid development. As an important growth point in the future medical and health field, rehabilitation medical market has already been researched by many Internet medical companies. Existing applications such as rehabilitation assistant, rehabilitation express and sports rehabilitation are cutting into the market from different perspectives such as prevention and diagnosis. Here I select three rehabilitation applications designed for different special groups separately.

3.3.1 Diabetes: Self Monitor

Service target population: diabetes

"Diabetes: Self Monitor" is an application specially designed for people with diabetes to help them manage the disease. (Figure 3.3-1) Its functionalities were carefully selected, based on requests of actual users.

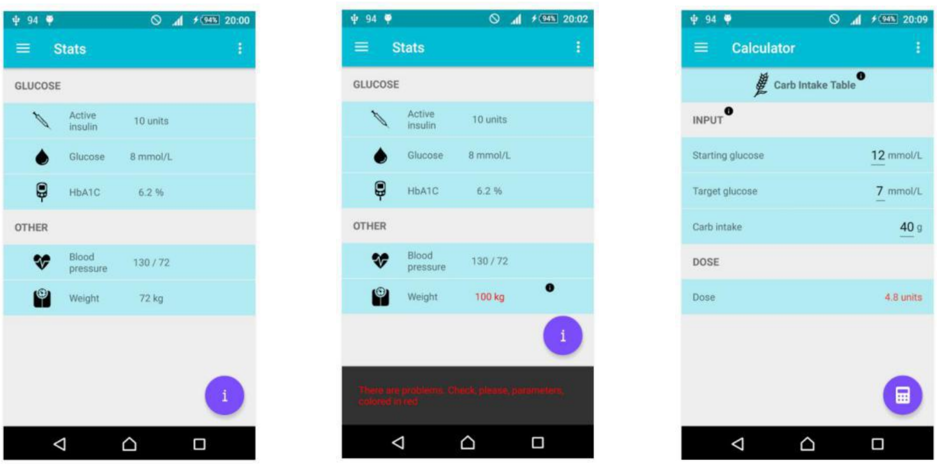

Figure 3.3-1 Data collection and calculation

Source: Google Play, 2018

The application can help users monitor key diabetes aspects to maintain the disease. The tools for determining blood glucose level, blood pressure and weight are present. (Figure 3.3-2) With the bolus calculator, one can efficiently and simply calculate the doses of a short and prolonged bolus insulin that is vital for maintaining diabetes. It also has a vast nutrition database, to help users keep track of food intake and determine appropriate meals for everyone because the diet is very important in managing diabetes.

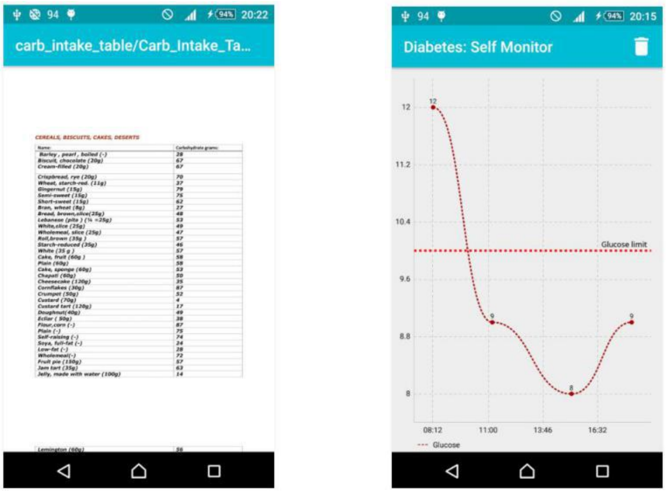

Figure 3.3-2 Data analysis chart

Source: Google Play, 2018

With the help of charts, users may track glucose level day by day, without unnecessary in practice statistics by day, month or year. Handy notifications inform users about problems with diabetes vital parameters.

3.3.2 Fitness for amputees

Service target population: amputees

Although a variety of fitness apps are emerging in retrofit formats, these apps are designed for healthy people and are not suitable for people living with a disability. However, for people with disabilities who have prostheses, they have a great demand for fitness. Therefore, a company called Ottobock developed an app for amputees with leg prostheses. The app has 16 tailor-made training sets inside, eight for force training and eight for endurance training which is suitable for personal training or system rehabilitation.

The Fitness for Amputees app includes a range of easy-to-follow exercises designed by experienced physiotherapists at Ottobock and is tailored specifically for people with a unilateral leg amputation. The app can offer regular guidance for up to 6 months after a prosthetic fitting and provides with the training user's need during this period. (Figure 3.3-3) All one need for the exercises is a mat, a towel, and a ball. The user has to install the app on a device, they can also use it offline as well.

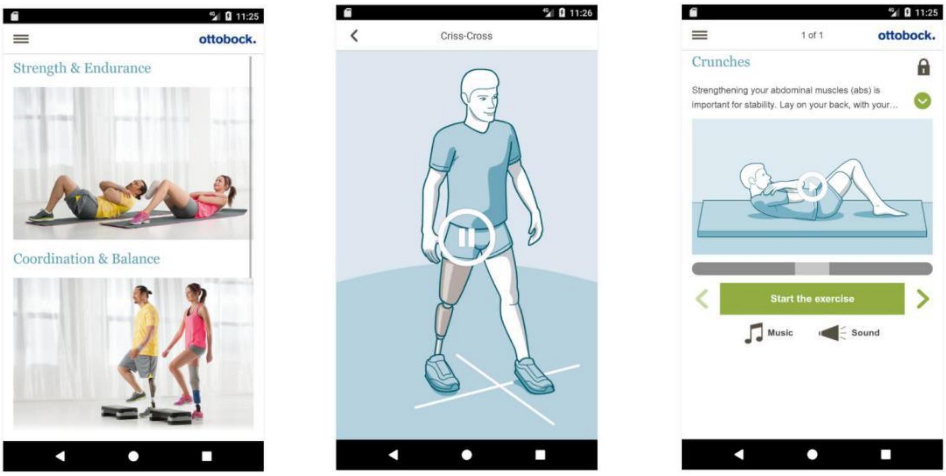

Figure 3.3-3 Different modules and action guide

Source: Google Play, 2018

The app consists of 3 modules:

- Strength and Endurance: For strengthening the upper body muscles and stabilizing the spine. This is the foundation for a natural gait pattern.
- Coordination and Balance: For improving coordination and supporting safe standing on the prosthesis. To enhance one's comfort and achieve more natural movement patterns.
- Stretch and Relax: For relaxing the muscles and for faster regeneration. These exercises can increase muscle flexibility.

Further functions and benefits:

- Selection of exercises: Complete either a predefined training program or create a person's own individual training program.
- Music selection: Train to the music available in the app or to the user's own music on smart phone or tablet.
- Statistics function: Keep an eye on the progress and get an overview of the number of exercises one has already completed.
- Reminder function: Allow the app to remind the user of the next training session.

3.3.3 Backup Memory

Service target population: Alzheimer disease

Recent research has shown that constant mental stimulation can delay the loss of memory with Alzheimer early stage. At that level, people living with Alzheimer disease face unexpected futures. To help preserve their memory, they need solutions in helping them to be continuously connected to their memories.

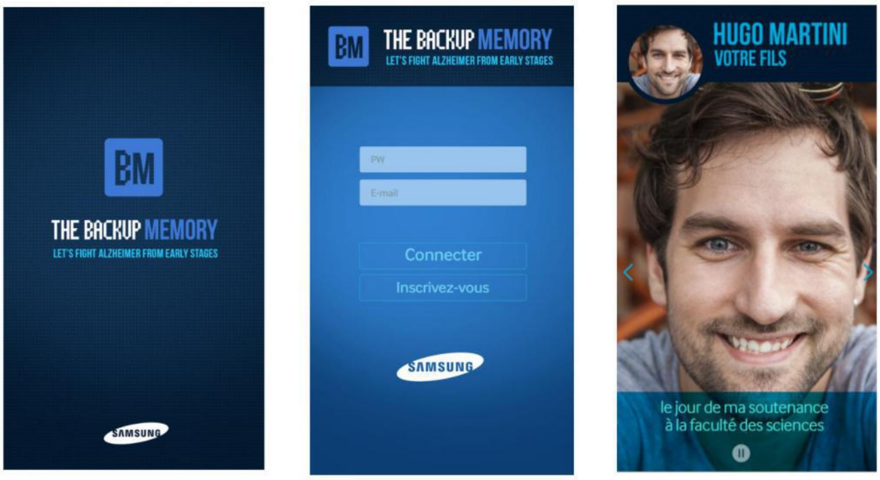

Figure 3.3-4 Operation interface and image

Source: Google Play, 2018

In real time and directly to their phones, the Backup Memory provides users with reminders of the identity of the person entering their field of intimacy, via instant notifications. (Figure 3.3-4) Users can thus view their relationship status with that person, as well as memories, photos or videos related to them. This is a non-medical therapy that continuously exposes the individuals to the past and helps them with their memories.

3.4 Foot droop orthopedic - use XFT-2001D as example

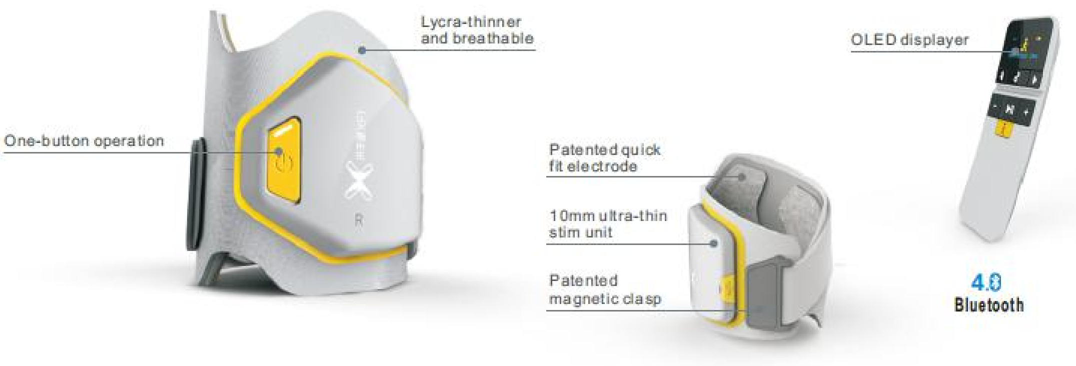

Figure 3.4-1 Component of XFT-2001D system

Source: Xft-china, 2018

XFT-2001D Foot Drop System adopts advanced MEMS sensor technology and intelligent algorithms (Figure 3.4-1), precisely controlling the time and duration of electrical stimulation by tracking the swing angle and pace of the user's leg. XFT-2001D delivers electrical pulses to the common peroneal nerve as well as the tibialis anterior and other muscles to make the movement dorsiflexion and eversion. Those mild electrical pulses stimulate user's leg muscle, making them lift the foot at an appropriate phase while walking and therefore enabling the person to walk more steadily, naturally and safely.

