AN INVESTIGATION OF USER INTERFACE DESIGN AND DEVELOPMENT OF A MOBILE HEALTH SYSTEM FOR INDIVIDUALS WITH DEXTERITY IMPAIRMENTS

by

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Mobile health (mHealth) systems have a great potential to empower individuals with chronic disease and disabilities to engage in preventive self-care. Before persons with disabilities can harness the potential of mhealth, the accessibility of mhealth systems should be addressed.

An innovative mHealth system called iMHere (Internet Mobile Health and Rehabilitation) has been developed at the University of Pittsburgh to support self-care and adherence to self-care regimens for individuals with spina bifida and other complex conditions who are vulnerable to secondary complications. However, the existing design of the iMHere system was not designed to accommodate users with dexterity impairments. The overall goal of this research is to design and transform an existing mHealth system to make it more usable and accessible for users with dexterity impairment.

To achieve this goal, three studies were conducted: *Evaluation*, *Design and Development*, and *Validation* of personalization and accessibility design in mobile health apps. The first study (*Evaluation)* was aimed to identify the barriers of the original iMHere apps to accessibility, and to explore the necessary features that may improve users' experiences. The second study (*Design and Development)* was aimed to develop innovative designs to improve the accessibility and usability of the mHealth system. The third study (*Validation)* was aimed to evaluate the users'

acceptance of and preferences regarding the personalized and accessible mHealth services on a smartphone.

The accessible design and development model that is presented in this dissertation incorporates user-interface components related to physical presentation (widgets, visual cues) and navigation (activity flow and layout order). Personalization that provides the ability for a user to modify the appearance of content, such as the size of the icons and the color of text, are proposed as an optimal solution to address potential issues and barriers to accessibility. The importance of personalization strategies for accessibility is also discussed.

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PREFACE

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1.0 INTRODUCTION

The overall goal of this research is to develop personalized and accessible mobile health (mHealth) services for persons with disabilities (PwDs). mHealth with treatment support is the provision of health services and information via mobile technologies such as mobile phones and PDAs (Cipresso et al., 2012; Vital Wave Consulting, 2009; World Health Organization, 2013a). mHealth involves the use of mobile devices to wirelessly link remote and highly mobile populations directly with healthcare systems. These emergent technologies with mobile apps have been popularly used to deliver medical reminders, to collect data, to provide treatment support (Kosaraju, Barrigan, Poropatich, & Casscells, 2010) in behavior changes and healthcare delivery (Asangansi & Braa, 2010; Boyer, Smelson, Fletcher, Ziedonis, & Picard, 2010; Han, Lee, & Park, 2010).

mHealth has been described as a patient-centered approach to care (Barton, 2010). It aims to encourage self-care (Patrick, Griswold, Raab, & Intille, 2008) and self-monitoring for patients (Agarwal & Lau, 2010; Istepanian, Sungoor, & Earle, 2009). The use of mHealth inspires the hope that the technologies, including health text messaging, mobile phone apps, remote monitoring and portable sensors (Department of Health & Human Services, 2014), will improve or promote health or health services use and quality (Free et al., 2010). Particularly, mHealth technologies can influence healthcare in the following ways:

1) They increase patients' self-efficacy and their adherence to treatment (Franklin, Waller, Pagliari, & Greene, 2006; Patrick et al., 2008). By using mHealth, healthcare professionals and patients are able to communicate and exchange information such as treatment plans over distance. For instance, text messaging has improved diabetes self-efficacy and adherence, and has achieved high satisfaction among users (Franklin et al., 2006). A remote health-monitoring system for patients with diabetes or hypertension can improve the quality of healthcare by collecting blood pressure readings from patients through mobile phones and allowing doctors to make more informed choices and provide feedback to patients from the web services (Agarwal & Lau, 2010). The ability to perform real-time and systemic monitoring from mobile devices allows clinicians to assess medical and psychological symptoms in a patient's natural environment and quickly deliver interventions (Massey, Marfia, Potkonjak, & Sarrafzadeh, 2010).

2) They offer a useful means to motivate behavioral changes in an individual with respect to managing daily activities and complying with treatment plans. Researchers at the University of Massachusetts found that mHealth has great potential for realizing true behavior modification for drug abuse treatments and with HIV therapies (Boyer et al., 2010). Furthermore, researchers at Syracuse University demonstrated that mobile technology could successfully deliver ecological momentary interventions (EMIs) to patients to treat a variety of health behaviors and physical and psychological symptoms (Heron & Smyth, 2010). These EMIs are treatments that are provided to people during their everyday lives (i.e. in real time) and in natural settings (i.e. real world). Using a smartphone app to upload capillary blood glucose (CBG) and medications for review by researchers at regular intervals, a mobile tele-monitoring system has been shown to

be an effective method for reducing blood pressure, as well as to empower patients with diabetes in monitoring glucose and blood pressure (Istepanian et al., 2009).

3) In addition, mHealth encourages and promotes effective communication among healthcare professionals and with patients. Chang et al. (2010) found that using a mobile clinic approach to shift clinical tasks from highly trained providers to community health workers (CHWs) offered a practical strategy for expanding and improving HIV care in Ugandan rural areas. To ensure the quality of such services, the less trained CHWs sent home visit data back to the central clinic for professional support. Another study showed that use of the Mobile Automated Medical Alert (MAMA) system improved the quality of school-based follow-up care by employing web-based and cell phone-based services when limited healthcare resources were available for students and faculty (Jen, 2009).

Over 50% of all Americans have at least one chronic illness (Wu & Green, 2000), and about one-fourth of people with chronic conditions have a disability that limits one or more daily activities (Anderson, 2004). Individuals with chronic conditions and disabilities who are vulnerable to secondary complications often require complex habilitative and rehabilitative services to prevent and treat these complications (Dicianno et al., 2014). For instance, people with Spina Bifida (SB) – the most common permanently disabling birth defect in the United States (NINDS, 2014) – are vulnerable to secondary complications, including urinary tract infections (UTIs) and skin breakdown, which have negative impacts on their community participation and quality of life (Handa et al., 2007).

The success of the in-person SB pilot project (Dicianno et al., 2012) in promoting wellness as well as achievements in other wellness programs (Ipsen, Ravesloot, Arnold, & Seekins, 2012; Ravesloot et al., 2011; Ravesloot et al., 2007; Stuifbergen & Becker, 2001;

Zemper et al., 2003) provides evidence that the goal of improving health and function through self-management is attainable with appropriate support. However, this in-person wellness program also had significant limitations in terms of the number of persons that could be served due to geographic constraints. Travel and time constraints and a lack of clinical resources prevented the program from including larger groups of consumers or those in remote locations. The use of mobile technology in healthcare, as with mHealth, is one way to lessen the abovementioned constraints. A mHealth system would allow Wellness Coordinators (WCs) to serve a larger number of patients, making the Wellness Program both cost-effective and scalable.

Specifically, we developed an innovative mobile health system called iMHere – **i**nteractive **M**obile **He**alth and **Re**habilitation (Figure 1). This system is aimed at empowering individuals to be more independent in managing their conditions with support from clinicians and/or family members and caregivers (Parmanto et al., 2013). Instead of a single app, the iMHere system consists of 1) smartphone apps, 2) a we-based clinician-monitoring portal, and 3) a two-way communication connecting the two to support self-management and service delivery (Parmanto et. al., 2013).

Figure 1. iMHere Platform

1) Smartphone apps serve as a self-management tool designed to empower patients to do preventive self-care and can be tailored to each person's needs and daily routine. For example, patients are able to schedule, view, or modify self-defined reminders. Such reminders prompt patients to perform specific tasks, such as taking medication or checking their skin. Any identified issue or problem, such as a photo of skin breakdown, as well as the basic monitoring data including the size, color and tissue condition of the affected skin and a record of the time, will be sent to the portal. As shown in Table 1, five apps have been released for patients' self-care activities in the areas of medication management (MyMeds), skin check-up (SkinCare), bowel management (BMQs), bladder self-catheterization (TeleCath), and mental health (Mood). Patients use this suite of smartphone apps to report compliance with treatment regimens, to ask questions, and to receive personalized treatment plans, education materials and messages from the clinician.

Table 1. Overall Satisfaction

Application Name	Short Description
MyMeds: Medication Management	Reminders to take medication; call pharmacy; receive medication information and schedule from health portal; send adherence to the portal.
SkinCare: Skin/Wound Management	Reminders to check skin; apps will provide a body diagram that can be used by patients to identify the location of a wound. Patients can take a picture of the wound and send it to the portal.
BMQs: Bowel Management	Reminder to perform bowel program and track adherence; inform the clinician about problems.
TeleCath: Self-catheterization	Reminder to catheterize, track performance, and inform clinician if there is a problem.
Mood: Depression Management	Reminder to complete Mood survey; tracks person's mood over time; sends messages to the clinician if determined to be "at risk."

2) The clinician portal is a web-based monitoring portal designed for clinicians to engage and track patients' adherence to a treatment plan. Clinicians could use the portal to tailor a

regimen or treatment plan for each patient (e.g., scheduled medication, wound care instructions, etc.) and the portal can push the plan to the smartphone app in real time. This clinician portal is capable of receiving image data as well as numerical and textual data. By accessing the iMHere portal, clinicians are able to monitor patient's adherence to self-care activities, to view reported problem and issues, to send personalized treatment plans to patients, to send education materials and messages to patients, to send medication data to patients, and to set up reminders of self-care tasks for patients.

3) A two-way communication protocol was developed to enable a secure and effective transference of data between the smartphone and the online portal. The data entered on a smartphone is saved to the local database and sent to the portal in real time by using and extending Extensible Messaging and Presence Protocol (XMPP) technology. In the event that an Internet connection is not available, the background services on the app stores the data and forwards the XMPP message again when a connection is available. Therefore, this innovative and unique two-way data exchange protocol is also designed to work in rural or low-resource areas with a spotty data connection.

Previous studies (described in Chapter 4) focused on the usability of iMHere. Three phases of usability testing were conducted to evaluate self-care workflow (Fairman et al., 2011), reliability of communication between the apps and the portal (Parmanto et al., 2013), and general issues with navigation and the user interface (Yu, Parmanto, Dicianno, & Pramana, in press). Though the iMHere system has been successfully used to support a pilot wellness program for persons with SB (Parmanto et al., 2013), there were still some accessibility challenges in the design of accessible apps (Yu et al., in press).

The purpose of this research study is to design and develop accessible and usable mHealth on smartphones for PwDs. Accessibility is the degree to which a person can use a product regardless of ability. The term “usability” refers to the ability to use a product to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use (The International Organization for Standardization, 1998). As applied to mHealth, accessibility refers to the extent that participants have access to the on-screen information. Usability is the perceived ease of use and level of convenience in using mHealth apps, including how well a participant can obtain information from a smartphone.

1.1 TARGET POPULATION

Disability, with respect to an individual, means: a) a physical or mental impairment that substantially limits one or more of the major life activities of such individual; b) a record of such an impairment; c) being regarded as having such an impairment ("Americans with Disabilities Act ", 1990). PwDs who have impaired self-management skills are susceptible to secondary conditions, i.e. wounds, urinary tract infections, incontinence. The target population of this research is individuals with dexterity impairments who can benefit from the iMHere system. Dexterity impairments affect a person's ability to manipulate objects and/or use arms, hands, or fingers. This impairment is often evident in individuals with neurological conditions such as Spina Bifida, Spinal Cord Injury, Cerebral Palsy and Muscular dystrophy.

1.1.1 Persons with Spina Bifida

Spina Bifida (SB) is a condition that affects the spine and is usually apparent at birth. It is a type of neural tube defect (The Centers for Disease Control and Prevention, 2014b). More than 166,000 individuals in the United States are living with all forms of SB and need ongoing, life-long comprehensive, quality medical and psychosocial care (NINDS, 2014). About 15,000 babies are born in the US with SB each year (Parker et al., 2010).

Persons with SB often have damage to the spinal cord and nerves. SB can cause physical and intellectual disabilities that range from mild to severe (The Centers for Disease Control and Prevention, 2014b). In particular, the meningomyelocele type of SB, the most common and most severe form of SB, is associated with disruption of the upper and/or lower motor and sensory pathways (Brunt, 1980; Dennis et al., 2009). A study shows that people with the myelomeningocele type of SB have abnormal brain organization in terms of the thickness of the cortex and the extent of gyrations (Treble, Juranek, Stuebing, Dennis, & Fletcher, 2013). These abnormalities can affect a person's fine motor skills, including motor strength, hand and finger dexterity, motor speed, motor planning, and bimanual coordination[1] (Anderson & Plewis, 1977; Hetherington & Dennis, 1999; Holler, Fennell, Crosson, Boggs, & Mickle, 1995), as well as eye–hand coordination (Dennis et al., 2009).

Persons with SB might also have issues with learning ability, memory and vision (Iddon, Morgan, Loveday, Sahakian, & Pickard, 2004). Fletcher et al. (2005) have shown that people with SB and higher levels of lesion have more brain abnormalities than those with SB and lower

[1] The two hands operate with relative independence (Albert, Weigelt, Hazeltine, & Ivry, 2007).

levels of lesions. This means that the aforementioned problems could be more pronounced in those with lesions higher on their spine.

1.1.2 Persons with Spinal Cord Injury

Spinal Cord Injury (SC) is generally the result of direct damage to any part of the spinal cord or nerves at the end of the spinal canal spine. The spinal cord is made up of bundles of nerves and nerve cells that carry messages from your brain to the different parts of the body (American Academy of Family Physicians, Teton Data Systems, & STAT!Ref, 2013). It is protected by a person's backbone, the bony rings in the back called vertebra that make up the spinal column, also called the vertebral column or spine (American Academy of Family Physicians et al., 2013). Some SCIs are caused by inflammation (interruptions of blood circulation) that damage cells within the spinal column (Donnelly & Popovich, 2008; Fleming et al., 2006; Hausmann, 2003). According to the World Health Organization (2013b), the symptoms of spinal cord lesion can include loss of sensory or motor control of the lower limbs, trunk and the upper limbs, as well as loss of autonomic regulation of the body. This can affect such functions as breathing, heart rate, blood pressure, temperature control, bowel and bladder control (World Health Organization, 2013b), and cause severe deficit in hand movements (Isa & Nishimura, 2014). The National Spinal Cord Injury Database estimates there are approximately 273,000 persons living with SCI in the US (NSCISC, 2013).

1.1.3 Persons with Other Chronic Conditions

Cerebral Palsy (CP) is defined as a disorder of movement and posture due to a defect or lesion of the immature brain. It is a well-recognized neurodevelopmental condition beginning in early childhood and persisting through the lifespan (Bax, 1964). Various abnormal patterns of movement and posture present in those individuals are related to defective coordination of movements and/or regulation of muscle tone (Bax, Goldstein, Rosenbaum, Leviton, & Paneth, 2005). Patients with CP may also have other neurodevelopmental impairments that can affect adaptive functioning, sensory function, learning, communication, and behavior, as well as seizures (Bax et al., 2005). CP is the most common of all childhood disabilities, affecting about two to three live births out of 1,000 in the US. About 764,000 children and adults currently have CP in the US (Krigger, 2006).

Another common chronic condition, Muscular dystrophy, or MD, is used to describe a group of neuromuscular diseases in which the muscles progressively weaken (Kim et al., 2008). MD is degenerative and rare disease that leads to muscle strength loss and progressive restriction of functional abilities (Magliano et al., 2014). The disease causes muscle degeneration, progressive weakness, fiber death, fiber branching and splitting, phagocytosis (in which muscle fiber material is broken down and destroyed by scavenger cells), and, in some cases, chronic or permanent shortening of tendons and muscles (National Institute of Neurological Disorders and Stroke, 2014). There are various types of MD that are present in the United States. According to Centers for Disease Control and Prevention, the most common forms – Duchenne/Becker muscular dystrophy – affects 15 out of every 100,000 males ages 5 – 24 years in the United States in 2007 (The Centers for Disease Control and Prevention, 2014a).

Many people with the abovementioned conditions could have difficulty in controlling their muscles and experience impairments of fine motor movements. Users within these particular populations could be significantly obstructed from partaking of the advantages of mHealth. Before persons with dexterity impairments can harness the potential of mHealth, its accessibility has to be addressed to ensure the quality of such service as a whole.

1.2 SPECIFIC AIMS

This research aims to develop personalized and accessible mHealth apps for people with dexterity impairments. A user-centered design was utilized here as a development approach to personalization and accessibility. The design and development procedures were focused on the end-users' needs, desires and limitations with respect to using mHealth services on a smartphone. The following three specific aims were identified to achieve the overall goals of this research:

Aim 1: To conduct a usability study to explore accessibility barriers to the mHealth system on a smartphone to users with dexterity impairments,

Aim 2: To design and develop accessible and personalized interface to improve the accessibility and usability of mHealth system for users with dexterity impairments,

Aim 3: To conduct usability study to compare the accessibility and usability of the newly designed interface with the original design to evaluate users' acceptance of and preferences with regard to the personalized and accessible mHealth.

1.3 RESEARCH QUESTIONS AND HYPOTHESES

Three studies were conducted in this research to approach the specific aims. As shown in Table 2, study 1 was aimed at identifying barriers to accessibility. Study 2 was focused on the design and development of personalized and accessible mHealth apps for users with dexterity impairments. Usability and accessibility studies were then conducted in study 3 to assess users' satisfactions and preferences with 1) the original apps from iMHere 2) and the personalized and accessible apps from Study 2. The following research questions and hypotheses were explored and answered at the end of each study.

Table 2. Research Questions & Hypotheses

Study1 – Exploration

- *Hypothesis$_1$:* The accessibility features provided in the iMHere system is not sufficient to enable individuals with dexterity impairments full access to the program.
- *Research Question:* What are the barriers for individuals with dexterity impairments to using mHealth services on a smartphone?

Study 2 – Design and Development

- *Hypothesis$_2$:* Accessibility of mHealth can be enhanced with user-centered user interface[2] (UI) design and development.
- *Research Question:* How can we design and implement personalized and accessible mHealth apps?

Study 3 – Evaluation

- *Hypothesis$_3$:* The personalized and accessible designs from study 2 are more accessible and usable for users with dexterity impairments.
- *Research Question:* What are the usability and accessibility of the redesigned system compared to the original design?

[2] User interface refers to the presentation of elements that are directly accessed by users, such as button size, text size, and colors.

1.4 PROBLEM STATEMENT

The smartphone is an ideal tool for implementing wellness programs for PwDs (Holman, 2004) but does pose accessibility challenges, including: 1) Lack of screen space (Brewster, 1998, 2002; Brewster & Cryer, 1999); 2) Small form factors, low contrast and tiny text, and undifferentiated keys (Abascal & Civit, 2000; Kane, Bigham, & Wobbrock, 2008; Kane, Jayant, Wobbrock, & Ladner, 2009); and 3) high number of steps to accomplish a task in an app (Kurniawan, Mahmud, & Nugroho, 2006).

The size of the screen and the mobile device itself is the main obstacle to accessibility. The small screen becomes easily cluttered when a designer wishes to fill the space with attractive text, images and widgets (Brewster, 2002). This small size of the screen leads to an issue with usability (O'Neill, Kaenampornpan, Kostakos, Warr, & Woodgate, 2006) because it is difficult for users to read (Kurniawan et al., 2006). The small target/touch size, low contrast, and inappropriate text size presented on a small screen might be problematic for users with visual and/or dexterity problems to access. In addition, unnecessary options and functions create difficulties for users to understand the process, as well as to recall procedures (Kurniawan et al., 2006).

Though PwDs found the size of the smartphone screen made it difficult to interact (Cheung, Janssen, Amft, Wouters, & Spruit, 2013), the portability of a mobile phone offers the value of being connected to others almost anywhere. These pocket-sized multifunctional devices, including smartphones, are easily carried in one hand for many uses, such as voice and video communication, wireless web browsing, gaming and daily activity management. A mobile phone provides the ability for individuals to get connected with their family, friends and business partners (Dawe, 2007; Kane et al., 2009; Palen & Hughes, 2007). Smartphones have great potential to change the lives of PwDs.

1.5 SIGNIFICANCE OF THE STUDY

The most recent report on cell phone use shows that at the end of April 2014 about 173 million people in the U.S. owned smartphones, with 71.8% mobile market penetration, (comScore Inc., 2014). This number is expected to reach 220 million in 2018 (Statista.com, 2014). According to the Mobile Behavior Report (Salesforce, 2014), 85% of mobile subscribers think mobile devices are essential in their day-to-day lives. These subscribers commonly use their mobile phone to send or receive text messages (81%), to access the Internet (60%), to send or receive email (52%), to download apps (50%), to get directions (49%), and to stream music (48%) (PewResearch, 2013a).

Mobile phones are the most commonly carried devices for PwDs (Kane et al., 2009). The smartphone is popular for facilitating self-management and social interaction activities (Demidowich, Lu, Tamler, & Bloomgarden, 2012; Gasser et al., 2006; Lane et al., 2011; Marshall, Medvedev, & Antonov, 2008; Rosser & Eccleston, 2011). The proximity of such devices to the participant makes them an ideal tool for self-management.

The overall emerging trends in the health-related use of the smartphone include the proliferation of mHealth for the care and monitoring of patients with chronic conditions (Tirado, 2011). Using mHealth technologies on a smartphone can improve health outcomes of patients by reducing secondary complications and can help to reduce the cost of care for people with chronic conditions, who account for three-quarters of healthcare expenditures in the U.S. (Bodenheimer, Wagner, & Grumbach, 2002; Holman, 2004; Wagner et al., 2005). Strong evidence supports the importance of self-management skills for improved health outcomes and independence in activities of daily living for PwDs (Clark, 2003; Lorig & Holman, 2003).

The large number of those with dexterity impairments does make accessibility especially important. According to the most recent National Health Interview Survey from CDC, about 4.04 million people who are over 18 years in the United States experience problems grasping or handling small objects (Pleis, Ward, & Lucas, 2010). Enabling those with such dexterity impairment to live independently and participate fully in all aspects of life (United Nations, 2006) is the optimal goal of providing accessibility.

By using iMHere services on a smartphone, patients could be more independent in managing their own health (Parmanto et al., 2013). As described in Chapter 4, prior studies have been conducted to address usability issues for persons with SB in general. Though the iMHere system has been successfully used to support a pilot wellness program for persons with SB (Parmanto et al., 2013), accessibility challenges were not addressed in the previous studies. Before people with dexterity impairments can harness the potential of mHealth trends, accessibility has to be addressed.

2.0 BACKGROUND AND LITERATURE REVIEW

2.1 MOBILE PHONE AND APPS

The mobile phone is one of the fastest growth areas in computing (Brewster & Cryer, 1999). Besides the basic services offered in voice and data communication, the functionalities on some mobile devices today have become similar to those for desktop computers (Guerreiro, Nicolau, Jorge, & Gonçalves, 2009). More advanced mobile phones, called smartphones, often provide additional features, including e-mail, Web browsing, a built-in camera, a speakerphone, and a voice recorder (Kosaraju et al., 2010).

The smartphone has transcended the original purpose of the mobile phone – the ability to make phone calls anywhere – and become a leisure and productivity tool (Guerreiro et al., 2009). Today's smartphones enable the user to store and manage personal data such as contacts, notes and scheduled task; therefore, smartphone are able to remind us of upcoming events, to help coordinating daily activities among various people, to confirm the safety and well-being of someone, and to allow the user to call for help (Dawe, 2007). Overall, the functionality of smartphones has transformed the way we communicate with friends and families, coordinate our daily activities, and organize our lives (Dawe, 2007; Kane et al., 2009).

Mobile devices, including the smartphone, have been widely adopted and play an important role in our daily lives (Brewster & Cryer, 1999; Guerreiro et al., 2009; Kurniawan et al., 2006; Watanabe, Miyagi, Minatani, & Nagaoka, 2008). According to the Pew Internet Survey, about 75% of adults in the US have either a mobile phone or a PDA, which is hard to give up (Horrigan, 2008, 2009). As of May 2013, 91% of the adult population in the US owns some kind of cell phone; 56% of all American adults are smartphone adopters (PewResearch, 2013b). About 58% of adults have used their smartphones to do at least one of non-voice data activities, including sending a text message, writing an email, taking a picture, looking for directions to an address, or recording a video (Horrigan, 2008). About 39% of adults have seen their online use grow as mobile access makes them more available to others (Horrigan, 2009).

The expectations for using a mobile phone is similar for all users, that is to provide immediate and fully reliable personal communication and services, thereby improving the safety and quality of lives (Abascal & Civit, 2000). A user can increase his/her feeling of safety and independence by carrying a mobile phone (Abascal & Civit, 2000; Dawe, 2007; Kane et al., 2009). Additionally, Mobile phones are popular used to keep families in touch (Dawe, 2007; Kane et al., 2009; Palen & Hughes, 2007). Parents and other family members perceive their mobile phones as a means of staying connected (Palen & Hughes, 2007).

Smartphone apps have been implemented practically as a learning platform (Boeder, 2013) to support medical students' learning (Robinson et al., 2013). Most medical students believe a smartphone would be a useful addition to their education (Robinson et al., 2013). Moreover, access to an electronic library has contributed to enhanced patient care by supporting trainee doctor's workplace learning (Hardyman, Bullock, Brown, Carter-Ingram, & Stacey, 2013). Boeder (2013) suggests that e-learning applications on smartphones will become an important topic in the future.

Because of the adaptability and portability of smartphones, the use of a smartphone app to collect data was more efficient and effective than use of traditional/non-electronic methods in public health research (Patel, Nowostawski, Thomson, Wilson, & Medlin, 2013). Kumar et al. (2012) showed that smartphones could be used as a supportive tool for fungus photo assessments of diabetic retinopathy. Huang et al. (2012) demonstrated the potential for using a smartphone as a novel embedded system for portable medical ultrasound applications. Additionally, life-logging software using the smartphone camera makes smartphones good candidates for a new generation of wearable sensing devices (Gurrin et al., 2013). This function is valuable in health research as it can provide invaluable information related to the behavior of an individual when communicating with health professionals (Gurrin et al., 2013).

Specific mHealth apps have been implemented to help monitor, manage and support health-related behavior changes (Dennison, Morrison, Conway, & Yardley, 2013; Luxton, McCann, Bush, Mishkind, & Reger, 2011). Healthy lifestyle apps have been developed to prevent unhealthy weight gain and helps patients manage their diaries for obesity prevention (Hebden et al., 2013; Kristjánsdóttir et al., 2013; Nes et al., 2012). A study from McTavish et al. (2012) found patients with alcohol dependence, alcohol and drug dependence, and mental health issues would be willing to use smartphone apps for ongoing support, resources and information. Additionally, smartphone-based technologies have been widely used for HIV intervention (Muessig et al., 2013) and cardiovascular disease detection (Oresko et al., 2010).

The use of apps for healthcare services and medical support is not limited to the abovementioned areas. The portability and adaptability of smartphones, along with the advanced technologies they offer, such as connection with the Internet and the ability to store and analyze data, have generated the power to extend patient care and improve the quality of healthcare services. Smartphones with software in the form of apps are an optimal consumer engagement tool for supporting healthcare interventions embedded in users' daily lives.

2.2 SMARTPHONE TECHNOLOGIES FOR PWDS

Software technologies for the smartphone have been developed to help PwDs in their daily lives. The components of the smartphone have the potential to be used to mitigate the sensory impairments of PwDs by enabling them to see (using the camera), to hear (using the microphone), to notice (using Bluetooth), and to interact with the environment (Ipina, Vazquez, & Sainz, 2005). The following technologies were identified as having the potential to improve quality of life for PwDs:

1) Apps were developed that used the built-in computer on a smartphone to analyze images captured from the built-in camera to help users to detect a crosswalk on a street (Ivanchenko, Coughlan, & Shen, 2008), to have an indoor way-finding system by distinguishing color markers attached on the wall (Coughlan & Manduchi, 2009), and to identify currency (Liu, 2008; Narasimhan, Gandhi, & Rossi, 2009).

2) A text-to-speech feature was developed for users a) to use a mobile commute-planner system to receive real-time information about public transportation (Narasimhan et al., 2009), b) to use a Global Positioning System (GPS) to find their way (Ivanov; Narasimhan et al., 2009), c) to identify a grocery item by scanning the UPS or barcode (Narasimhan et al., 2009), d) to have an automatic reading assistant to detect text from images (Gaudissart, Ferreira, Thillou, &

Gosselin, 2004), e) to hear their email and information from the Internet (Watanabe et al., 2008).

3) Text input navigating methods (Guerreiro et al., 2009) and a method for nonvisual multi-point touches with 6-bit Braille encoding (Azenkot, Wobbrock, Prasain, & Ladner, 2012) were developed for visually impaired users to enter text more accurately. A specific mobile messenger was also developed for the blind to enable them to communicate with instant messages (Sanchez & Auguayo, 2006).

4) A communication system on smartphones was developed to convert audio speech to text for hearing impaired users (Tak·cs, Tihanyi, B·rdi, Feldhoffer, & Srancsik, 2006; Zekveld, Kramer, Kessens, Vlaming, & Houtgast, 2009).

5) A smartphone software that emulates a TTY provides emergency access for the deaf (Zafrulla, Etherton, & Starner, 2008).

6) A learning support system through smartphones was shown to motivate hearing-impaired students in participating in continuous learning activities (Liu & Hong, 2007).