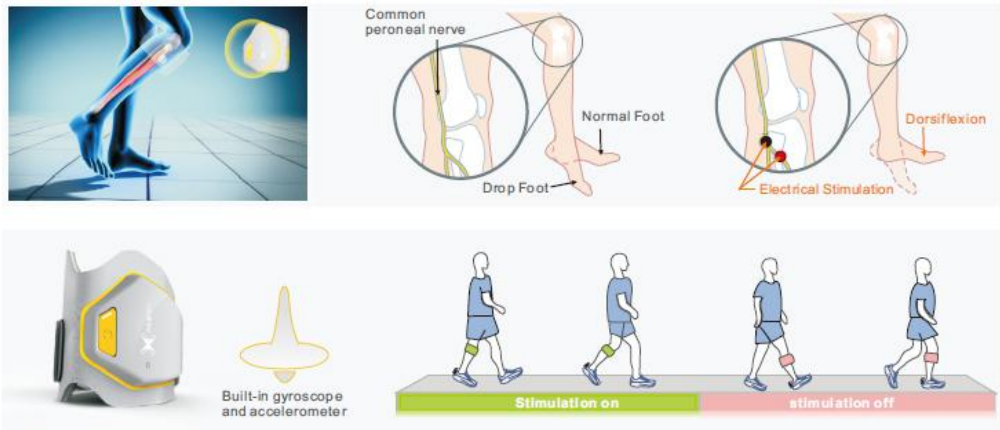

Figure 3.4-2 Working principle of the XFT-2001D system

Source: Xft-china, 2018

During walking swings, the timing of electrical stimulation is controlled by tracking, where and when the user rocks back and forth during walking. Electrical stimulation will stimulate the common peroneal nerve distributed in the anterior tibial muscle and other muscles to cause ankle dorsiflexion or valgus and valgus movement so that the legs of users can be lifted in time to achieve the purpose of preventing foot drooping in the process of walking. (Figure 3.4-2) Therefore, the walking ability of people living with foot drop can be improved, gradually restoring walking function. The system can also stimulate the retraining of the leg muscles, maintain or increase the range of activities of the ankle.

The system can be used with most types of shoes, compact, convenient and comfortable. It can reduce muscle atrophy, calf muscle spasticity, improve walking speed and gait quality as well as stability while walking to reduce the risk of falls. Moreover, the system hopes to enhance the mobility during walking and improve the self-confidence and ability to walk independently.

Compared with other orthotics, XFT-2001D is compact designed, easy to wear without any exposed wires. It can be precisely controlled to give electrical stimulation through the gait sensor timer. Users do not have to wear shoes (even barefoot) to walk. The passive plastic braces product is heavy and needs users to take the initiative to adapt to them. What's more, AFO does not provide the neurorestorative function.

With XFT-2001D, users need to understand the function and adapt to the system, which makes it limited. In addition, the independent remote control systems are not convenient to carry. Furthermore, there are also functional and structural elements of the design that can be innovated.

3.5 Chapter 3 Discussion

In this chapter, physiological data associated with foot drop are discussed, which provided a theoretical basis for the settings of the WalkingGuardian system. With this data, it will be more convenient for users to communicate with doctors and more advantageous to examine long-term treatment effects.

Three rehabilitation applications were presented, which shows that people have made use of intelligent technology as a way of rehabilitation in their daily life. Related smart shoes and applications were shown to verify the feasibility of the designs. The beneficial parts of the existing designs can be directly tested and used while other parts could be improved. I also used XF-2001D foot drop system as an example. As a complete system design, it has many ideas for me to learn from. Compared with other orthoses, it's more comprehensive also more cumbersome and needs to be improved. In the next chapter, I will introduce some design strategies and principles of assistive design to support my design, the WalkingGuardian system. These design principles can help me avoid mistakes and makes the design more rigorous.

Chapter 4

DESIGN STRATEGIES AND PRINCIPLES OF BEHAVIOUR CHANGE

4.1 Behaviour change theories

Changing behaviour is crucial in helping inactive people become active, which is why it's been at the heart of all healthy and active projects. (Sports England) However, daily habits for humans often work themselves into repetitive systems and behavioural patterns that can be very difficult to break. Human behaviour is a complex system of conscious and subconscious triggers, and the link between psychology and design is therefore an important topic in behavioural models. As a result, in the emerging field of persuasive design and design for sustainable behaviour, the methodology around user mentality and how to change entrenched habits become important for designers. (Kristin, 2016)

Persuasive design is something that is intentionally designed by designers to change users' unhealthy behaviour or attitude to continue doing the healthy behaviour. The persuasive design considers how to create user engagement and work with emotional and behavioural barriers and triggers to increase the chance of a specific action. (Galdo, 2011) It is a holistic design approach that relies heavily on context based designer empathy and has a user-centered point of view. (Oinas-Kukkonen, 2009) To reach the rehabilitation purpose for older adults living with foot drop, the WalkingGuardian should be designed to encourage and motivate users to take daily activities regularly.

Persuasive designs have an initial link to persuasive technologies and user experience (UX). These technology ties come from the design of the user interface and how it is possible to customize user experiences, often tailored to create a specific set of user outcome. (Jsselsteijn, 2006) When designing the WalkingGuardian for older adults living with foot drop, the interface, functions, and other related elements should be designed according to their preferences to achieve better using experiences.

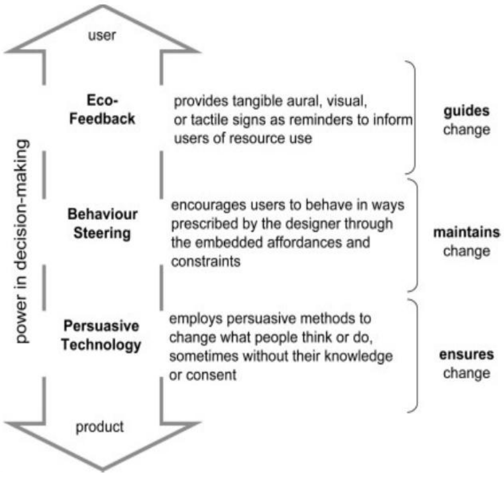

Figure 4.1 Strategies for designing for sustainable behaviour

Source: Debra Lilley, 2009

When designing for sustainable behaviours, such as the rehabilitation process of foot drop, using a mixture of the strategies is essential. It is vital to know how to influence the users most efficiently, but also maintain a level of personal choices and user control. (Kristin, 2016) Debra Lilley classifies potential strategies according to the degree of which the user or product has the power in the decision-making. (Figure 4.1)

4.2 Behaviour model - Motivation, Ability and Triggers

Professor Fogg at Stanford University summarized a model of behaviour that can be applied to the design based on the predecessors. Fogg's behavioural model indicates that human behaviour consists of motivation, ability and trigger conditions. Only when all of three elements meet at the same time will the behaviour happen. The model could be simplified with an equation: B = MAT. B is behaviour, M is motivation, A is ability, and T is the trigger. (Figure 4.2)

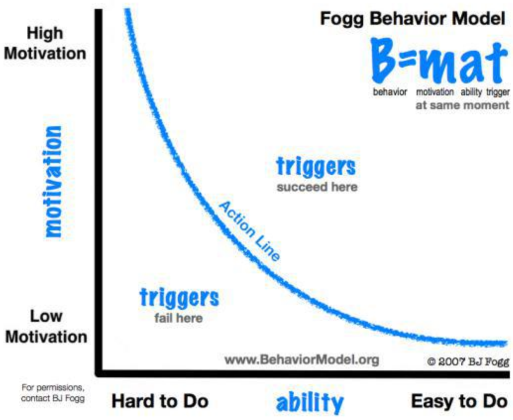

Figure 4.2 Fogg's behaviour model

Source: Behaviour model.org, 2018

Here is a brief analysis of Fogg's behaviour model:

First, there must be sufficient motivation for the behaviour to take place. The application designed in this thesis project is for older adults living with foot drop. Therefore, only this kind of users will choose this application to help with their rehabilitation. Other types of users will also choose the appropriate application to help with their own illness. The results of using the application are certainly beneficial. The results of rehabilitation are gradually be reflected in the daily data records and analysis.

Second is the ability, that is, users must have the ability to complete this action. In some applications, we often forget this and always think users are omnipotent, assuming that users are more capable than they actually are. We have to understand that in most cases the behaviour happens because the behaviour is easy to do and the user needs fewer resources to do it. When applied to the application, the functions of the design should be as simple as possible to make it easy to understand for the older adults. In addition, setting some simple goals in early stage also makes the older adults more motivated to complete the goals and get a better sense of accomplishment.

The third element that affects behaviour is triggering. Advertising, product operation is constantly providing a variety of triggers. Trigger content can be a reminder, it can also be a deadline or other related things. The essence of the trigger is to inform the user to do it now. (Dahui, 2016) In order to remind the older adults, daily activities reminders and data analysis are displayed on the lock screen by regular reminders.

Through this model some of the principles of behavioural design can be summarized:
Identify the target behaviour that needs to be completed, the behaviour is specific and can be easily implemented. Do not mistake the wishes, the results, the plans as actions. If users want to achieve phased rehabilitation results, they should set milestones and take action every day.