The abovementioned technologies (including software and systems) are concentrated on the needs of hearing and visually impaired users, who are commonly disabled from smartphone use. The following accessibility features are more beneficial for users in general:

1) Auditory feedback can be used to enhance the accessibility of mobile phones (Amar, Dow, Gordon, Hamid, & Sellers, 2003; Astrauskas, Black, & Panchanathan, 2008; Kane et al., 2008; Li & Patrick Baudisch, 2008; Pirhonen, Brewster, & Holguin, 2002). It is able to replace the visual interface on smartphones for blind use (Li & Patrick Baudisch, 2008), that allows users to

keep their visual attention on navigating the world around them and allows information to be presented through hearing (Pirhonen et al., 2002).

2) Sound feedback can be used to improve the usability of buttons (Brewster & Cryer, 1999).

3) Universally designed models featuring large font sizes can help visually impaired users to have access to e-mail messages and mobile Internet sites (Watanabe et al., 2008).

4) Larger button size can be used to enhance the accuracy of touches. Particularly, Chen et al. (2013) found that the non-disabled users plateaued with minimal button size at 20mm, and disabled users at 30mm. Colle and Hiszem (2004) found that 20mm square buttons resulted in optimal user performance for younger participants, while Jin, Plocher, and Kiff (2007) suggested a button size of 19.05mm for elderly users. Moreover, Monterey Technologies Inc. (1996) recommends the button size to be at least 19.05mm. Apple recommends a minimum target size of 44 pixels wide and 44 pixels tall (converted as 11.64mm) (Apple Inc., 2014).

Limited studies have concentrated on identifying accessibility technologies for users with dexterity impairments. Such individuals, having reduced functionality of the hands and fingers, have trouble pressing buttons/icons on a smartphone. Some of the abovementioned technologies, which involve added use of fingers and hand controls, would not be appropriate for this group of users. Other features including the use of feedback and the universally designed services for all users might help to improve the smartphone experience of PwD.

2.3 ACCESSIBILITY REGULATIONS AND POLICIES

The United States has a range of general and specific laws mandating telecommunication access for persons with disabilities (G3ict, 2012). Particularly, Section 255 of the Communications Act, as amended by the Telecommunications Act of 1996, requires telecommunications products and services to be accessible to people with disabilities ("Telecommunications Act Section 255 Accessibility Guidelines," 1998). Section 508 ("Section 508," 1998), a provision in the Rehabilitation Act 0f 1973, mandates that electronic and information technology funded, developed or used by the US federal government or US federal agencies should be accessible to persons with disabilities who may be employees or general members of the public. The Hearing Aid Compatibility Act of 1998 requires all telephones manufactured or imported for use in the United States and all essential [3] telephones to be hearing aid- compatible ("Hearing Aid Compatibility Act," 1998). The Federal Communications Commission has also extended this requirement of hearing aid compatibility to wireless/mobile telephones (FCC).

More recently, in October 2010, US Congress passed the Twenty-First Century Communications and Video Accessibility Act of 2010 ("21st Century Communications and Video Accessibility Act (CVAA)," 2010). The aim of this act is to improve access to "advanced communications" (including interconnected and non-interconnected voice over Internet protocol, electronic messaging, and interoperable video conferencing services) and "consumer-generated media" for persons with disabilities.

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[3] Essential telephones are defined as coin-operated telephones, telephones provided for emergency use, and other telephones frequently needed for use by persons using hearing aids (G3ict, 2012).

Web Content Accessibility Guidelines 1.0 (WCAG 1.0) from the World Wide Web Consortium (W3C) (W3C, 1999) is one of the most well-known guidelines in addressing and regulating web accessibility. WCAG 1.0 is an official recommendation and is considered a benchmark in establishing other regulations and policies. It primarily addresses the needs of PwDs by outlining ways to make web content accessible. The 91 checkpoints from WCAG 1.0 guidelines are divided into three priority levels: Priority 1 – the basic requirements a web content developer *must* satisfy; Priority 2 – the recommended checkpoints a web content developer *should* follow; Priority 3 – checkpoints which a web content developer *may* address to improve access to Web documents (W3C, 1999).

Changes in Section 508 of the Rehabilitation Act as amended in 1998 resulted in a regulation based on the checkpoints in Priority 1 of WCAG 1.0 (Faett, Brienza, Geyer, & Hoffman, 2013). This regulation ensures that PwDs as well as persons without disabilities have equal access to federal government websites. Section 508, as the federal standard, is popular utilized in designing the state governments' to ensure their accessibility (Yu & Parmanto, 2011).

Web Content Accessibility Guidelines 2.0 (WCAG 2.0) provides newer and updated recommendations for web accessibility (W3C, 2008). WACG 2.0 now consists of twelve guidelines that are organized around four general principles of accessibility (e.g., perceivable, operable, understandable, robust). Comparing with WCAG 1.0, WCAG 2.0 applies more broadly to different types of Web technologies and to more advanced technologies. It offers a wide range of recommendations for making Web content more accessible.

Additionally, international agencies have been improving accessibility and usability standards for PwDs. The Standardization Sector of the International Telecommunication Union (ITU) are concentrated to develop accessibility and usability standards for PwDs, older persons, and children. Some ITU-T recommendations are as the follows:

- E.121: Pictograms, symbols and icons to assist users of the telephone service" (Easy-to-understand symbols);
- E.135: Human factor aspects of public telecommunication terminals for people with disabilities;
- E.138: Human factor aspects of public telephones to improve their usability for older people;
- F.790: Telecommunications accessibility guidelines for older persons and Pwds.

The European Telecommunication Standards Institute (ETSI) is a telecommunications' standards setting organization for the European Union. The ETSI develops standards and guidelines for ease of use and access to ICT including the followings:

- EG202 116: Guidelines for ICT products and services; "design for all;
- ES 202 076: User Interfaces – Generic spoken command vocabulary for ICT devices and services;
- TR 102 612: European accessibility requirements for public procurement of products and services in the ICT domain.

3.0 DESCRIPTION OF IMHERE APPS

Again, the iMHere system provides the clinician with the ability to engage with patients through monitoring their progress and devising personalized treatments. The specific reminders and prompting on the smartphone are utilized in the iMHere apps to empower patients for self-management and self-care.

3.1 MYMEDS APP FOR MEDICATION MANAGEMENT

The MyMeds app helps patients manage their medication, provides reminders, and monitors adherence to medications. Patients with chronic conditions, such as SB or SCI, are frequently prescribed several medications for the management of urinary incontinence, seizures, bowel management, depression, etc. Taking five or more medications two or more times a day and consistently following the prescribed regimen is always challenging. The MyMeds app helps patients by keeping track of all the medications they are currently taking or have taken in the past and keeping track of their medication schedule.

Figure 2. Example of Medication Management

As shown in Figure 2, medication information (e.g., brand name & dosage) and schedules can be entered either by patients through the MyMeds app or by clinicians through the monitoring portal. A red bar next to the medication name indicates no alert is scheduled. A green bar means the medication is scheduled with one or more alerts. This information received on the portal, including the patient's response time for intake of medications and the total number of responses the patient made with respect to taking these medications on different days, can help clinicians to understand and assess patients' behaviors with regards to taking medication.

3.2 SKINCARE APP FOR SKIN & WOUND MANAGEMENT

The SkinCare app enables patients to take pictures of any wound or skin conditions, to keep track of their skin problems, and to communicate with clinicians on how to care for skin problems. Loss of sensation in the lower body associated with the lesion of the spinal cord means there is no trigger to indicate a need to reposition oneself and reduce the pressure on a particular part of the body (Parmanto et al., 2013). People with chronic conditions, such as SB or SCI, have to be constantly vigilant for skin injury and breakdown over the lower body resulting from pressure ulcers. Poor circulation below the waist and improper functioning of the lymphatic system also causes the lower extremities to receive an inadequate supply of nutrients and oxygen and to have a buildup of fluid. These combined issues mean that pressure ulcers can develop very quickly in this population and that they tend to heal very slowly (Agnarsson, Warde, McCarthy, Clayden, & Evans, 1993).

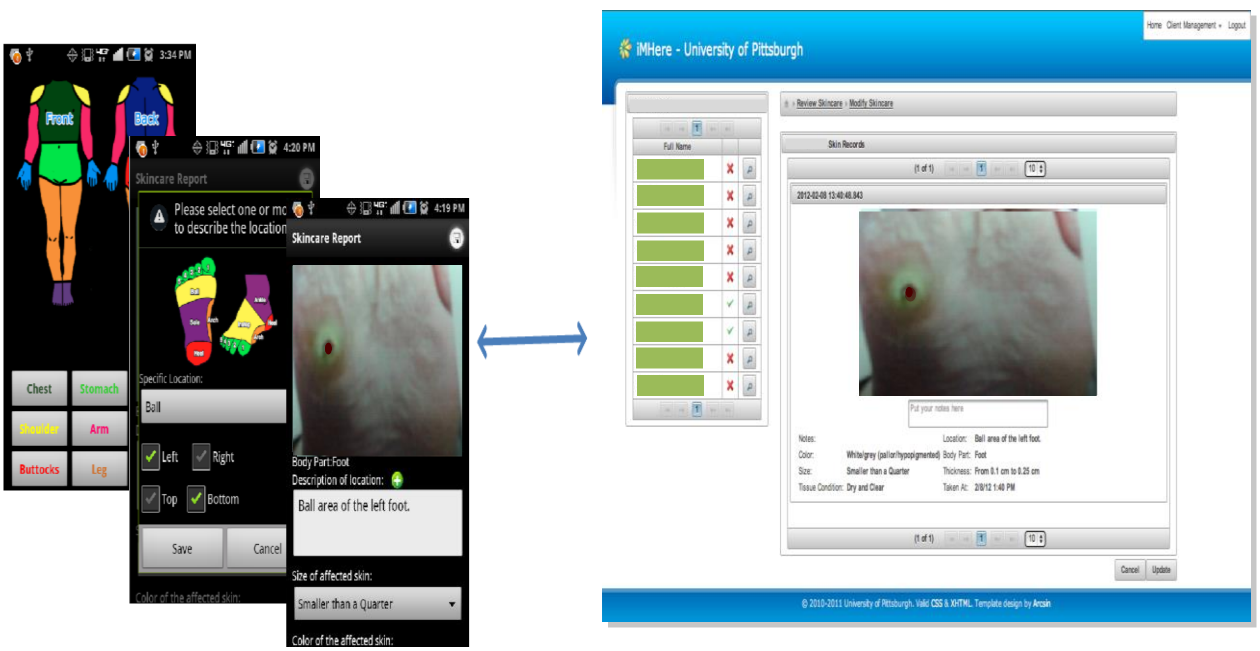


Figure 3. Example of SkinCare Management

The SkinCare app allows patients to track the progress of skin problems, including pressure ulcers or lacerations, by taking pictures with the smartphone's digital camera. Pictures can be taken periodically for comparison, and photos are stored on the phone for the patients' reference, as well as being synched through the secure portal for clinician review (Figure 3). Daily reminders can be set from a patient's smartphone or the clinician portal. These reminders will alert a patient to perform skin care checks and to take additional photographs to track changes in specific wounds. After the patient takes a picture of the affected skin, a short questionnaire to describe the affected skin needs to be filled out so that the clinician can have more detailed information about the problem. This detailed information includes the size, color, tissue condition and depth of the wound.

3.3 BMQS APP FOR BOWEL MANAGEMENT

Bowel management is critical for people with high spinal lesions, who have low internal sphincter pressure and rarely experience rectal sensation, and for people with low spinal lesions, who have increased internal sphincter pressure and experience frequent rectal sensation (Turner, Lewis, & Nielson, 2006). As shown in Figure 4, the BMQ app helps to remind patients to perform their bowel program and report problems encountered. Bowel continence is important for maintaining skin integrity (Flanagan et al., 2014) and is related to social issues (Johanson & Lafferty, 1996) including quality of life (Handa et al., 2007) and social isolation (Norton, 2004). Forgetting to perform any portion of a bowel program on time or at regular intervals will make it ineffective, and incontinence is likely to occur (Parmanto et al., 2013).

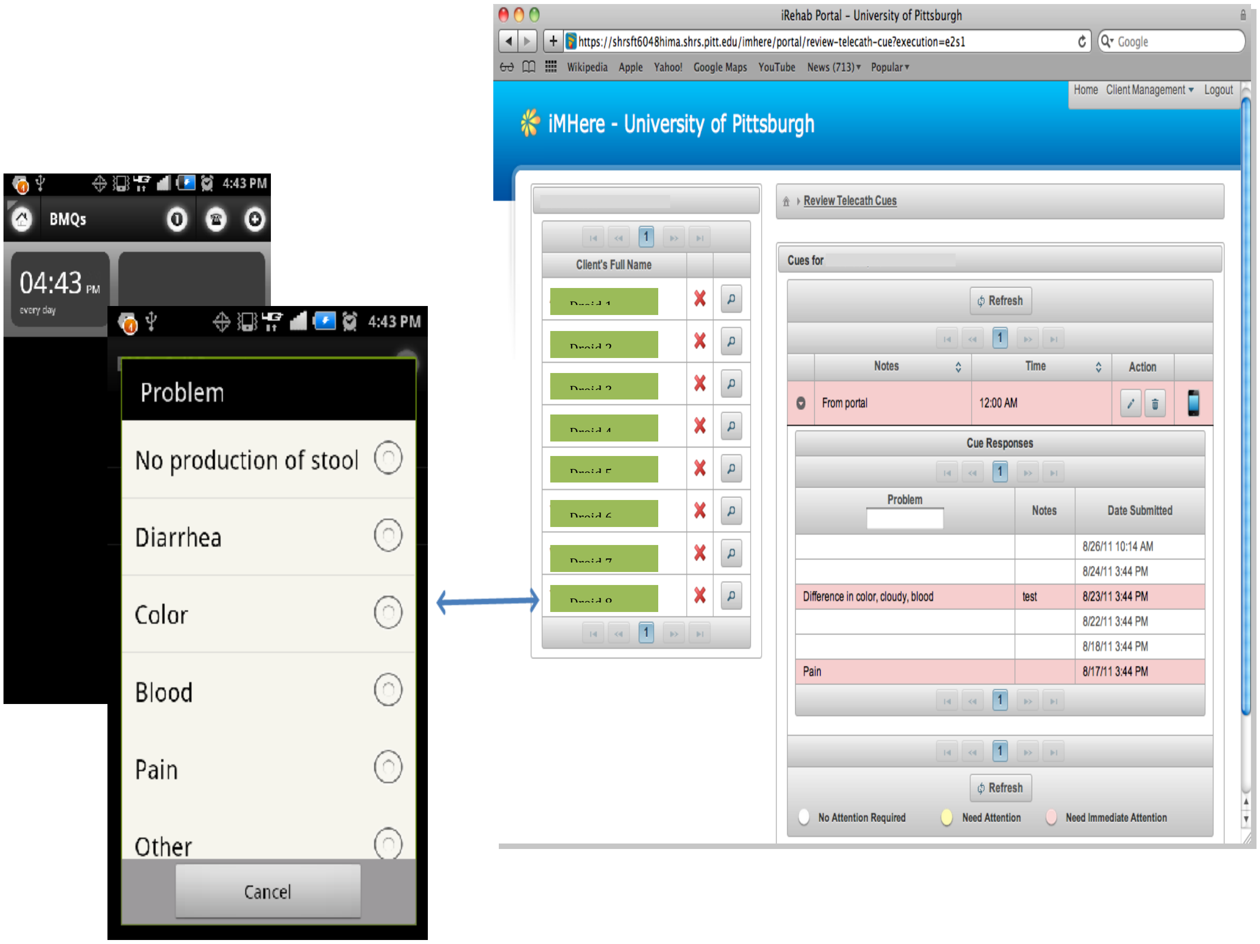


Figure 4. Example of BMQs Management

The BMQ app allows a patient or clinician to set daily reminders for performing bowel management and to schedule daily inquiries about defecation or incontinence. The app reminds patients to use their medications, enemas or other interventions important for maintaining bowel health. Any problems with bowel management, such as diarrhea, blood, and pain, can be reported along with the reminder. All information regarding defecation problems or incontinence are synched to the clinician portal for clinicians to review.

3.4 TELECATH APP FOR SELF-CATHETERIZATION

The TeleCath app reminds patients when it is time to perform bladder self-catheterization and to report potential problems encountered (Parmanto et al., 2013). Most people with SB and SCI have a neurogenic bladder. This means they are unable to perceive the sensation of bladder fullness, and they lack the neurologic integrity to have coordinated contraction of the bladder muscle and opening of the bladder sphincter. Many people with SB and SCI have uninhibited bladder contractions, which may be accompanied by high bladder pressure (Dicianno et al., 2008). Some people may be able to empty their bladders partially by straining, but the emptying is incomplete. Even small amounts of residual urine in the bladder can lead to urinary tract infections. The combination of high bladder pressure and infection can place the kidneys at risk (Dicianno et al., 2008).

The TeleCath app allows a patient or clinician to set daily reminders for bladder catheterization and to schedule daily inquiries about urinary incontinence. Any problems with catheterization (such as pain, difference in urine color, cloudiness or blood in the urine, or lack of urine output) can be reported along with the patient's response to the reminder to catheterize. All information regarding catheterization problems or incontinence is synched to the clinician portal in real-time (Figure 5).

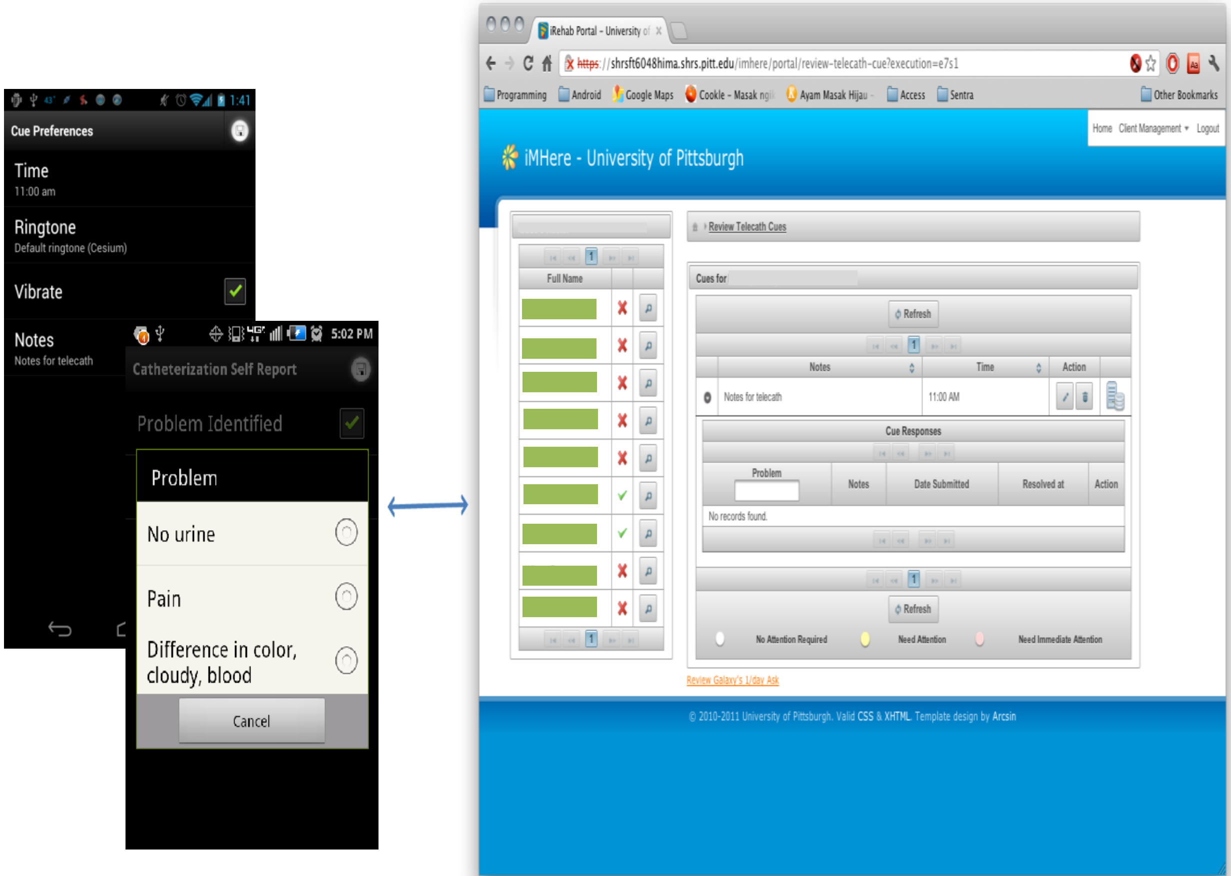


Figure 5. Example of TeleCath Management

3.5 MOOD APP FOR DEPRESSION MANAGEMENT

The Mood App allows the patients to let the clinician know what type of mood related symptoms they are exhibiting and allows the clinician to provide timely intervention for mental health problems (Parmanto et al., 2013). A study has shown that, in comparison to the general population, people with SB are at a higher risk of depressed mood and lower self-worth, and they are more likely to think about suicide (Liptak, 2008). A cross-cultural study shown that the incidence of depression for persons with SB was around 41%, while the incidence of anxiety was at 19% (Kalfoss & Merkens, 2006). On the other hand, chronic neuropathic pain is a common consequence of SCI, develops over time and negatively impacts quality of life, often leading to substance abuse and suicide (Hassler, Johnson, & Hulsebosch, 2014). Suicide mortality among persons with SCI still remained three times higher than that of the general population (Cao, Massaro, Krause, Chen, & Devivo, 2014).

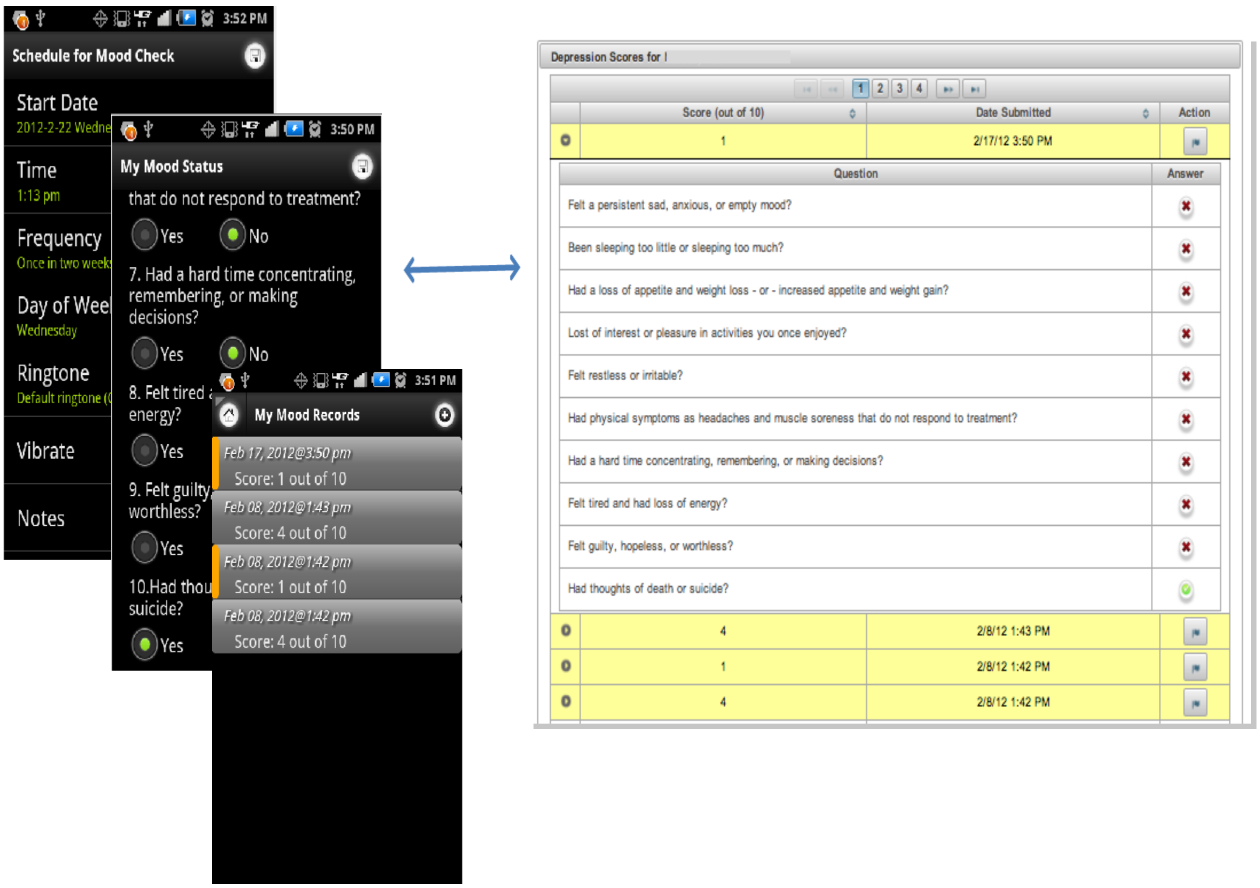


Figure 6. Example of Mood Management

The Mood app lets a patient or clinician schedule routine mood questionnaires or lets the patient take them on demand (Figure 6). The questionnaire is based on the standard symptoms of clinical depression from DSM-IV, the Diagnostic and Statistical Manual of Mental Disorders, 4th edition (American Psychiatric Association, 2000). This 10-item survey (Appendix A) asks questions to determine the patient's mood, including whether the patient has been sleeping too little or too much, has thoughts of death or suicide, has a hard time concentrating, remembering, or making decisions, has a loss of appetite and weight loss or increased appetite and weight gain, etc. The app records the results of the questionnaire and sends them to the clinician.

The iMHere system was designed using concepts found to be extremely effective in managing patients with complex chronic conditions within a medical home model (Dicianno et al., 2012). The iMHere platform with its suite of self-care apps was designed to be scalable to allow support service delivery for patients with SB and other conditions, such as SCI. The apps can also be implemented and repacked for patients with other chronic conditions and cognitive deficits, such as CP and MD.

4.0 RELATED WORK

The initial design and development of iMHere was based on clinician's predictions about and developers' understanding of patients' needs with respect to encouraging self-care. The scenarios designed from the research perspective were deemed to perhaps not be adequate to represent real use. Prior studies were conducted from three phases to ensure the usability of the iMHere system for persons with SB in general (Figure 7).

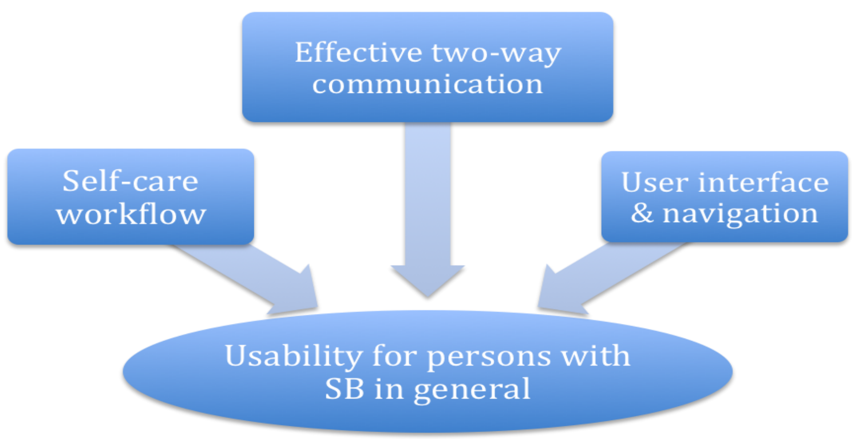


Figure 7. Approaches to Usability

4.1 SELF-CARE WORKFLOW

The evaluation of self-care workflow[4] (Fairman et al., 2011) was conducted in a natural environment by giving smartphones to patients for a few weeks and asking patients to use the stand-alone apps (the apps was not connected to the portal). The main problem identified with workflow was related to the scheduling, which was originally designed to be object-centered (such as "medication") instead of patient-centered. The main problem identified with workflow was related to the scheduling, which was originally designed to be object-centered (such as "medication") instead of patient-centered:

1) In the medication app, a separate alarm would ring for every medication because each medication is entered and scheduled separately. It was not convenient to have multiple alarms ringing at the same time.

2) We discovered that a better design is patient-centered: all medications included in a person's regimen should be scheduled using one reminder for all medications that need to be taken at a specific time. For example, a patient who needs to take three medications three times a day can set up reminders for Morning 8:00 AM, Afternoon 1:00 PM, and Evening 7:00 PM, with each reminder applied for all three medications.

3) The same concept should also be applied to the response to a reminder. When the patient accesses the app after receiving the reminder, she should see a list of medications to take. The patient could respond by pressing a check box next to each medication to indicate that the dose was taken. If the patient does not or cannot take

[4] Workflow is the processes of activities that are necessary to complete a task.

the medication, a place to indicate the reason why can be included and this information could then be immediately reported back to the WC through the portal.

4) In relation to the scheduling and reminders, the snooze function and repeated alerts have been removed. Instead, if the patient does not respond to a reminder, it will be put into a missed schedule list that the patient can access. The missed schedule list will appear as a notification, similar to a “push” notification in email or digital calendar.

Another main problem was related to the varying frequency of self-care tasks. This problem was uncovered as a result of more intense discussions with the clinicians who are working with persons with SB. The apps for BMQ, Mood, and medication were originally designed with daily schedules in mind, but some of the self-care tasks are not performed on a daily basis. Patients who complete bowel program regimens typically perform this self-care task every other day or every third day. The mood questionnaire is typically needed only one time per week. There was also a need for the ability to take medication less frequently than on a daily basis: for instance, only on certain days of the week, once per month, etc. A patient may also need to vary the time of day they perform their bowel management program if it interferes with other activities or they are reliant on a caregiver to assist them with performing this task in some way.