Start with the smallest and simplest behaviours. Behaviour changes occur not by willpower, but by slow and small changes, similar to snowballing. Individuals may not get the results immediately when they make some small changes towards their goals. But accumulated these small changes over a long period of time and huge gains can be made. Similarly, the rehabilitation process of foot drop is quite long, individuals will not have an astonishing compensate effect in a short period of time. Such conditions often frustrate the individual, which makes it important to reset the expected treatment effects periodically. What’s more, reward behaviour is an important part of the rehabilitation process. Instant rewards for behaviour can motivate ongoing behaviour. When individuals have the confidence and motivation to carry out rehabilitation activities, the effects tend to be more effective. In the designed application, I also set different levels of training exercises for users with different levels of rehabilitation.

Behavioural design process needs to consider motivation first, then the individuals' ability and last is the trigger. Give priority to the analysis of motivation, motivation is the energy source of behaviour. Behaviour designers should follow the user's motivation, do not think about creating motivation or changing motivation. Outstanding products can stimulate motivation by influencing emotions to produce action. Besides, motivation fluctuates over time. Everyone's motivation is based on different external environment issues changes that can at any time, every month, every week, every day will be different. Being able to walk like "normal" people is definitely the ultimate goal of all the people living with foot drop. Thus, only when individuals see the effect of the treatment, will they conform to a daily rehabilitation training. Which also emphasizes the practicality of rehabilitation applications.

There are two ways to enhance abilities. One is to train users, one is to design a product that is easy to use. Designers should start with product optimization, allowing users to expend as little resources as possible to achieve the goal. Similarly, succinct and precise interfaces or functions are needed for rehabilitation applications.

The trigger should match the target user and the target behaviour. A smart trigger can make the behaviour happen, and the poor trigger, on the contrary, disrupts the user and cause negative emotions. It is very important to set different rehabilitation goals and training according to different conditions of individuals.

4.3 Imitate successful examples

In order to test my design of the WalkingGuardian, I have relied on existing research data and knowledge such as personalization, colour theory, simplicity, and related interactive principles. The final application would need to be further tested to ensure more details about the design of the application, such as the functions of perception and readability on the screen under a testing prototype.

4.3.1 Strategies of developing a mobile app user experiences (UX)

- Ability to personalize

Personalization has become one of the most attractive qualities of an app. The app users prefer to use an app that they feel in control of. Users need to be engaged and have the capability to optimize their experience with the application. Personalization makes it possible for users to make changes until they feel satisfied with what they are using. This will ensure long-term use of the application as more users will prefer to personalize their experience. (Oleg Babentsov, 2017) Therefore, the WalkingGuardian need to have the functions that present individuation as well as customized design.

- Colour and graphics

Colours can leave a great impression on users, and some will be drawn to and away from the application based on this quality. Therefore, choosing the right color for an application is very important. Choosing the right color can be done by carrying out an online survey or by simply carrying out an online search about the most popular color or color palettes that people are more attracted to. The target user of the WalkingGuardian is older adults living with foot drop, and they prefer high purity, bright colours that give a strong visual impact. In addition, colour choice is especially important when text is involved as readability depends on it.

In visual experiences, harmony is something that is pleasing to the eye. Colour harmony delivers visual interest and a sense of order. The visual task requires that we present a logical structure. There are many theories of harmony, a colour scheme could base on analogous colours, complementary colours, or nature. (Colour matters, 2018)

In order to increase legibility, all the icons, graphs and typeface of the text are used or designed to be simple and understandable for the older adults to recognize at first glance.

- Develop a minimal user interface

A good app does not have to provide too many features. It is important to pay more attention to developing the apps' primary function.

This is known as the minimal rule and is what many successful apps have in common. However, other features can be added to the application but only after the app can efficiently do what it was initially made for.

4.3.2 Code of interactive design

- **Follow the user's mental model**

When users interact with an application, they operate the interface based on their previous experiences and instinct. In short, when they encounter a button, they will think of what action the button will trigger to meet their needs. If this button does not meet the user's intended mode of operation, then this button design is problematic.

Users have the final right to use the application since they are not designers or developers, most of them do not understand the design concept and development process. Therefore, the language and text of the application should be clear for ordinary users. It is appropriate to think users as mid-level learners to optimize the design of the application. For mid-level learners, the design does not be too basic or too complicated.

- **Less is More**

Originally proposed by architect Ludwig Mies van der Rohe, it is a design philosophy that promotes simplicity and opposes excessive decoration. This principle has a long history and has led to many different interpretations in many industries.

The interface should be designed as concise as possible, simplicity is the key to success when it comes to apps. Nobody wants to deal with the complicated app. Make sure the users feel like they are in control of the app, that is, icons, language options or any other important features of the application are created in specific patterns.

- **Intuitive principle**

The intuitive principle can be used throughout the user experiences design. Using the simplest way and the shortest amount of time to help users achieve their goals is a good user experience. In the application, correct operating parts must be obvious, but also to convey the correct information to users. Users do not need to learn these modes of operation, instead, they can easily operate the application by their life experiences and instinct.

- **Information feedback principles**

The "communication" between people and machines is essentially the process of information transmission. Information has to go back and forth in order to be coherent, which will form an effective interaction and mutual understanding. So timely effective feedback and explanation is particularly important. In almost all the interfaces that require human-computer interaction, when the user performs certain operations, the system needs immediate feedback to the user in the form of discoloration, shape change, vibration, light emission. The purpose is to inform the user that the machine knows about the interaction. (Mockplus, 2017)

4.4 Chapter 4 Summary

This chapter introduces the behaviour change concepts and some successful examples, which all provide guidelines with the function and interface design of the WalkingGuardian, makes it a better application for communication with users. Besides, just like the rehabilitation applications I used for example in Chapter 3, the designed application in this thesis project also embodies the spirit of sustainable use. Moreover, a sustainable application can continuously motivate users to use and get unexpected results.

In the next chapter, a detailed design concept of WalkingGuardian is presented, followed by a discussion of design process and development. All the functions and interface design are largely influenced by the design principles and strategies in this chapter.

Chapter 5

THE WALKINGGUARDIAN SYSTEM

Previous chapters have discussed the following: rehabilitation theories and treatment for people living with foot drop which can be applied in the practice part of WalkingGuardian; dynamic ankle-foot orthosis together with its stimulator become the core part of rehabilitation treatment in this application. Current research of foot drop and auxiliary devices are used for reference to enrich the background of rehabilitation devices and applications; some motion tracking devices and applications are compared; three design strategies and principles inform and guide the design of assistive technology. In this chapter, the assistive technology to motivate older adults living with foot drop to enhance the walking experiences is presented. WalkingGuardian (Figure 5) is designed for older adults living with foot drop who have the ability and motivation to incorporate physical activity into daily lives and to make the walking function better gradually or keep it from getting worse. The target users of WalkingGuardian are older adults living with foot drop who have walking difficulties but still have the capacity for active daily mobility.

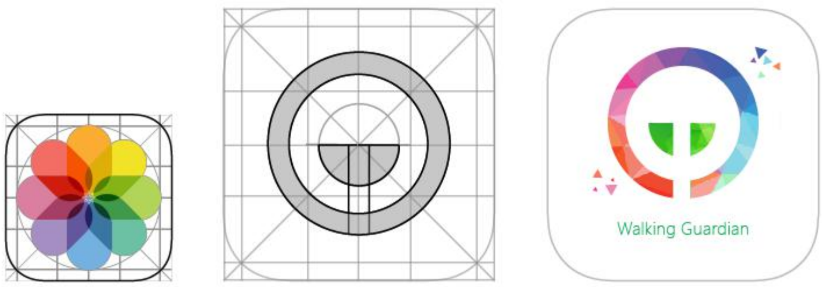

Figure 5 Images for the WalkingGuardian's icon Design
Developed by the letters W and G. From left to right:
Colour system; WalkingGuardian's grid system; WalkingGuardian's icon rendering

WalkingGuardian consists of three main components: (1) basic functions, (2) reminder system, (3) reward system. The basic functions can cover all the needs of the individuals' daily activities and their demand for rehabilitation. The reminder system can promote individuals to take activities every day for rehabilitation purposes. The reward system can provide them with motivation and confidence, as the rehabilitation of foot drop is a long process, individuals may lose their confidence easily. The theme of the application changes with different stages, individuals can check their data and record at any time to make the comparison, they can also unlock different training modes depending on different rehabilitation stages. The WalkingGuardian uses a phone-based sensor to calculate and infer physical activity data to the system in real time. Each of the three main components of WalkingGuardian is presented, followed by a discussion of how the design strategies and principles described in Chapter 4 largely guided and influenced the design of WalkingGuardian.

5.1 WalkingGuardian concept and basic functions

WalkingGuardian is an auxiliary application designed for foot drop rehabilitation purposes. The target users of the application are older adults living with foot drop who have the ability and motivation to incorporate physical activities into daily lives to improve walking functions gradually. Connections with orthotics are described in the function of movement while the connections with DFS are described in the function of DFS control. Smart insoles (or other types of smart shoes according to personal choice) is required to be used throughout daily activities as well as dynamic and static standing to collect all the related foot data.

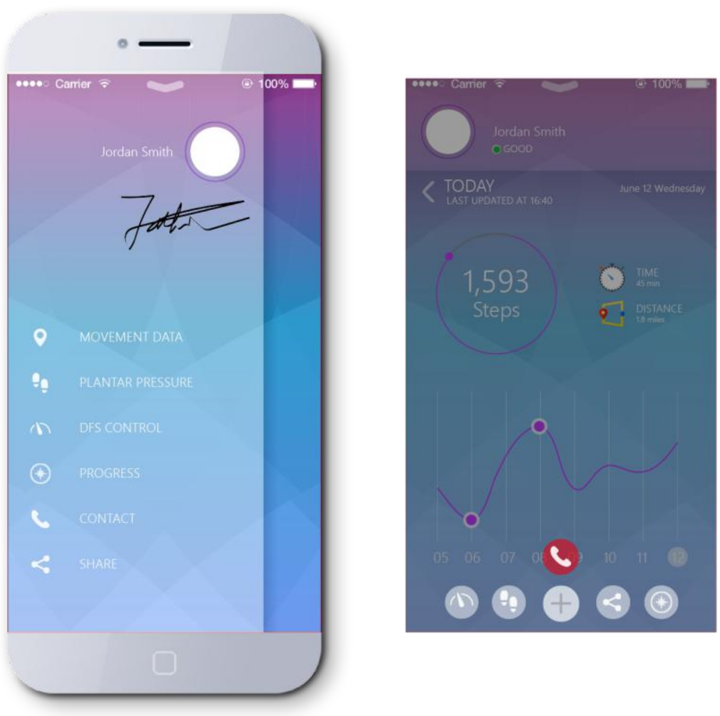

Figure 5.1 Main menu of the the WalkingGuardian

Enter from the main menu to the use functions. Switch between different functions: press the button on the bottom and choose.