Based on the evaluation results from this study, changes were applied to improve the users’ experiences and the usability of iMHere apps in the following areas:

1) Input fields were simplified to improve user’s interaction with the apps.
2) A short beep notification for missing scheduled activities was implemented, replacing the annoying snooze function.

3) More options for alert frequency have been added, such as one or two times a week for BMQ reminders.
4) Records for the same skin problem are grouped in the same case for tracking and comparison purposes.
5) Patients are directed to call 911 or a crisis-line if he/she is in significant depression (mood score is high) or have felt suicidal.

4.2 EFFECTIVE TWO-WAY COMMUNICATION

The evaluation of two-way communication was focused on the communication between the apps and the clinician portal. The goal of this study was to evaluate problems in the clinical service delivery model and to address the problems before moving on to a full-scale clinical implementation (Parmanto et al., 2013). We encountered problems with the implementation of XMPP protocol in a 4G wireless connection. The 4G wireless signal is not always stable, and the signal can be lost or work only intermittently in some areas. The iMHere protocol was designed to handle an unavailable connection.

One problem that we encountered was the inability of the XMPP protocol to accurately detect the availability of a connection. This situation led to packet loss when the app would attempt to send data in spite of an absence of a connection. We added two mechanisms to improve on the reliability of the XMPP protocol: verifying the connection's availability before sending data (app to portal transmission), and determining wireless signal strength to inform the portal about the device's actual signal condition (portal to app transmission). The first mechanism was to ensure that the data would be sent only when the connection was definitely available and otherwise would be stored locally for later transmission.

The second mechanism was developed to ensure that the portal would send data to the device only when the device was receiving a good wireless signal. When the device was receiving poor signal strength, it would notify the portal to hold the data until the signal strength improved. Extensive testing in various signal conditions was conducted by having smartphone apps send data to the portal and by having clinicians send treatment plans to the patients. The result was a reliable two-way protocol that works under any signal condition and in any version of the Android operating system.

4.3 USER INTERFACE & NAVIGATION

The evaluation of accessibility for persons without dexterity impairments was conducted in a controlled (lab-like) environment, where patients were asked to perform specific tasks while their performance was observed and measured (Yu et al., in press). Five apps available in the iMHere system were utilized in this accessibility study.

This study explored the usability of iMHere apps, focusing on the user interface and navigation. Scores from the TUQ indicated the iMHere apps were viewed positively (6.52 out 7 points, 93 percent). All of the participants were satisfied with the iMHere apps and would use them again in the future. Neither the longer average time to complete tasks nor the number of mistakes significantly impacted participants' perception of iMHere usability (TUQ). Participants' actual experiences with the apps might play a more important role in the overall usability and satisfaction. Since the lowest score was received under the usability factor of reliability on the TUQ, the ease of noticing and recovering from mistakes might have a negative impact on satisfaction levels. Several important findings from this study reveal ways to improve the accessibility of smartphone apps:

1) Appropriate use of words: Although the iMHere apps were designed by clinicians with expertise in the care of individuals with SB, 14% of mistakes were still associated with participants' perception of words. Using simple and common words such as "the reason to take medication" to replace the word "Alias" in the MyMeds app might be more effective to ensure the readability and understandability of the text for participants, particularly those with cognitive impairments or problems with reading comprehension.
2) Appropriate use of text style: Using a light text color such as white or yellow on a light background (e.g., gray) is not recommended. Using contrasting colors between the text and background and adding shadows to text may enhance the contrast and improve readability.
3) Use of in-app directional notes: Seventy-five percent of mistakes that were encountered by participants were related to task procedures. For instance, participants forgot to click the "plus" sign to add a new schedule, forgot to save data, or saved data without completing a survey. A short, one-sentence reminder for providing directional guidance might be useful to prevent these types of mistakes.
4) Use of large target size: Small target size on icons/button are not only a problem for users with dexterity impairments, but also an accessibility issue for people with large

fingers or for those who prefer to have larger icons. Using larger icon/buttons would improve physical access to icons/buttons.

5) Use of thematic colors: Participants highlighted the usefulness of colors to indicate the status of whether or not a medication is scheduled (green vs. red). The use of color to separate body parts also helped participants to correctly specify the location of problem skin areas. Using color to separate the apps would easily let users know which app they are using.
6) Use of personalized app list: Not all five apps are useful for all participants. Providing the ability for users to choose which apps they want to use might help increase user satisfaction.

5.0 RESEARCH DESIGN

5.1 RESEARCH CONCEPTUAL MODEL

As mentioned in Chapter 4, prior studies were concentrated on the usability of iMHere apps for persons with SB in general. The research described here was a qualitative descriptive study for designing and developing personalized and accessible mHealth apps for persons with dexterity impairments. This research was approved by the University of Pittsburgh Institutional Review Board with full board review (#PRO12090453). An example of the approved informed consent shows in Appendix B.

The smartphone apps from the iMHere platform were utilized as the foundation for the redesign and development and as benchmarks for comparison purposes. User-centered design (UCD) was utilized in this research as a development approach to accessibility. This means that the end-users of the target population were included at the beginning of this research. Their needs and wants with respect to using mHealth for self-care and their physical or sensory limitations in interacting with smartphone apps were considered and addressed in the design process and the development lifecycle.

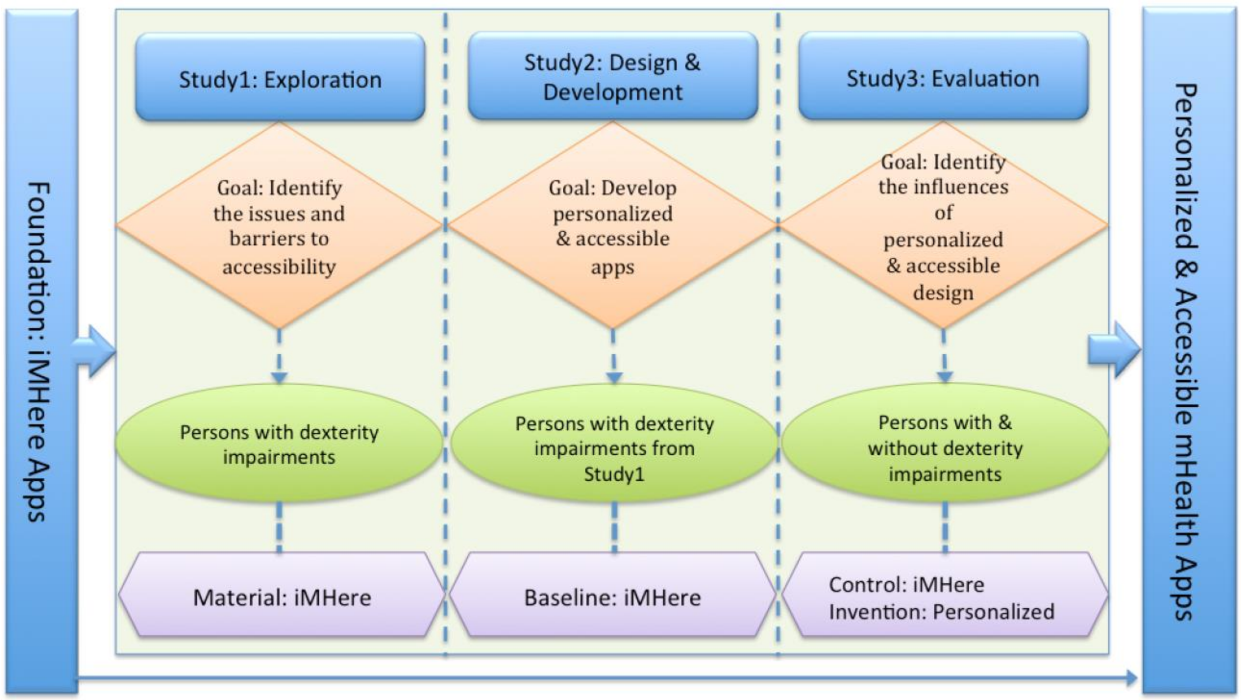


Figure 8. Conceptual Model of the Research

Figure 8 illustrates the process of the three studies in achieving the research goal. Study 1 (Evaluation) was aimed at identifying the accessibility barriers to iMHere apps and exploring the features necessary for improving users' experiences with mHealth apps. Study 2 (Design and Development) concentrated on the design and development of personalized and accessible mHealth apps for this underserved population. Study 3 (Validation) was aimed to evaluate user's acceptance and preference of using the redesigned apps. The respective study procedures are explained in detail in Chapter 6 (Study 1: Exploration), Chapter 7 (Study 2: Design and Development) and Chapter 8 (Study 3: Evaluation).

The selected apps, target device, modeling tool, participants, recruitment, inclusion and exclusion criteria described next (section 5.2 – 5.9) applied to three studies. Also see section 6.2 (study 1), section 7.2 (study 2) and section 8.2 (study 3).

5.2 SELECTION OF APPS FOR REDESIGN

The MyMeds and SkinCare apps from the iMHere system were selected for redesign and development in this research for a number of reasons. First, medication management ranks as one of the most important data contents for a user in self-management (Alkhatlan, 2010). Second, skincare and wound management is important in preventing secondary complications (Dicianno et al., 2012; Fairman, 2013). Third, MyMeds and SkinCare apps were selected based on the complex nature of the tasks described below.

5.2.1 MyMeds App

Again, the MyMeds app for managing medications with reminders helps patients in following prescribed and non-prescribed medication regimens. Three tasks can be performed in the MyMeds app: 1) scheduling a new medication; 2) modifying an existing medication alert; 3) responding to a medication alert.

1) As shown in Figure 9, the task of scheduling a new medication requires a user to complete the following activities located at 4 different levels of access[5]:

a) Level 1: From the MyMeds main screen, which has a list of available medications, the user has to click on the plus sign ( ) at the top right corner to begin the process of adding a new medication.

b) Level 2: As the user types the medication name into the text field, a list of possible drug names appears. The user needs to expand the drug list to show all of

[5] This term, "levels of access", reflects the depth of navigation from the home screen for a user to complete a task.

the available varieties of the particular drug. Then the user needs to find the one that matches the drug he/she will be taking.

c) Level 3: The user is asked to add more information in a text box about the medication regimen, including the reason for taking the medication, under “Alias,” and the directions for intake, in the “Notes” area. Then, a user has to click on the plus sign (⊕) next to “schedule(s)” to begin the process of adding a new schedule.

d) Level 4: The user has to set the alert time, dosage for each intake, ringtone type, vibrate status, and the alert repeat type (such as once a week or everyday) to complete the activities for scheduling a reminder for taking a medication. These activities can be repeated multiple times for scheduling two or more alerts.

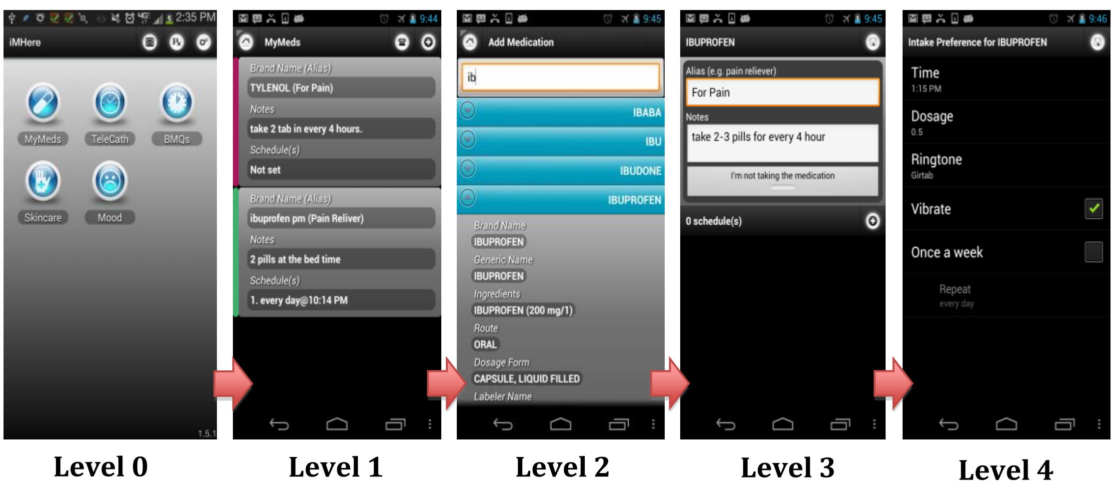
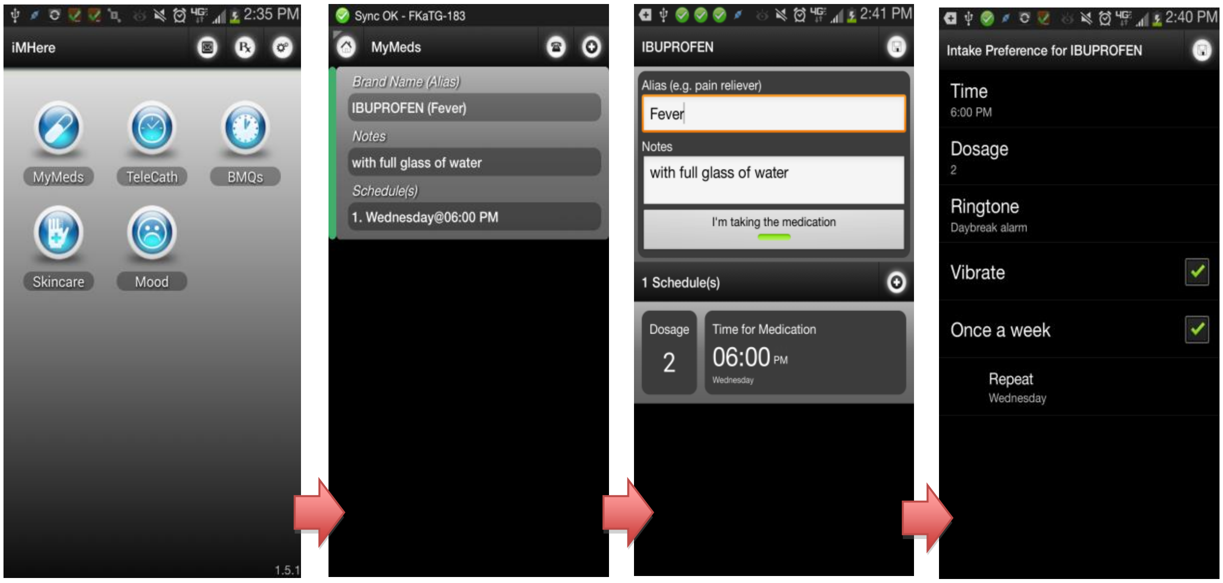


Figure 9. Scheduling a New Medication (4 Levels of Access)

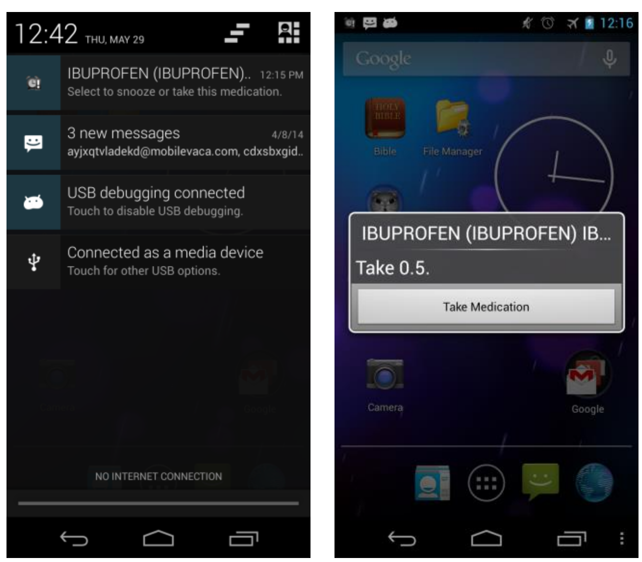
2) As shown in Figure 10, the task for modifying an existing medication alert requires a user to choose the medication he/she wants to modify at level 1, to choose the alert that needs to be changed on level 2, and to change the time of day he/she wishes to be reminded to take the medication on level 3.



Level 0 **Level 1** **Level 2** **Level 3**

Figure 10. Modifying Medication Alert (3 Levels of Access)

3) As shown in Figure 11, only one click on the reminder dialog is required to report that the medication has been taken. The response time for each alert is also saved and transferred from the patient's smartphone to the clinical portal for monitoring purposes.



Level 0 **Level 1**

Figure 11. Responding to Medication Alerts (1 Level of Access)

5.2.2 SkinCare App

Five tasks can be performed by a user in the SkinCare app: 1) scheduling a skin check, 2) modifying an existing alert, 3) responding to an alert by recording a new skin problem, 4) responding to an alert by updating and tracking the change of affected skin, 5) responding to an alert with no problem identified.

1) As shown in Figure 12, only 2 levels of access are required for a user to set a new schedule for a skin checkup. To perform the task for scheduling a skin check, at level 1 a user has to click the plus sign ( ) at the top right corner of the SkinCare main screen to begin the process of setting a new schedule (Figure 12). Then, a user can set the time of day he/she wishes to be reminded to perform a skin check, change the ringtone, change the vibrate status or add a note at level 2.

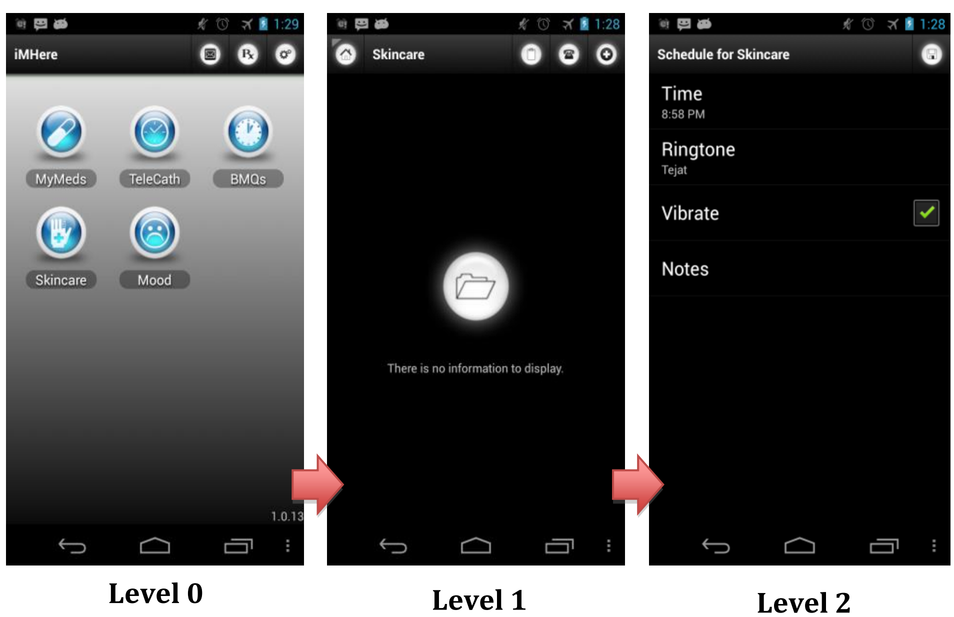


Figure 12. Scheduling a Skin Check (2 Levels of Access)

2) The task for modifying the skincare alert is similar as that for scheduling a skin checkup. However, a user has to choose the alert he/she wants to modify at level 1, then continue the process to change the time at level 2 (Figure 13).

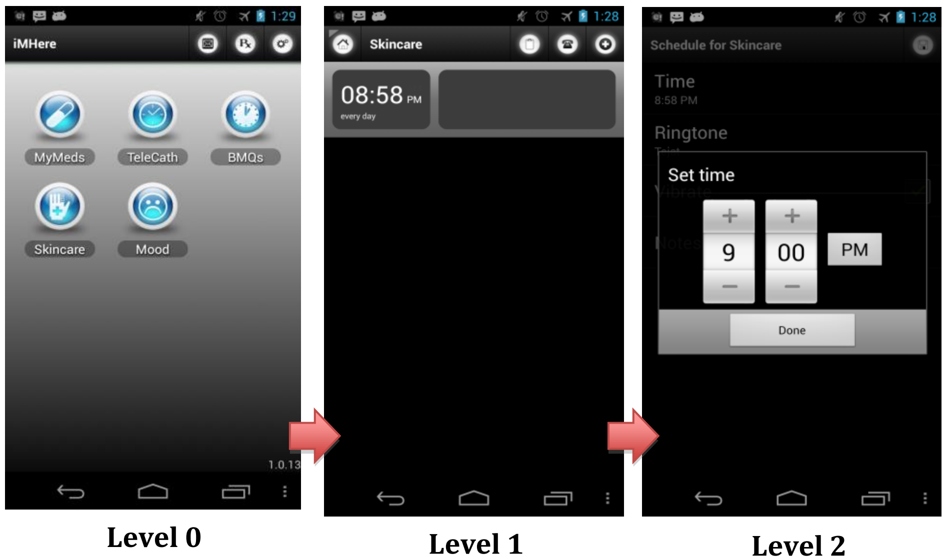
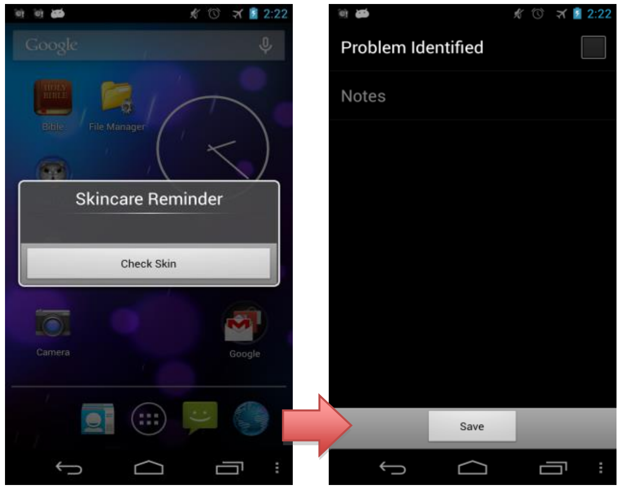


Figure 13. Modifying a Skincare Alert (2 Levels of Access)

3) After a patient inspected his or her own skin, one level of access is required for a user to report no problem (Figure 14). If a user checks the box for problem identified, the screen moves to the affected skin screen, where the user can add new or update an existing problem as described in tasks 4 & 5.



Level 0 **Level 1**

Figure 14. Skin Check: No problem identified (1 Level of Access)

4) As shown in Figure 15, the task to report on newly affected skin includes performing the following activities:

a) Level 1: A user has to click  on the Affected Skin Screen to begin recording a new problem.

b) Level 2: The affected area selection screen provides a color-coded diagram to aid in unambiguously describing the location of the affected area. Referring to the diagram, a user has to select which area best describes the location of the affected skin then click the button on the bottom of the screen.

c) Level 3: A user points the phone's camera at the affected area. He/she has to click  (camera icon) in the upper right corner of the viewfinder to take the picture of the affected skin.

d) Level 4: A user has to answer a list of questions to describe the problem of the affected skin. These questions include a description of location, the size of the affected skin, the color of the affected skin, the condition of the tissues around the affected skin, the thickness of the affected skin, and a note to the clinician.

Figure 15. Skin Check: Recording a New Skin Problem (4 Levels of Access)

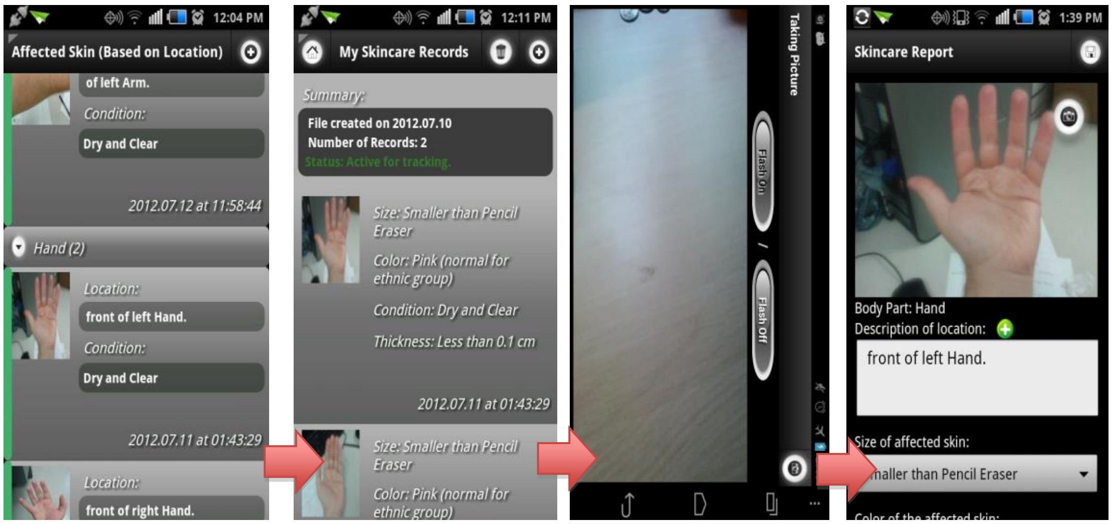
5) The primary function of the SkinCare app is to track changes in skin problems, taking numerous photos of the problem over time so that the clinician and the patient can note changes. As shown in Figure 16, the SkinCare app organizes skin problems as cases. To update or track the changes in an existing problem skin, a user has to do the following:

a) Level 1: A user has to view and locate the case/problem he/she wants to update. Clicking on one of those cases will take the user to the skincare record list.

b) Level 2: The screen for the skincare record list will show all of the records under a particular case. The user can scroll to see previous records or click  on the top right corner to begin recording the changes.

c) Level 3: The user must point the phone's camera at the area and take a picture of the affected skin by clicking on  (camera icon).

d) Level 4: The description of the skin conditions such as location, color and size of the affected skin are pulled from the previous record. A user only needs to modify the ones that have changed, such as reporting that the color changed from bright red to white.



Level 1 **Level 2** **Level 3** **Level 4**

Figure 16. Skin Check: Updating Existing Problem (4 Levels of Access)

5.2.3 Comparison of the TeleCath, BMQs and Mood Apps

The tasks in TeleCath include scheduling and modifying alerts and responding to alerts. Scheduling or modifying a TeleCath alert requires a patient to make a selection from drop-down lists or pop-up options. These are the most complicated tasks in TeleCath app, requiring 2 levels of access. The task to modify an alert for a bowel movement is one of the most complicated tasks, requiring 2 levels of access. Two levels of access are required for scheduling a mood checkup and completing the mood survey. These tasks are considered the most complicated tasks in the Mood app.

The activities in MyMeds and SkinCare are more complicated because the tasks to schedule a new medication alert in MyMeds and to report a skin problem in SkinCare require four levels of access. When considering a user's experiences on the number of touches/clicks, the steps that require entering text (such as entering a reason or notes to take medication) and making a selection from drop-down lists (such as answering survey questions to describe the condition of the affected skin) might also increase the difficulty for a user. Therefore, MyMeds and Skincare, as the most complicated apps, are the focus of this research about personalization and accessibility redesign and development.

5.3 TARGET DEVICE

The development of personalized and accessible mHealth apps in this research focuses on their use on the Google Android operating system (OS) because the original iMHere apps run on Android. Android OS is an open-source software platform designed for mobile phones and other devices, such as tablets (Android Open Source Project). It is ranked as the top smartphone platform, owning 51.5% of the market share as the end of 2013 (comScore Inc., 2013).

Manufacturers have moved to replace the physical keyboard with virtual keys in order to reduce the size and weight of smartphone devices. So as not to leave PwDs behind in the area of smartphone touch-screen technologies, this research examines use of the apps on a smartphone with virtual keys (touch screen). Specifically, this research utilizes the Samsung Galaxy, a lightweight, touch screen-enabled, slate-format android smartphone with no physical keyboard, shown in Figure 18(dimensions: 4.82 in x 2.53 in x 0.55 in, weight=5.5oz).

5.4 MODELING TOOL

CogTool (http://cogtool.hcii.cs.cmu.edu/), developed by Carnegie Mellon University, was utilized in this research to evaluate and predict human performance with respect to completing the tasks. This tool that analyzes tasks performed on an interactive system from a storyboard is commonly used for human performance modeling and UI prototyping (Bellamy, John, & Kogan, 2011; Bellamy, John, Richards, & Thomas, 2010; Harris, John, & Brezin, 2010; Ludwig, 2006; Teo & John, 2008; Teo, John, & Blackmon, 2012). The step-by-step performances as shown in Figure 17 and Figure 18 helped us to locate the bottlenecks for identifying navigation problems. CogTool was used in Study 1 (Evaluation) and Study 2 (Design and Development) to test the original design of iMHere and SkinCare apps and several alternative designs developed based on users' experiences and feedback. The result of this process is a final design with the simplest and most efficient navigation.