Basic functions are designed in order to ensure that the application can cover all aspects of a person's daily walking and rehabilitation demand. In figure 5.1, the user's profile will show on the top side of the main menu, together with his/her signature to ensure the personality of each individual. The functions contain movement data, plantar pressure, DFS control, rehabilitation progress, emergency contact, and sharing system. When logging in to the system for the first time, users can choose options from the main menu, when switching between different functions, they can also press the bottom button of each page to call the simplified menu out and switch easily (Figure 5.1). Considering the particularity need of the aged population, voice interactive is added, so the users can hear the content through the voice broadcast of the application.

5.1.1 Movement Data

As an auxiliary application, WalkingGuardian aims to help individuals with foot drop to have better walking experiences. Therefore, using smart insoles through dynamic and static standing to record and analyze movement data is particularly important. In addition, in order to achieve better walking experiences, individuals can choose to wear orthotics or stimulators during daily activities according to their own conditions.

Figure 5.1.1 Movement data interface of the WalkingGuardian

Users can rapidly interpret how far they are from in reaching their daily or weekly goals through a glance.

WalkingGuardian uses data abstraction representations to convey key information about users' behaviour and their goal attainments such as time, distance and the step number. Users can rapidly interpret their progress in reaching their daily or weekly goals through a glance at the application (Figure 5.1.1). Meanwhile, WalkingGuardian also supports with detail data about physical activity information using graphs and numbers. Individuals can visually view the trend graph of this week's movement data as well as click on a specific date to see detailed data for that day. In order to prevent inaccurate records of the physical activity, this system also allows individuals to add, edit, and delete data.

Any physical data related to the foot drop condition will be analyzed to get the current status, which shows below a user's name on the top of the screen. There's three status altogether: poor, good and better. For movement data, if the individual reaches the daily goal and maintains a certain amount of activities, the status is good. If the steps are beyond the daily or weekly goal, the status is better. Otherwise, if the individual does not reach the goal, the status will be worse.

5.1.2 Plantar data

In addition to the movement data, plantar data is another significant element closely related to the state of foot drop. As mentioned before, to achieve the purpose of data tracking, smart insoles are needed to record plantar data. Smart insoles are small and portable, which would be convenient to be loaded on orthotics as well as put in shoes.

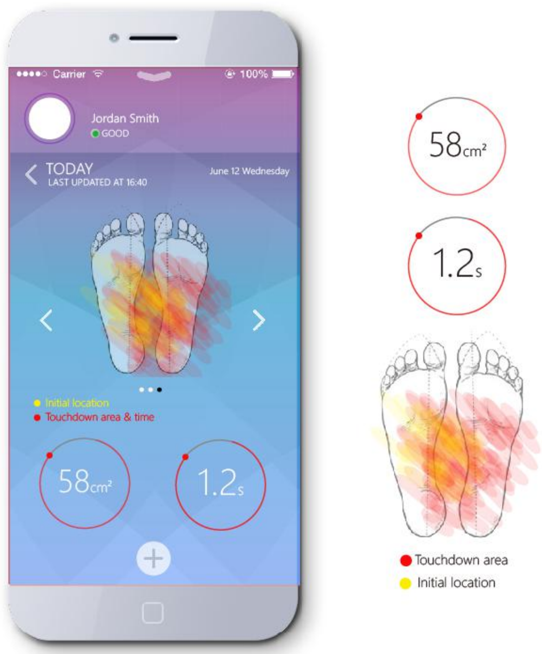

Figure 5.1.2 Plantar data interface of the WalkingGuardian
Individuals can visually get the initial location, touchdown area and plantar status.

If walking condition improves, the status of plantar data will show as good or better. As mentioned in Chapter 3.1, the track of center gravity pressure will become smoother, the initial touchdown location will move from outside of the foot to the heel or middle of the foot. Touchdown time will significantly delay. Touchdown area of the heel and the inside area of foot will increase while outside area of the foot will decrease. Comparison of touch time accounts for the proportion of the total support phase, heel medial and lateral can be seen to increase.

Individuals can visually get the initial location, touchdown area and plantar status to know about the development trend of their condition (Figure 5.1.2). Graphs and detail numbers are also provided for deeper information, individuals can slide the screen to see plantar data on different dates, all the data can be sent to facilitates communication with health professionals.

5.1.3 DFS control

The previous chapter has discussed the functions of DFS for the rehabilitation of people living with foot drop (see Chapter 2.4). Through active muscle contraction, DFS can improve muscle strength and endurance. As the muscles contract, they help stabilize ankles and tendons, increase bone density, and make the entire skeletal system more stable. More importantly, the DFS is small in size and easier for users to hide with clothing.

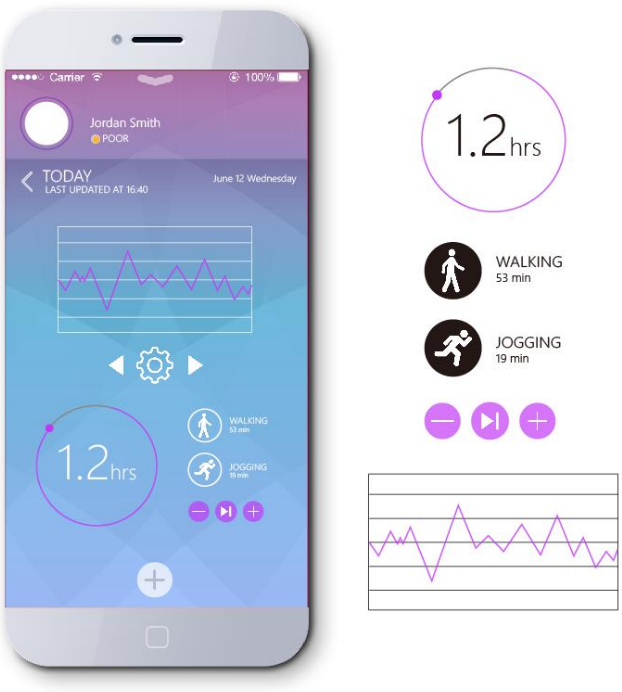

Figure 5.1.3 DFS control interface of the WalkingGuardian
Individuals can easily control DFS through WalkingGuardian.

For people living with foot drop, utilizing DFS when walking can reduce their discomfort and achieve better walking experiences. Individuals can connect their DFS (or other types of stimulators according to personal preferences) with WalkingGuardian by Bluetooth connection. In this way they can easily control DFS through WalkingGuardian, details of using time and model are also recorded (Figure 5.1.3). Displayed in the same way as other physical data, the status of DFS control will show on the top of the screen. If the status is worse, it means that the user has spent less time using DFS than usual and more activities are needed.

5.1.4 Emergency Contact and Sharing system

Emergency Contact

The target users of WalkingGuardian are older adults living with foot drop, these individuals are more likely to have accidents while exercising alone. Because of these circumstances, the emergency contact is an indispensable part of WalkingGuardian.

Individuals can set up several emergency contacts and choose one as auto-associator. When an accident happens, individuals can contact their friends or family members immediately by one click on the screen, which is easy to operate and saves time (Figure 5.1.4-1).

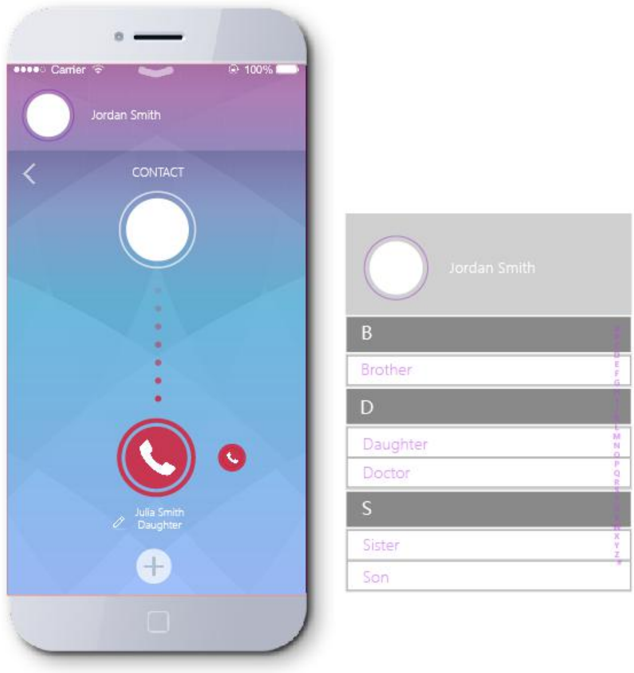

Figure 5.1.4-1 Emergency contact interface of the WalkingGuardian
Individuals can contact with their friends or family members immediately by one click on the screen, which is easy to operate and save the time.

Sharing system

WalkingGuardian's sharing system is mainly designed for communication between foot drop clients and health professionals. With the help of the sharing system, there will be no time or space limitations for diagnosis. Also, by clicking on the share button, individuals would be able to share any graphs or data together to a variety of social media, such as Facebook or Twitter (Figure 5.1.4-2) to share their feelings with friends and family members.

Figure 5.1.4-2 Sharing system interface of the WalkingGuardian
By clicking on the share button, individuals would be able to share any graphs or data together with their feelings to a variety of social media.