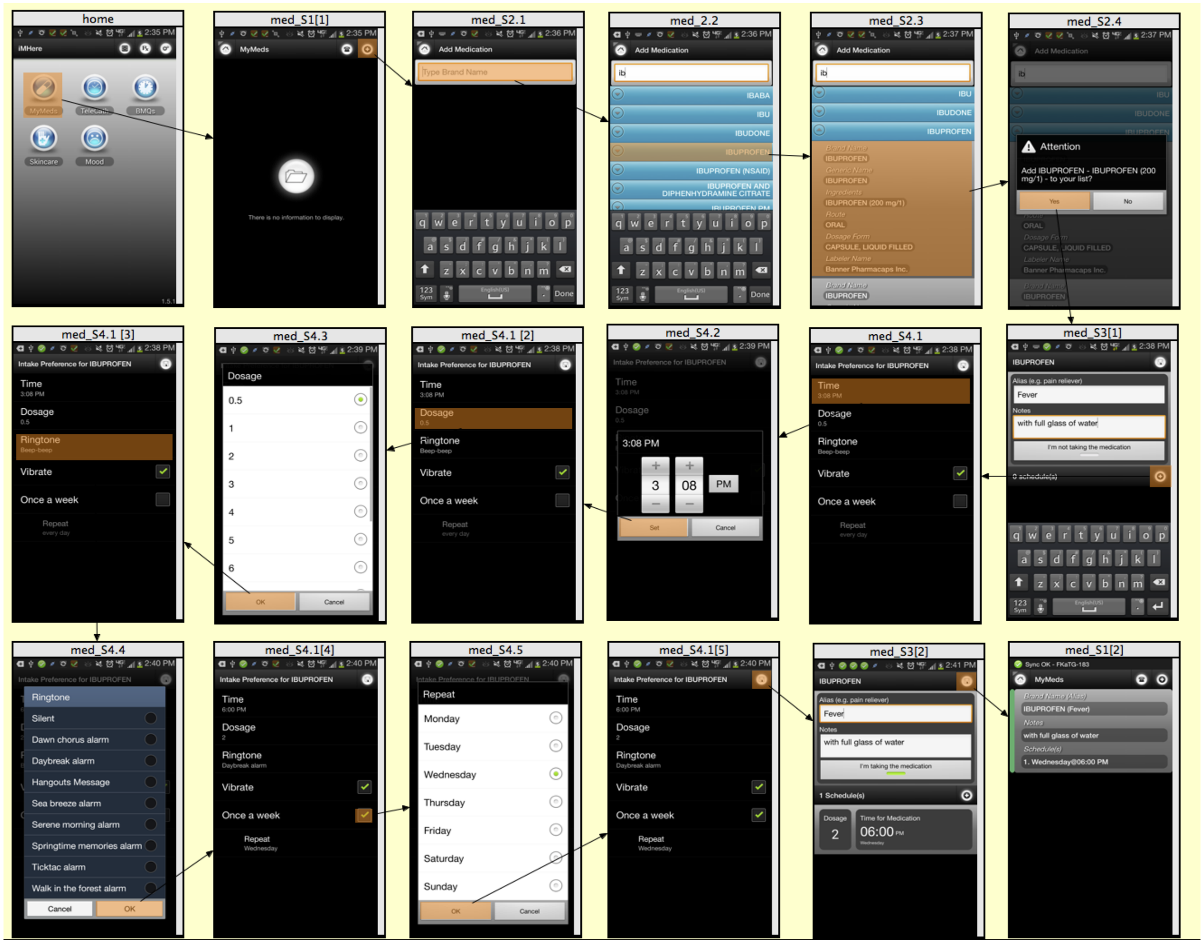


Figure 17. Activity Flow of MyMeds

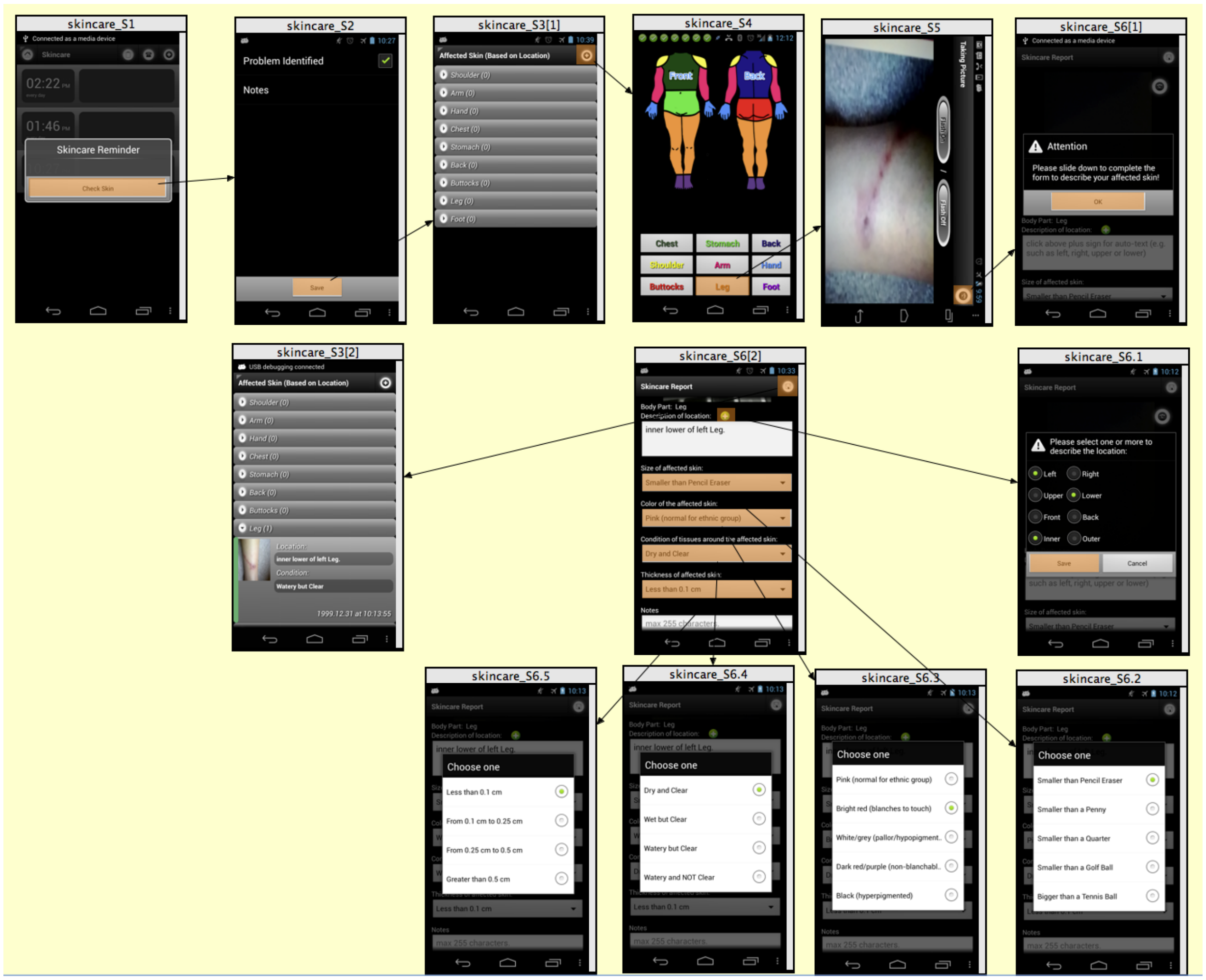


Figure 18. Activity Flow of SkinCare

5.5 DESCRIPTION OF PARTICIPANTS

Participants were recruited from the local Pittsburgh, PA area. They are working-age adults between 18 and 64 years old. Both experienced and inexperienced smartphone users were eligible to participate. They had to be interested in using smartphones to manage their own health. These particular populations include, but are not limited to, patients with SB, patients with SCI, and patients in wheelchairs.

Eligible participants were required to have the potential for skin breakdown (e.g., pressure sores, pressure wounds, or pressure ulcers) or insensate areas of skin, meaning a participant may not feel pain, touch, or respond to heat or cold on an area of skin. Since studies 1 & 2 included field trials, participants who participated in these two studies were required to have at least one prescription medication and/or over the counter medication to simulate the real daily use of the MyMeds app. However, this is not required for participating in study 3 (a lab test).

5.6 RECRUITING

Participants were recruited from the Physical Medicine and Rehabilitation (PM&R) research registry. This registry includes patients who have agreed to be contacted about potential research projects for which they may be qualified to participate. Clinicians from PM&R also referred patients. A flyer (Appendix C) were printed to briefly describe this research study and posted in patients' residential living facilities or clinic areas.

5.7 SCREENING MATERIALS

This research concentrated on the accessibility needs of people with dexterity impairments. It was paramount to mitigate any effects that other types of limitations might have on this study, including sensory impairments. The participant's cognitive level, providing the necessary abilities to carry out study related tasks, was also important. Three instruments were utilized in the screening procedure to determine the eligibility of participants (Figure 19):

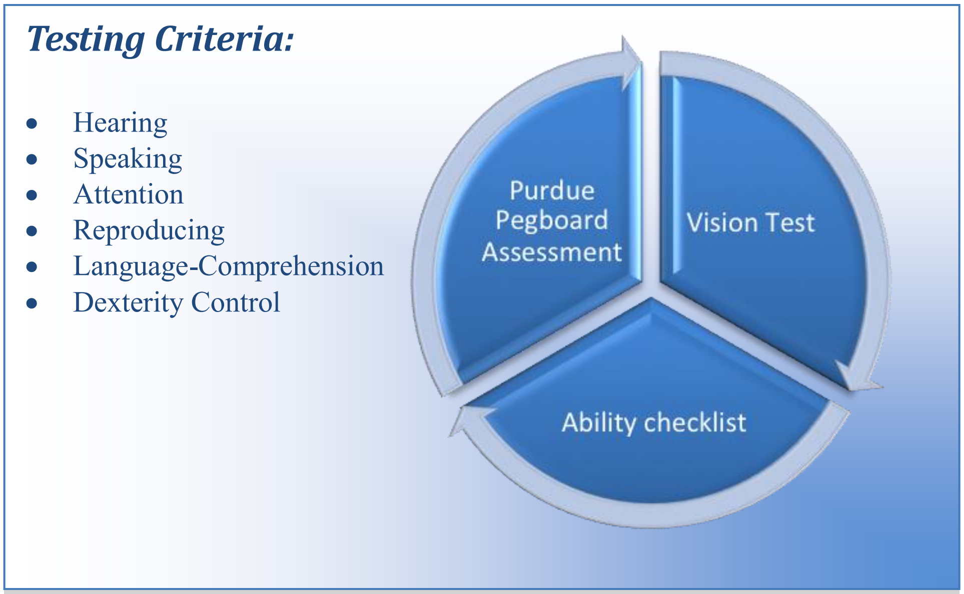


Figure 19. Screening Tests

1) Purdue Pegboard Assessment: As shown in Figure 20, this evaluation tool was developed by Joseph Tiffin, Ph.D., Industrial Psychologies, Purdue University (Lafayette Instrument). Utilization of this tool allows for measurement of the gross movements of the fingers, the hands and the arms (Delp & Newton, 1986; Desrosiers, Hebert, Bravo, & Dutil, 1995; Ozcelik et al., 2009; Smoot et al., 2010; Wilson, Iacoviello, Wilson, & Risucci, 1982). Four tests from the Purdue Pegboard assessment were conducted for this research: 1) Right Hand (30 seconds); 2) Left Hand (30 seconds); 3) Both Hands (30 seconds); 4) Right + Left + Both Hands (a mathematical sum from calculation). Following the researchers' directions (Appendix D), participants were asked to pick up pins, collars or washers from the top of the board and drop them in the peg holes. The score for each test was based on the total number of pins, collars, or washers dropped in the holes correctly. Lower scores indicated more difficulty with making a particular movement. The assessment scores were compared to the mean of general factory workers, which are suggested as the original norms (Appendix E).

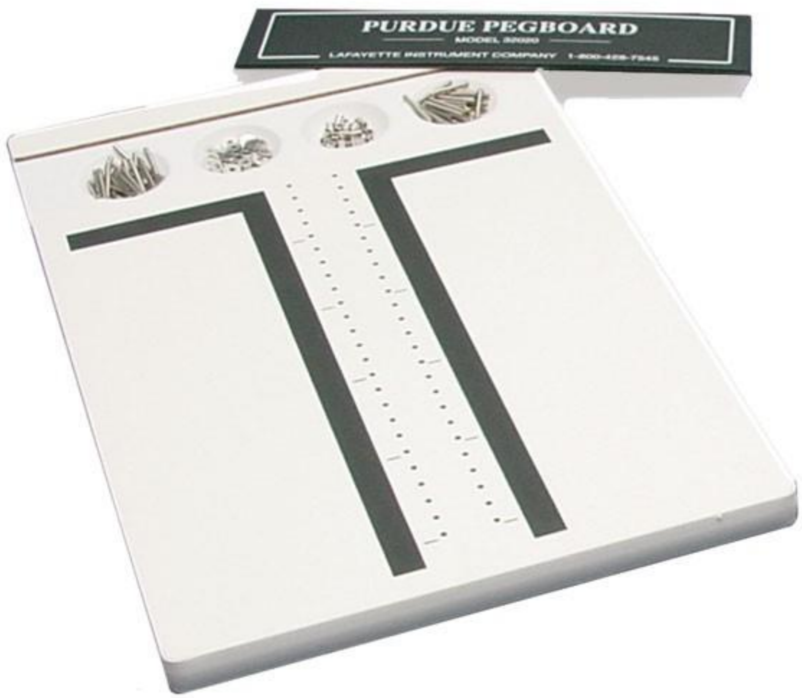


Figure 20. Purdue Pegboard Assessment

2) Vision Test: A medication bottle was handed to the participants. They were asked to find the correct dosage information and to enter the information on a smartphone device as a note. If no real medication was available at the time for the vision test (e.g., subject did not bring his/her medication to the meeting), a trial bottle (sample of non-prescription medicine) was provided to complete this vision test.

3) Ability Checklist: Based on the observations from the aforementioned Pegboard and Vision tests, the researcher was required to answer a binary questionnaire (answer Yes or No). Each question on the checklist corresponds to specific assessment criteria (Table 3).

Table 3. Criteria of Ability Assessment

Assessment Criteria	Questions
Hearing	Was participant able to hear the test directions?
Attention, Hearing	Was participant able to pay attention while listening?
Language Comprehension	Was participant able to understand the test directions?
Language Comprehension, Speaking	Was participant able to ask questions?
Language Comprehension, Memory	Was participant able to follow the conversation?
Vision, Reading Comprehension	Was participant able to find dosage information from a medication bottle?
Reproducing, Fine Motor Control to use Smartphone	Was participant able to correctly reproduce the dosage information from the medication bottle onto a Smartphone?

The instruments used for the screening procedures described above were used throughout this research. The Purdue Pegboard Assessment and the Vision test provided the information necessary to determine whether the person met the criteria for inclusion in the study. In order to complete the Pegboard and Vision tests, a potential participant had to have a general conversation with researchers (speaking), concentrate (pay attention), hear, understand (language comprehension) and follow (memory) the directions given by researchers. The vision test, specifically, was utilized to evaluate subject's ability to see (vision) and to read (reading comprehension) from a sample medication bottle.

Since we wanted to exclude people who have impairments that are too severe, including hearing, vision, speaking and/or language comprehension, that they would not be able complete the study. The researchers used the observations they made during these tests to fill out the Ability Checklist (see Chapter 5) and so determine a potential subject's eligibility to participate.