5.2 WalkingGuardian reminder system

Task activated memories of the older adults may be degraded, some older adults may suffer from short-term memory loss. Based on this circumstance, WalkingGuardian is designed to have the function of reminding users to take activities every day, that is, the reminder system. The design style of WalkingGuardian is based on the change in color and shade, the three keynote colour: warm-toned blue, yellow and red are relatively acceptable colours for the aged cause they prefer high purity, bright colours that give strong visual impact (see Chapter 5.3).

The WalkingGuardian's reminder system is designed to be succinct and clear in order to let older adults perceive the reminder directly. The system mainly uses the shade change of color to represent reminder elements in real time about individuals' physical activity behaviour and goal attainment. This non-literal but understandable format of reminder is more gentle and acceptable for older adults.

As can be seen in Figure 5.2-1, the shade of the screen color intensity is relatively low in normal condition. When there is half an hour left until the scheduled activity time, the screen color gradually darkens, a pale exercise icon appears and is accompanied by a short prompt. At this moment, individuals can start doing warm-up exercises and set up daily goals (Figure 5.2-2). As time passes, the exercise icon gradually rises with the lines to the center of the screen and becomes more clear. When the scheduled time arrives, the colour of the screen reaches the strongest, the exercise icon clearly presented in the middle of the screen and accompanies with constant gentle reminder music, which means the individual can start their daily activities right now.

Figure 5.2-1 Reminder system of the WalkingGuardian

The system mainly uses the shade change of colour to represent reminder in real time about individuals' physical activity behaviour and goal attainment.

WalkingGuardian's display is implemented on the lock screen background and the theme of the individuals' mobile phone. Therefore, individuals can see the background/theme as a kind of reminder every time they use mobile phones. During daily activities, individuals can click on the exercise icon on the background of the lock screen any time to check the numbers of steps taken and see the remaining numbers of steps. Relevant activity data are presented at the same time for individuals to evaluate the amount of activities that day (Figure 5.2-2).

The implementation of the background/theme also serves as a reminder to individuals. Recent data indicate that modern people use mobile phones 150 times per day (Daily mail, 2017), considering such high frequency of mobile phone usage, individuals should reflect on the display often enough to fulfill the requirement of maintaining good initiatives to achieve rehabilitation goals every day.

Figure 5.2-2 Daily goals of the WalkingGuardian
During daily activities, individuals can click on the exercise icon on the background of the lock screen any time to check the numbers of steps taken and the remaining numbers of steps.

5.3 WalkingGuardian reward system

The rehabilitation of foot drop is a long-term process. As a consequence, WalkingGuardian is designed to be used long-term and should sustain an individual's interest and support of his/her personal lifestyle. In order to prevent the initial engagement from fading away, a reward system is an important component of WalkingGuardian. By offering unexpected and new experiences, it caters to an individual's desire for freshness.

Award collection library

Everyone will have the satisfaction of having achievements recognized. The award collection library provides a variety of awards which contain all aspects about the individual's physical data and using data, such as the amount of activities, total numbers of walking steps, the number of days one has been using the application (Figure 5.3-1). All the awards are set up to encourage individuals and to keep confidence and motivation in their rehabilitation processes.

With this award collection library, we hope that individuals can direct their attention away from raw numbers of data, and value the efforts they have spent in rehabilitation. Individuals can view the awards they get any time in the award library and share them with friends or family members.

Figure 5.3-1 Awards collection library of the WalkingGuardian
Individuals can view the awards they get any time in the award library and share them with friends or family members.

Training section

Discussed in Chapter 2.3.2-3, specific exercises that strengthen the muscles in the foot, ankle and lower leg can help improve the symptoms of foot drop in some cases. Exercises are important for improving range of motion, preventing injury, improving balance and gait, and preventing muscle stiffness.

In the training part of WalkingGuardian, different levels of training exercises are established. Individuals can start by doing simple exercises that improve proficiency through continuous practices (Figure 5.3-2). When the proficiency of a certain exercise reaches five stars or the user's recent state of status gets better, an exercise with a higher level of difficulty will be unlocked. It is the desire to increase individuals' motivation in this way, what's more, taking different difficulty levels of exercises step-by-step can help the rehabilitation progress become more effective.

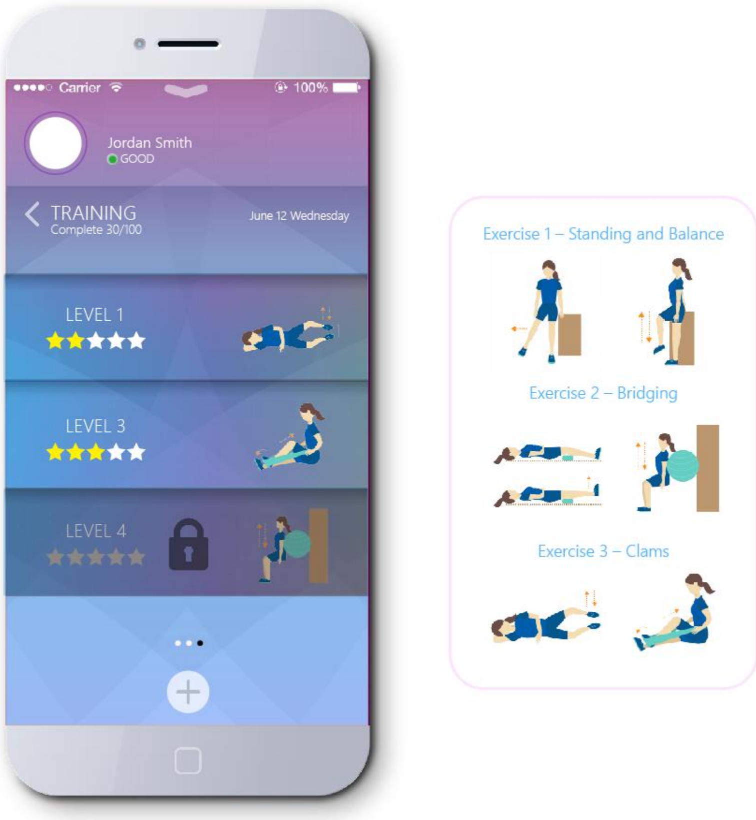

Figure 5.3-2 Training exorcise of the WalkingGuardian
Individuals can start from doing simple exercises and improve proficiency by continuous practices.

Change of theme

Discussed in Chapter 5.2, WalkingGuardian's display is implemented on the lock screen background and the theme of Individuals' mobile phone. The theme can exist in a visual environment without drawing the unnecessary attention of other people, as it is common for people to use and change their background wallpapers. As can be seen in Figure 5.3-3, the theme changes with the status of the individuals and has three stages in total. The three stages use blue, yellow and red as the basic colour, the three colour changes with shade have a connection between each colour.

Stage 1 is the original state, which appears when individuals use the application at the beginning of their rehabilitation. With the progression of time and status, the theme is likely to enter stage 2, which means individuals are using WalkingGuardian daily for a period of time (usually 6-12 months) and have achieved elementary success already. These kinds of success can be simple such as unlocked all level-2 exercises but show healthy development towards the final rehabilitation goal. Entering stage 3 means individuals are using WalkingGuardian for a long period of time (at least 12 months) and achieved a higher level of the goals towards rehabilitation. However, at that time, individuals should continue doing a certain amount of activities every day and should not treat the daily activities minimally, if the status gets poor, the theme will return to stage 2 or even stage 1 automatically. With the implementation of the theme, individuals can rapidly interpret and understand where their stages of rehabilitation are through a glance at the screen. Understanding their status can help individuals physical and mental state in order to cooperate with rehabilitation schemes.

Figure 5.3-3 Changing theme of the WalkingGuardian

Colour changes with shade and have a connection between each colour.

Other conceptual ideas besides the normal theme can also be explored, for example, weekend or holiday theme would also be available in cases that the user is colour blind. Those themes could be different from the everyday themes by adding certain patterns or changes in the colour/font of the text.

5.4 Implement the design principles and strategies

In Chapter 4, design principles and strategies were introduced for guiding and designing assist technologies, which included the following: code of conduct design, code of interactive design and sustainable design of rehabilitation products. WalkingGuardian utilized all these principles and strategies as follows:

5.4.1 Strategies of developing a mobile app UX

- **Offer the ability to personalize**

WalkingGuardian has set up many functions such as the change of theme, the award system and training system to show the maximum personalization and specificity of every individual. Other custom parts, for example, font size and shading can also be adjusted by individuals until they are satisfied. Rehabilitation is a long-term process, and WalkingGuardian will meet personal needs as far as possible to improve user experiences and achieve long-term use.

- **Pay attention to the colour and graphics**

The basic colour of WalkingGuardian is warm-toned blue, yellow and red, which are used according to older adults' preferences for high purity, bright colours that gives a strong visual impact. Of which the yellow and red stages appear when the status of individual gets better since research showed the majority of the older adults psychologically responded favourably to vibrant, warm colours.

All the colours generally use the medium to high brightness to show on the screen to account for the general weakening of the visual abilities of older adults. All the icons and the typeface of the text are used based on the principle of simplicity and legibility. When considering colour harmony, the theory of a color scheme base on analogous colours is used. The background of the WalkingGuardian used different shades of color to make changes.

Considering the visual characteristics of the older adults, less monochrome and more complex colour is used.

- Develop a minimal UI

As mentioned in Chapter 5.1, the functions of WalkingGuardian mainly focused on (1) basic functions, (2) reminder system and (3) reward system. The basic functions can cover all the needs of the individuals' daily activities and their demand for rehabilitation. The reminder system and reward system can provide individuals with motivation and confidences together with the general status, which are all essential and indispensable necessary functions for a long-term using rehabilitation application.

5.4.2 Code of interactive design

- Follow the user's mental model

WalkingGuardian is designed to follow a user-centered model. The interface is succinct and clear and is configured to work with a wide range of individuals. The buttons and icons used in WalkingGuardian are intuitive, which meet the users' intended mode of operation and individuals can associate with the action immediately.

The design concept and development process in WalkingGuardian is clear enough for individuals to understand even if they are not designers or developers. The language and text of the application are designed for the majority of user's ways of thinking.

- Less is More

The interface of WalkingGuardian is designed as concise as possible, so individuals can deal with it easily. All the icons, language options and any other important features of the application are created in specific patterns to make Individuals feel like they are in control of the application.

- Intuitive principle

The intuitive principle is applied throughout the whole design of WalkingGuardian. Individuals can get all the information from a glance at the screen, using the shortest amount of time to achieve their goals. In WalkingGuardian, correct operating parts are obvious, they also convey the correct information to users. Users do not need to learn the modes of operation, instead, they can easily operate the WalkingGuardian from their life experiences, instincts and from interfacing with everyday technology.

- Information feedback principles

The communication between users and WalkingGuardian is essentially the process of information transmission. WalkingGuardian can provide users with timely effective feedback and explanation. In almost all the interfaces that require human-computer interaction, when the user performs certain operations, WalkingGuardian will immediately give feedback to the user in the form of discoloration, shape change, vibration, light emission to inform the user that the application already knows about the operation.

5.5 Chapter 5 Summary

In this chapter, the version of WalkingGuardian that was designed for this thesis project was described. Three main components of the WalkingGuardian were introduced: (1) basic functions, (2) reminder system, (3) reward system. The basic functions can cover all the needs of the individuals' daily activities and their demand for rehabilitation. The reminder system can promote individuals to take activities every day for rehabilitation purposes. The reward system can provide them with motivation and confidence, as the rehabilitation of foot drop is a long process, individuals may lose their confidence easily. Meanwhile, the theme of the application changes with different stages, individuals can check their data and record at any time to make the comparison, they can also unlock different training modes depending on different rehabilitation stages. In the end, a discussion of how the design strategies and principles described in Chapter 4 guided and influenced the design of WalkingGuardian was also presented.

Chapter 6

EVALUATION OF WALKINGGUARDIAN

In the previous chapters, the WalkingGuardian that was designed for this thesis project is to facilitate the older adults living with foot drop to enhance the walking experiences was presented. In order to evaluate whether WalkingGuardian is able to improve the walking condition of the older adults living with foot drop and whether it has the potential to encourage individuals to have positive attitudes towards everyday use, participants were interviewed to evaluate the WalkingGuardian concept. The qualitative analysis used in this project focused on interviews and questionnaire.

This chapter contains the following aspects: qualitative analysis, study details and participants, overall reactions and participants' suggestions to the WalkingGuardian concept. In the evaluation part, participants' reactions to the main components of the WalkingGuardian system were recorded. The reminder system and reward system, are discussed specifically to address the importance of the two systems and the participants' understanding towards them. According to these participants' responses, future improvement of the concept of WalkingGuardian has been considered.

6.1 Interviews

The interviews contain a series of questions about a participants' existing experiences and attitudes towards their rehabilitation process of foot drop, as well as their daily activities and exercise patterns. Introduction to the WalkingGuardian and the rehabilitation system were explained to the participants and their family members. The model application is sent to participants for operating.

Open-ended questions were mainly asked through voice communication interviews. The content of the interviews covered the concept of the WalkingGuardian, participants' daily behaviour, and their experiences and attitudes of using rehabilitation applications. These questions can help with the development of WalkingGuardian's concept in the future. In addition to questions related to the concept design, the interviews also collected information about a participants' demographics and their family composition which helped in analyzing their situation.

Study details and study participants

The telephone interviews were administered in April, 2018. Two older adults living with foot drop, one female and one male participated in the interviews (all assisted by their daughters). Participants were aged 62 (female) and 71 (male) and lived in urban regions of Shanghai, China. Both participants were retired, and their foot drop symptoms were caused by stroke.

The female participant had foot drop since she was 55, her condition had improved through daily exercises. Currently she could raise her foot a little consciously and walk on tiptoe by herself without any help for a short period of time. She reported positive experiences in using DAFO and DFS, recently, her daily activities was a half-hour walk by herself wearing intelligent walker (similar as the orthopedic described in Chapter 3.4). In addition, she had experiences of using applications by smart phones, and could understand the functions and concept of WalkingGuardian quite easily through the explanation.

The male participant, has had foot drop for more than 10 years. His condition was not positive as his foot became quite stiff and he could not walk independently by himself. He was familiar with DAFO and knew about DFS (or FES), but did not have experience in using DFS. Currently, his family members would accompany him for approximately a dozen minutes of walking every day (in the case of wearing DAFO) indoors. He had a smart phone but rarely uses applications. With the help of his daughter's explanation, he could generally understand the function and concept of WalkingGuardian.

Open-ended questions were mainly asked for general feedback about the concept of the WalkingGuardian, which are listed below:

- ✧ How do you feel the design would improve your walking experience?
- ✧ Do you think the basic functionality is comprehensive enough? Which part needs to be added/deleted?
- ✧ How do you feel about the reminder system? Do you think the lock-screen reminder is able to affect your daily exercises awareness? Why?
- ✧ How do you feel about the reward system? Do you think it can motivate you to continue with your rehabilitation?
- ✧ How well do the detailed data and abstract theme provide representations of your condition and goal attainment?

- ✧ Does the changing theme provide a softer way of presenting condition for you? In addition to changes in colour/ depth, is there any way of representation would you be interested in?
- ✧ Do you find the WalkingGuardian in some way enjoyable? What aspects make you feel that way?
- ✧ Which parts of the design are your favorite?
- ✧ What do you dislike about the concept?
- ✧ Please add any feedback you have on how the WalkingGuardian could be improved.

The interviews were conducted in Chinese, I recorded the complete content of the interviews, translated and transcribed them verbatim. Each of the participants responded to the questions in detail. General reactions and suggestions to the WalkingGuardian concept are provided in the next section.

Overall reactions

Consistent with expectations, the female participant was very positive about the concept of WalkingGuardian. She believed that the WalkingGuardian was suitable for older adults living with foot drop who are in a recovery stage just like her:

"I really like this idea, I can imagine it working well especially for older adults living with foot drop just like me, who have the personal mobility to do the activities alone. Maybe my foot drop won't fully recover, but at least it will stay in good condition. The basic functions of it (the WalkingGuardian) can fully cover my daily behaviour, which makes me satisfied."

"I prefer to do exercises every day on schedule, therefore, the reminder is just right for me. Generally, I exercise for a certain amount of time every day ignoring walking steps. But I guess provide walking steps and other related data is a better choice."

"The reward system, well, I think it gives me something to do at least. I am very idle since I retired. And I think, it (the reward system) can provide me with certain motivation, though I am not sure how much it can provide."

Although the female participant accepted the concept of WalkingGuardian, she expressed her doubt about the possibility of the interference of the reminder:

"When I am watching TV or cooking meals at the kitchen, it often happens that my mobile phone is not around me. Even if there is a warning sound of the reminder, it's still very likely to be covered by the noise surrounding it."

The male participant expressed some concerns about the WalkingGuardian. Since the concept required individuals to carry smart phones during daily activities, his daughter worried about how to utilize the concept as her father didn't have the habit of carrying a smart phone with him. Likewise, her father is not able to utilize the WalkingGuardian system by himself at present. However, she accepted the concept of WalkingGuardian as she used the application for her father and taught him gradually until he was able to operate the system himself:

"My father is 71-years old, so I don't think he can accept the whole concept of it (the WalkingGuardian)…as you know, he needs my help to walk. Our family members don't think he can exercise alone… and we won't let him to exercises alone. But I can imagine myself using the application to assist my father's daily activities, which would be helpful. If possible, I'll teach him slowly to use it (the WalkingGuardian), but I'm not sure whether he can use it by himself at the end."

The male participant together with his daughter also expressed their concerns towards the reward system and reminder system, as the male participant commented:

"The reward system is good… daily activities could be really frustrated and boring sometimes. It is a little bit complicated for me so I might need some time to learn about it."

"The changing theme is a good idea, but I am not very interested in the changing of colour/depth maybe I don't have the kind taste of art. Maybe you could change it into something more concrete."

"Personally, I really need the reminder system…older adults tend to forget things. However, at present, my daughter reminds me to do daily activities every time."

Her daughter also gave additional remarks:

"I can understand the reminder system, and I believe it can work well. The problem is, we don't have a certain time to do the daily activities. By weekdays, we may take the activities before or after dinner. On weekends, we might choose afternoons to take the activities. "

Suggestions

As introduced in Chapter 5, WalkingGuardian is intended to cater to an individuals' interest and personal style. Other possible forms of expression the concept of WalkingGuardian were put forward by participants, suggestions were that family members' photos together with their voices could be shown in the lock-screen as reminder to motivate daily activities; the colour/depth of the changing theme could be chosen by personal interest; and the reminder could be shown on other smart devices:

- Family photos and voices as reminder

"I would be more interested if my grandson's photo appeared progressively on the lock-screen to motivate me doing daily activities. It would be better if his voices are contained. Although we meet once a week, I still miss him very much."

The suggestion might be attractive for older adults, for they usually very concerned about their family members. This approach may give them more confidences and motivation to keep rehabilitation.

- The colour/depth chose by individuals

"Changing in colour and depth of the theme to present the condition is acceptable for me. However, it could be better if I can choose my favorite colour to be the background. "

The idea would make the WalkingGuardian more appealing as the background of the mobile phone is something individuals need to look at frequently. It is hoped that their favorite choices could be shown on the background.

- Reminder showed through different smart devices

" If the reminder could be shown on the smart TV or smart watch, then, to a great extent, I won't miss it. And...sometimes, I can carry my smart watch instead of smart phone to do daily activities outside, which would be more portability for me."

The possibilities of applying the WalkingGuardian into the different operating system would make the WalkingGuardian more flexible. In this way, it would have more comprehensive coverage and can operate into an individuals' daily life more deeply.

6.2 Questionnaires

The questionnaire collected feedback on the feasibility of the WalkingGuardian system and design suggestions to improve the overall concept. All the feedback helped to evaluate whether the design would work well if realized to a prototype. A range of open-ended questions was asked about participants' opinions towards using the WalkingGuardian and the compatibility with their daily activities. Further considerations on how to improve the design concept were also included.

The questionnaire was spread together with the introduction of the WalkingGuardian and the link of the model application in chat groups of older adults living with foot drop. Adhering the principles of voluntary and anonymity, the optional questions can be answered selectively. Altogether, seven participants' feedback was received.

Study details and study participants

The questionnaire was distributed in April, 2018 with seven participants participated. Among them, three were female and the other four were male, all aged from 55 - 75. All of them were retired and lived in different urban areas in China.

Among all the participants, one has foot drop less than 5 years, four have foot drop between 5-10 years and two have foot drop more than 10 years. They were all familiar with DAFO and had known about DFS (or FES). All the participants have smart phones yet four of them seldom used smart phone applications. However, all the participants indicated that they were willing to learn about the application if it can help them maintain or improve their condition of foot drop.

The questions in the questionnaire are mainly open-ended questions, which consist of two parts - the required questions and optional questions. Optional questions were mainly the same as the questions asked in the individual interview in the previous chapter. All these questions were asked to improve and examine the utility of the WalkingGuardian concept.

Required questions:
- ✧ Gender and age?
- ✧ How many years since you have foot drop?
- ✧ Are you familiar with DAFO and DFS?
- ✧ Do you have smart phones? Have you used smart phone applications?

Optional questions:
- ✧ How do you feel about the design would improve your walking experience?
- ✧ Do you think the basic functionality is comprehensive enough? Which

part needs to be added/deleted?

- ✧ How do you feel about the reminder system? Do you think the lock-screen reminder is able to affect your daily exercises awareness? Why?
- ✧ How do you feel about the reward system? Do you think it can motivate you to continue with your rehabilitation?
- ✧ How well do the detailed data and abstract theme provide representations of your condition and goal attainment?
- ✧ Does the changing theme provide a softer way of presenting condition for you? In addition to changes in colour/ depth, is there any way of representation would you be interested in?
- ✧ Do you find the WalkingGuardian in some way enjoyable? What aspects make you feel that way?
- ✧ Which parts of the design are your favorite?
- ✧ What do you dislike about the concept?
- ✧ Please add any feedback you have on how the WalkingGuardian could be improved.

Due to the nature of the questionnaire, some participants did not finish the questionnaire completely. Even so, some positive opinions were raised by participants. General reaction and suggestions towards the WalkingGuardian concept are listed in the following.

Overall reactions

The questionnaire tended to test whether the concept of WalkingGuardian can work well and become a commercial product in the future. Participants were asked to imagine what will happen when they use the application. The overall reactions were positive from the participants. According to the feedback collected from the questionnaire, most participants accepted the concept of the WalkingGuardian and appreciated how it is functioned:

"I think...overall the concept is good, as a rehabilitation application, it (the WalkingGuardian) has quite comprehensive functions."

"I like the design style of it (the WalkingGuardian), which is simple and clear. And I can understand all the functions easily."

Participants also appreciated the reminder and reward system:

"Reminders seems to be a must for older adults, of course, it's all I need."

"Reward is something everyone enjoys... it is appealing that your actions can be turned into rewards. It motivates me...especially in such a long rehabilitation

process… For me, I would like to collect more awards. Although I am not young, I also enjoy trying new things."

"The expression of changing theme is definitely better than telling me ' you're getting better' or 'you're getting worse'…After all these years, you know, I become numb sometimes. It might be better if the theme could present more detail."

Several participants commented that WalkingGuardian can fit their activity pattern well and shows clearly information about their condition:

"With it (the WalkingGuardian), I don't have to remember so many things myself. If I want to know something, just look at it through my mobile phone, anytime and anywhere."

"I am doing activities and rehabilitation training every day, which is just included in the application. So I think, it would be helpful for me."

"Sometimes I just don't know how to plan my daily activities. It (the WalkingGuardian) can give me guidance and arrange everything perfectly for me. I just need to consult with the doctor to set up my daily goals first."

"I can imagine it's really convenient for me to send the detailed data directly to my doctor and get his feedback. I am also satisfied with other functions of it (the WalkingGuardian)."

"I love this idea, it (the WalkingGuardian) is more like a personal assistant to me. The detailed data can let me know more clearly about my condition (of foot drop), which makes me feel I have the initiative to recover. "

Suggestions

In the questionnaire session, questions were asked of the participants to evaluate the concept of the WalkingGuardian. Further considerations on how to improve the design concept were also included. Participants were asked to include any additional feedback on how the concept could be made more appropriate and appealing for them.

Overall, participants appreciated how the WalkingGuardian concept functioned. Additionally, they had suggestions towards personal preferences and future improvements, which are listed below:

- Target population could be expanded

"I think the concept is quite complete, with some slight improvement, it could be suitable for people with foot drop of all age."

In the future, there could be different versions of the WalkingGuardian aimed at various different age groups of people with foot drop.

- Family members receive reminder as well

"Sometimes I might miss the reminder, if my son or my daughter can receive the reminder as well, they'll find I missed the reminder and inform me about that."

In addition to reminder shown in different smart devices described in the previous chapter, there could be multiple receivers of the reminder to guarantee the attainment of daily goals for activities, which might increase the communication among family members as well.

- Communications between individuals

"I have several friends who have foot drop as well, if we all use the application, I would be interested to know about the detail of their daily activities, for instance, the walking steps... it could be better if we can share about our condition and communicate with each other."

The comparison and communication part could be added into the WalkingGuardian. The comparison makes the application more attractive for the user and gives individuals more enthusiasm to share that will enhance socialization.

- Looking for other users around

"I would like to do activities outside with other people living with foot drop. I mean, if I can find another person near me, maybe we can exercise together and share our experiences. We can take care of each other when we go out."

If added the function of location, individuals can find other people living with foot drop near them, they can communicate and exercise together. For those individuals who prefer to take activities alone, they can close this function manually.

- Establish partnerships with hospitals

"I am thinking beyond communications with doctors. Since the display can combine DAFO and DFS together... the hospital could introduce these three

issues together to the users, which I believe would be more comprehensive."

If the WalkingGuardian worked as a commercial product, build the partnership with hospitals that can certainly popularize the application and the concept of the rehabilitation system. Foot drop assistive devices such as DAFO and DFS could be introduced together with the WalkingGuardian to users. With more people living with foot drop using the application, more related cooperate projects can be carried out.

- Walking data comparison with normal people

"People living with foot drop is eager to get recovered, as you know, walking is a basic skill that normal people have. It's really good that the application could collect my detailed data. Furthermore, I hope there is a comparison of my data with normal people's data. And, maybe I can record the daily walk video and make a comparison."

Comparison with non-affected persons will not only let people living with foot drop have a clear understanding about the correct gait but also let them feel the narrowing gap between everyday persons and themselves when their foot drop condition gets better.

6.3 Chapter 6 Summary

In this chapter, feedback collected from both the in-depth interview and questionnaire are presented. The content of the interview covered the concept of the WalkingGuardian, participants' daily behaviour, and their experiences and attitudes of using rehabilitation applications. The questionnaire collected feedback on the feasibility of the WalkingGuardian and design suggestions to improve the overall concept. All the feedback helped to evaluate whether the design would work well if realized to a commercial application. A range of open-ended questions was asked about participants' opinions towards using the WalkingGuardian and the compatibility with their daily activities.

Overall, findings from both the interviews and the questionnaire suggested that most participants found the activity display very appealing when they were introduced to it. The evidence provided in this chapter showed that most participants accepted the concept of the WalkingGuardian and appreciated how it is functioned, especially the reminder and reward system.

Participants' opinions toward some certain aspect of the activity display, which all helped to improve the concept of the WalkingGuardian, were included:

Family photos and voices as reminder; The colour/depth chose by individuals; Reminder shown in different smart devices; Target population could be expanded; Family members receive reminder as well; Communications between individuals; Looking for other users around; Establish partnerships with hospitals; walking video and data comparison with other persons.

Chapter 7

CONCLUSION AND FUTURE DEVELOPMENT

7.1 Conclusion

This thesis project is on the subject of designing a rehabilitation application to guarantee stage goals for older adults living with foot drop to reach rehabilitation goals. It is developed to be an interactive activity display to facilitate self-monitoring and specifically focused on presentation of information on the lock screen (reminder system) and background (changing them of reward system) to increase awareness of daily activities. The motivation of this project is to help individuals to be aware of their condition of foot drop and to take exercise regularly in order to get accurate and comprehensive data. Together with abstract information presented on the screen it will inform them of the stage of their rehabilitation processes. As the rehabilitation process usually takes a long period of time, it is believed that WalkingGuardian can give individuals living living with foot drop the confidences and motivation to succeed, as well as different types of data to help analyze the foot drop condition effectively. WalkingGuardian can play an important role as a companion to accompany the individuals to recover physically and mentally and urge them to make greater efforts towards their recovery. This kind of information companionship is especially important for older adults and can help relieve their isolation caused by their condition and enhance their socialization.

Although the concept of WalkingGuardian is not the first project to focus on assisting individuals for sustainable rehabilitation, it is still useful in the field of rehabilitation, persuasive design and technology, activity display and the health problems of older adults. The technologies used in WalkingGuardian system such as real-time monitoring, stylized data visualization could also be adapted for use in other rehabilitation or sports systems.

The design of WalkingGuardian was presented and evaluated to determine if the concept is acceptable as well as to explore further opportunities for the application. In addition, some design issues and study limitations were presented, which could be used to improve the design concept of WalkingGuardian in the future.

7.2 Study limitations

Overall, this thesis project has contained some implications for future work in the field of sustainable rehabilitation, persuasive design and technology, activity display and the health problems of the older adults. However, there are still some user restrictions cause the target users of the WalkingGuardian are individuals who are active and able to walk. Many people who have foot drop are wheelchair users that do not apply to this application.

In the evaluation of WalkingGuardian, evidence suggested that most participants found the application attractive. Evidence showed that participants appreciated how WalkingGuardian functions, in particular, the reminder system guaranteed the implementation rate of daily activities. The changing theme together with award collecting and unlock-style training section offered great inspiration towards training behaviour and goal attainment.

Participants' feedback showed that they had satisfactory experience overall when using WalkingGuardian. However, all the positive feedback of WalkingGuardian so far does not necessarily mean that the activity display will effectively improve individuals’ walking condition. It may help them also to incorporate regular daily activities to achieve the purpose of rehabilitation. It only shows that WalkingGuardian has the potential to do so.

In order to demonstrate the feasibility and validity of the proposed concept of WalkingGuardian, a working prototype is needed. The application can be implemented for an operating smart phone system, such as Android or IOS. Due to constraints in time and funding, a fully functioned working prototype that runs on a smart phone is beyond the scope of this thesis project. If possible, the next step in this research would contain large-scale study with more participants over a longer period of time. Nevertheless, the findings of this thesis research could hopefully still be used as a reference for a rehabilitation research designer or an application developer to realize the system in the future.

In addition to the limitations summarized above, this thesis project also leaves many opportunities for future work.

7.3 Implication for future work

In the previous chapter, participants from both interviews and questionnaires came up with different suggestions toward the WalkingGuardian concept. Based on those suggestions and reflections further improvement of the design are listed as follows:

- **A working prototype of WalkingGuardian**

As described in above Chapter 7.2 Study limitations, it is hard to come to the conclusion that WalkingGuardian will effectively improve individuals' walking function and be able to help them incorporate regular activities of daily living to achieve the purpose of rehabilitation.

Therefore, future research needs to investigate the effectiveness of the WalkingGuardian when implemented on an operating smart phone system so that the research could not only test the concept and functions of WalkingGuardian but also launch the in-depth investigation of the user's experience. In the future, different versions of the WalkingGuardian aimed at various different age groups of people with foot drop could be developed.

Additionally, the system requires professional guidance from experts in related electronic technology fields, such as electrical engineering and electrocommunication.

- **Expansion of the functions of WalkingGuardian**

In the future, WalkingGuardian can be developed in the direction of private customization. It can provide individuals with more intimate personal services. During the daily activities, functions such as location could be added, which would help older adults living with foot drop to find partners nearby and share experiences with each other. Planning the route and real-time navigation can also be added according to personal preferences.

In order to cater to an individuals' interest, family members' photos and their voices could be used as reminders to show progress on the lock-screen. The colour and intensity of the changing themes could also be selected by the individual user.

In order to allow older adults with foot drop to communicate at any time, real-time communication sessions would be needed. If necessary, individuals should be able to share their daily data with friends to help them interact with positive motivational cues.

In addition to the functions above, more customized programs to help analyze the condition such as comparison with normal people's walking data could be added according to different individuals' need when the WalkingGuardian system becomes more mature.

- **Establish the on-line website for the WalkingGuardian system**

The on-line website can have a publicity effect that allows older adults living with foot drop to be informed about the WalkingGuardian system and its use as a daily assist. In this way, a strong connection between the user and the WalkingGuardian system can be build to consolidate and strengthen the system

When individuals have any comments or feedback, they can publish opinions on the website any time, the system will also reply in time to inform the problem has been received. When the system will be updated or there is any notification, the information will be posted on the website in advance to inform the individuals.

When the WalkingGuardian system develops to a certain extent and has a certain amount of users, some offline activities such as public lectures can be held and posted on the website to raise public awareness. In addition to the online website, promotion of videos, posters, or media is sometimes necessary as well.

- **Establish partnerships with hospitals**

The WalkingGuardian can build partnerships with hospitals that can popularize the concept of the rehabilitation system. As doctors are already included in the communication loop with older adults living with foot drop, doctors can have access to data that helps analyze the condition overall and hence more cooperative projects. At the beginning of the individuals' rehabilitation process, DAFO, DFS together with the WalkingGuardian could be introduced since there is a connection between them. In this way, individuals can receive more comprehensive care that saves both time and labour.

- **More possibilities of applying the WalkingGuardian system**

In this thesis project, WalkingGuardian was implemented on the background and theme of a smart phone based operating system. However, future research could explore more possibilities for applying the WalkingGuardian system in different operating systems. For example, the benefit of implement WalkingGuardian on smart watches or other wearable devices can be explored.

Furthermore, the WalkingGuardian system can be implemented in different devices at the same time. For instance, the smart TV or smart watch can also give daily activities reminders to individuals when their mobile phones are not around. In addition, there could be multiple receivers of the reminder to ensure the attainment of daily goals for activities.

- Exploring the applicability to other types of the sustainable rehabilitation process

This thesis research has explored using activity display to improve older adults' walking condition and achieve the purpose of rehabilitation. In the future, research could investigate the applicability of the activity display to other types of the rehabilitation process, such as muscular dystrophy. For some people who have multiple symptoms, the WalkingGuardian system can be put into use soon with the proper adjustments made according to the relevant medical specifications.

- Sustainable design of rehabilitation

Sustainability is the mainstream of future rehabilitation design, which can be looked at from two perspectives. From the physical perspective, rich rehabilitation products and the varied assortment is the guarantee. From the non-physical perspective, individuals not only need the improvement and compensation of related physiological functions but also need the respect on the psychological level.

The WalkingGuardian and the rehabilitation system designed in this thesis project are consistent with sustainability principles, for there is no any time or usage limitations. However, it is hoped that psychological functions such as real-time emotional monitoring could be developed when related technologies become more mature.

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LIST OF FIGURES

Images retrieved from Google Play

Images retrieved from http://www.xft-china.com/english/Products/FES_Foot_Drop

Image retrieved from published works by Debra Lilley, 2009

Image retrieved from behaviour model.org

Designed by Xin Lou

Appendix: Interview scripts, information letter & consent form

Interview Questions

Required questions:

- Gender and age?
- How many years since you have foot drop?
- Are you familiar with DAFO and DFS?
- Do you have smart phones? Have you used smart phone applications?

Optional questions:

- How do you feel about the design would improve your walking experience?
- Do you think the basic functionality is comprehensive enough? Which part needs to be added/deleted?
- How do you feel about the reminder system? Do you think the lock-screen reminder is able to affect your daily exercises awareness? Why?
- How do you feel about the reward system? Do you think it can motivate you to continue with your rehabilitation?
- How well do the detailed data and abstract theme provide representations of your condition and goal attainment?
- Does the changing theme provide a softer way of presenting condition for you? In addition to changes in colour/ depth, is there any way of representation would you be interested in?
- Do you find the WalkingGuardian in some way enjoyable? What aspects make you feel that way?
- Which parts of the design are your favorite?
- What do you dislike about the concept?
- Please add any feedback you have on how the WalkingGuardian could be improved.

INFORMATION LETTER

Study Title: Activity Display For Elderly Patients With Foot Drop

Research Investigator
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Supervisor
Robert Lederer
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Background

- You are being asked to participate in the research because your experiences will help me understand how to improve the design of foot drop rehabilitation application.
- The results of this study will be used in support of my Master's thesis work.

Purpose

- By conducting this research, researcher will get deep understanding of the existing problems and demand of elderly foot drop patients. Patients' understanding of rehabilitation applications can also make design more reasonable and practical.
- The result of the research can help to propose a rehabilitate way for elderly patients with foot drop to walk or even jog more steadily as well as possibly having a healing effect.

Study Procedures

- The interview method will be voice communication. The whole process takes about half an hour, participants can terminate at any time during the interview.
- The interview content will be recorded. All the information will be stored and only be accessed by the researcher.
- All the information collected will only be used for analyze by the researcher. Audio recording will not be used in any public presentation.

Benefits

- There will be no direct benefits for participants.
- The potential benefit of the proposed research to the participants would be the opportunity to influence the development of the rehabilitation system.
- All the information I get in this thesis project is hoped to establish a better rehabilitation system for foot drop patients.

Risks

- The risk to participants is minimal. There will normally be no risks for participants.
- Participants can withdraw participation from the study at any time if they feel uncomfortable.

Voluntary Participation

- Participating in this research is completely voluntarily.
- Participants are under no obligation to participate in this study. Even if participants agreed to be in the study, they are not obliged to answer any specific questions.
- Participants are not possible to withdraw data since data two weeks after the interview. All data that asked for withdrawn will be removed.

Confidentiality

- All the collected data will possibly be shown in my Master's thesis work and public presentations. If participants have any concerns, please feel free to contact me.
- Participants will not be identified by name in any presentations and written dissertation.
- Audio/ video recording will only be used to collect and analyze data. Audio/ video recording will not be used in any presentations.
- Data will be kept in a secure place for 5 years following completion of research project, all the data will be protected and devices will be encrypted. After 5 years, all the data will be destroyed.

Further Information

If you have any further questions regarding this study, please do not hesitate to contact me, Xin Lou at xlou@ualberta.ca or my graduate supervisor Robert Lederer at rlederer@ualberta.ca

The Research Ethics Board at the University of Alberta has reviewed the research plan, for its adherence to ethical guidelines. For questions regarding participants' rights and ethical conduct of research, contact the Research Ethics Office at (780) 492 2615. This office has no direct involvement with this project.

CONSENT FORM

Study Title: Activity Display For Elderly Patients with Foot Drop
Principal Investigator: Xin Lou, University of Alberta

Do you understand that you have been asked to be in a research study?	YES	NO
Do you understand the benefits and risks when participated in this thesis research?	YES	NO
Have you had an opportunity to ask questions and discuss this research?	YES	NO
Do you understand that you are free to refuse to participate without consequence?	YES	NO
Do you understand that the latest point to ask for data withdrawn is two weeks after the interview, if withdrawn, all the data will be removed?	YES	NO
Has the issue of confidentiality been explained to you? Do you understand who will have access to your information?	YES	NO
Do you understand that audio/video recording in the voice communication will only be used to collect and analyze data. I will not use the recording in any presentation?	YES	NO

This study was explained to me by: ______________________________

I have read and understood the attached information letter and agree to take part in this study:

______________________________ ______________________________
Signature of Research Participant Date

____
Printed Name

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.

______________________________ ______________________________
Signature of Investigator Date

A COPY OF THIS DOCUMENT SOULD BE GIVEN TO THE PARTICIPANT