5.8 INCLUSION CRITERIA

Generally, participants whose Pegboard scores were below the general mean of factory workers were eligible to participate in this research. However, the particular criteria varied slightly from studies 1 & 2 to study 3 (see Chapter 6, Chapter 7 and Chapter 8). Additionally, if potential participants were able to do the following, they were included in this study:

1) Follow the directions to complete Purdue Pegboard tests;
2) Transfer the dosage information from a medication bottle to a smartphone in the Vision Test;
3) Receive all “yes” answers from researchers on the Ability Checklist.

In the case of participants who were not able to conduct the Pegboard assessment due to limitations with respect to picking up small objects such as pins or washers, the ability checklist was utilized to determine eligibility to participate. The participant was qualified if he/she received the answer "yes" for all of the ability questions. This means that, regarding their dexterity impairments, they were able to follow the directions to complete vision test; they didn’t have a problem with communication; they didn’t have vision problems preventing them from finding and transferring dosage information from a medication bottle; and they were able to use a smartphone.

5.9 EXCLUSION CRITERIA

Participants with a diagnosis of severe intellectual disability as determined by the clinicians were excluded from this research study. Additionally, participants who had problems completing the

Vision Test, and/or receiving a "no" for any question on the Ability Checklist were excluded from this research study. This is because potential issues could emerge such as: 1) being unable to follow the directions to complete the test; 2) having problems with communication; 3) being unable to see or find the dosage information from a medication bottle; 4) being unable to enter the dosage information on a smartphone device.

6.0 STUDY 1: EXPLORATION

6.1 INTRODUCTION

The overall goal of this study was to explore and to identify the accessibility needs and preferences of users with dexterity impairments when using iMHere smartphone apps. Globally, chronic conditions currently account for 60% of the global disease burden, and this figure is expected to reach 80% by 2020 (Pruitt & Epping-Jordan, 2002). A global shortage of health care workers, coupled with increasing life expectancy, have made it a high priority of health care systems worldwide to develop innovative strategies to improve care for those with chronic conditions and to find ways to prevent secondary complications (Pruitt & Epping-Jordan, 2002).

Individuals with chronic conditions are vulnerable to such secondary complications as infections, amputations, wounds, and depression. A recent prospective study has identified those secondary complications as the strongest predictors of risk for premature death for people with chronic conditions (Krause, Carter, Pickelsimer, & Wilson, 2008). Evidence from around the world suggests that people with chronic conditions benefit most when they receive effective treatments beyond acute care, usually in the form of regular follow-up and self-management support in their living environments. Patients with effective self-management skills make better use of health care services and have improved health behaviors and health status (Lorig et al., 1999). Innovative approaches of mHealth to chronic care have been seen as key to improving healthcare while at the same time reducing costs related to the secondary complications.

Innovative approaches of mHealth using a smartphone for chronic care have been seen as a cost-effective solution to improve health through offering empowered self-care tasks. The iMHere system provides such approaches to improving healthcare (Chapter 3). Prior studies were conducted to exam and to improve the usability of iMHere with respect to the efficiency of self-care workflow, the accessibility of iMHere smartphone apps, and the effectiveness of two-way communication (Chapter 4). However, all of these studies concentrated on the needs of patients in general. The needs of PwDs with physical or sensory limitations with respect to accessing iMHere apps on smartphone might be different from those of other users.

Dexterity limitations are commonly associated with chronic disease, accidents, or aging. Before populations with these limitations can harness the potential of mHealth and other emerging trends in healthcare, the accessibility of mHealth has to be addressed to ensure the quality of such services as a whole. We expected that the accessibility features provided in the iMHere system is not sufficient to enable individuals with dexterity impairments full access to the program (*$Hypothesis_1$*). This study was designed to identify the potential issues and barriers to accessibility related to UI components (e.g. the size of text and buttons, the use of visual cues) for persons with dexterity impairments.

6.2 METHODS

6.2.1 Study Design

This was a descriptive and observational study examining the original iMHere apps. Two iMHere apps were concentrated on here: MyMeds for medication management and SkinCare for monitoring and reporting of skin breakdown. These two apps were selected based on their importance to self-care for patients with chronic conditions such as SB and SCI and the relative complexity of completing the tasks, as described in Chapter 5.

Inclusion criteria were 18 to 64 years of age, has trouble moving or using their fingers, has the potential for skin breakdown, and uses at least one prescription or non-prescription medication. Exclusion criteria included vision, hearing, or speech problems that entirely precluded the use of a smartphone. The right+left+both score from the Purdue Pegboard Assessment (see Chapter 5) were recorded to represent participant's dexterity levels.

6.2.2 Study Procedure

Figure 21 illustrates the study flow for participants. A face-to-face orientation and training (about 15 minutes) were conducted after the questionnaire was filled out. Participants were trained and asked to perform tasks using the MyMeds and SkinCare apps until they were confident about using the apps. At the end of this training, the researcher watched the participants entering schedules for medication and skincare. Then participants were asked to use the apps and respond to their daily alerts in a one-week field trial.

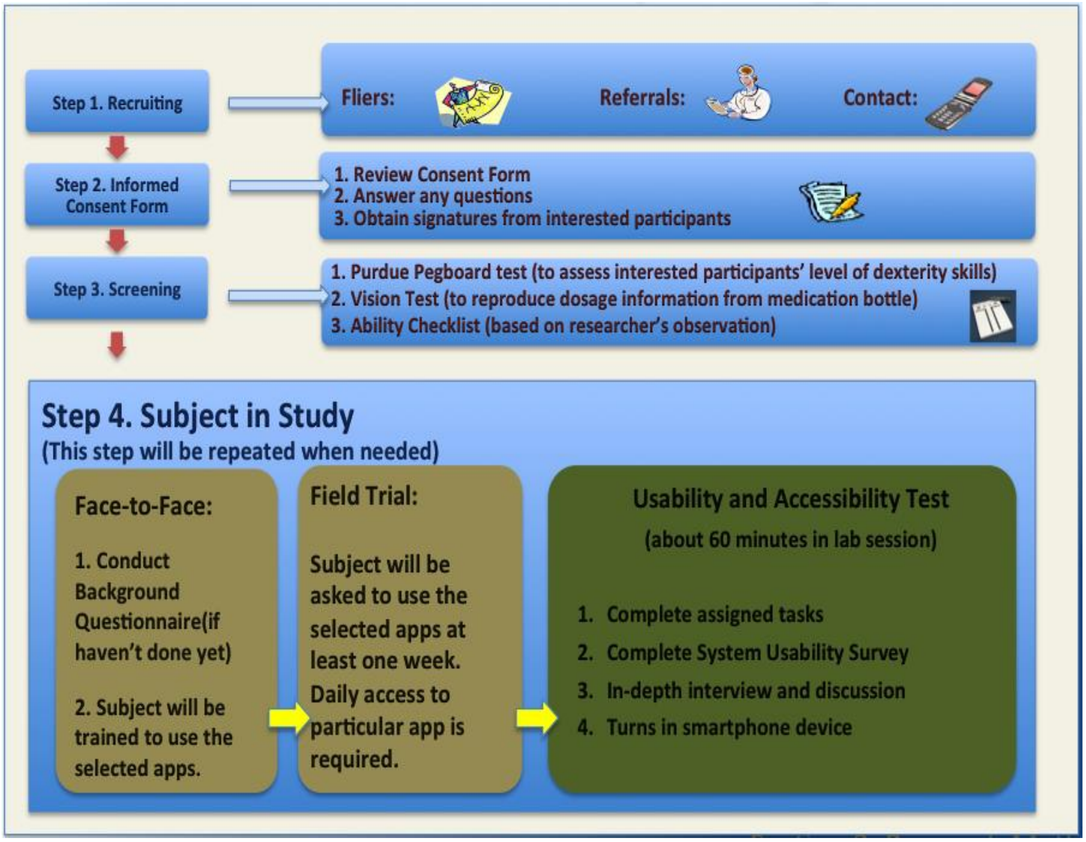


Figure 21. Study Flow for Participants

To simulate realistic daily routines for the MyMeds app, participants received their medication alerts and were required to indicate if they had taken the medication. The scenario for the SkinCare app was a little different: after receiving an alert, participants were required to respond to the alert to demonstrate that a problem had or had not been identified; then they were required to take a picture of any problem skin and fill out a form to describe the problem. After this field trial, a lab-test with and an in-depth interview were conducted.

Tests in a lab environment were conducted either at the Department of Health Information Management at the University of Pittsburgh or a location named by the participant. Participants were being allowed to choose a preferred location, as they might feel more comfortable in their natural environment. Moreover, in their convenient work or living settings they might be more encouraged to focus, think and express their ideas. Such an environment would allow participants to conduct the tasks without distractions.

A think aloud method for product design and development (Lewis, 1982) was also utilized to gain comprehensive knowledge of participants' experiences in the lab tests. Participants were asked to describe aloud whatever they were looking at, thinking, doing and feeling as they performed the tasks. After performing the tasks, participants were asked to complete a usability questionnaire and participate in an in-depth interview.

The following five tasks were randomly given to participants during the test:

- Task 1 – Schedule a new medication: participants had to locate the correct medication, add more information about their regimen such as their reason for taking the medication, and set up a reminder.
- Task 2 – Modify a medication reminder: participants had to change the alert time for a medication.
- Task 3 – Respond to a medication alert: participants had to indicate he/she took a medication.
- Task 4 – Set up a schedule to check skin: participants were required to set a daily alert skin checkup.
- Task 5 – Report a skin issue: participants were required to respond to reminders, take a picture, and fill out a form describing the affected skin, including location, color, size, depth, and tissue condition.

6.2.3 Measurements

The current study used usability-testing methods to evaluate the performance of those with dexterity impairments when using iMHere apps for self-care. We defined “usability” broadly, according to the International Standard Organization (ISO) definition: “the effectiveness, efficiency, and satisfaction with which specified users achieve specified goals in particular environments” (Dix, 2009).

Particularly, “effectiveness” is defined as “the accuracy and completeness with which specified users can achieve specified goals in particular environments.” It relates to the accuracy and completeness of services available in the apps, the potential for a user to have mistakes, and the ability to recover from mistakes. “Efficiency” is “the resources expended in relation to the accuracy and completeness of goals achieved.” Efficiency refers to the effort and time it takes for a user to complete the tasks. “Satisfaction” is “the comfort and acceptability of the work system to its users and other people affected by its use.” Satisfaction relates to how users like the apps, whether the services meet their needs for self-care and how well they met the users’ expectations for interaction. Using these definitions for the components of usability, we utilized a mixed method, including quantitative and qualitative measurements, to develop a framework for this in-depth evaluation.

6.2.5.1 Quantitative Measurements

The time it took the participant to complete each task, the number of possible errors committed by a participant, and the number of errors a participant was able to self-correct were employed as objective measures of performance. The researcher explained the details of each task to the participant until the participant fully understood all the requirements. The time to complete was measured after participants began interacting with the iMHere apps and ended when participants finished all the required activities for each individual task.

The Step-by-Step Observation Notes (Appendix F) was also used as an objective measure to record the verbal and non-verbal behaviors and frustrations of participants in the lab tests. The corresponding weights were added to describe the difficulty-on-performance (DP) for participants to solve problems:

a) If the participant was able to solve the problem without any help, the problem was given a weighted score of “1”.

b) If the participant was able to solve the problem after a short suggestion in one sentence, the problem was given a weighted score of “2”.

c) If the participant was able to solve the problem after receiving extra help in two to four sentences, the problem was given a weighted score of “3”.

d) Finally, if the participant was unable to solve the problem even after being provided extra help, the problem was given a weighted score of “4”. In this case, the participant was shown how to solve the problem and asked to finish the task.

$DP_{total} = \Sigma\ (S_1 \times 1+S_2 \times 2+S_3 \times 3+S_4 \times 4)$	DP_{total}: Difficulty level for a participant to finish a task. s: Total weighted score for one task. S_1: Number of problems a user is able to solve without any help. S_2: Number of problems a user is able to solve after a short suggestion in one sentence. S_3: Number of problems a user is able to solve after receiving extra help in two to four sentences. S_4: Number of problems a user is unable to solve even after being provided with extra help.

Figure 22. Formula for the Difficulty-on-Performance

As shown in Figure 22, the DP score was calculated as the sum of weighted scores. A lower DP score indicates better and easier performance of the task. The average DP score was utilized to reflect the difficulty level for participants to complete individual task and the success of participants in completing all of the tasks for a specific app.

6.2.5.2 Qualitative Measurements

Subjective measurements were collected to achieve a qualitative evaluation enabling us to understand participants' experiences more clearly. Specifically, one measurement we used was a background questionnaire (Appendix G) that helped us to gather baseline information from a participant. In addition, this questionnaire also asked questions to elicit participants' experience with mobile phones and his/her knowledge of mHealth.

A second subjective measure, the modified Telehealth Usability Questionnaire (TUQ) for mHealth systems (Appendix H), was utilized to elicit users' levels of satisfaction with the iMHere apps. The TUQ is a comprehensive usability questionnaire that focuses on six usability factors: usefulness, ease of use and learnability, interface quality, interaction quality, reliability, satisfaction and future use (Parmanto et al., 2010). This questionnaire utilizes a seven-point Likert scale to measure usability, with the value of one (1) as least satisfied and seven (7) as most satisfied.

A semi-structured questionnaire, the Mobile UI Experience & Satisfaction Questionnaire, was also utilized after completion of the study to obtain participants' feedback and impressions regarding the complexity and effectiveness of UI components related to presentation and navigation. Participants verbally answered each question and explained their thoughts in detail. As shown in Appendix I, the 25 questions on the Mobile UI Experience & Satisfaction Questionnaire focused on six factors in order to elicit a specific type of information, specifically:

a) Complexity of task to determine whether the scenario of the tasks was related to a participant's daily routine and whether the description of tasks was easy for a participant to understand.

b) Ease-of-learning to evaluate the quality of orientation and training. Additionally, we were also interested in assessing the participants' ability to self-learn.

c) Value of presentation to explore participants' attitudes with respect to the presentation on a small screen. Failures or mistakes in using UI elements on smartphone apps including widgets, visual cues, buttons and images might have a negative effect on users' experiences.

d) Efficiency of navigation to determine the effectiveness of the navigation system and layout orders. Effective navigation and consistent layout across different apps would make smartphone apps easier for users to operate.

e) Use of terminology to elicit feedback on meaningful use of medical terms, menus and titles. This feedback is especially important in ensuring users' understanding of data contents in order to improve their experience.

f) Overall satisfaction and suggestions were included to explore participants' overall satisfaction with the MyMeds and SkinCare apps. Participants' suggestions were also collected for improving the accessibility of the MyMeds and SkinCare apps.

6.2.4 Statistical Analysis

Descriptive statistics were calculated for the demographic and usability variables. The average time for participants to complete tasks was utilized to reflect the effectiveness of an app. Error rates were calculated between the possible errors that confronted participants and the number of errors the participants was able to self-correct. Standard deviation (SD) and variance were used to measure the dispersion of the data, including the time to complete tasks, the satisfaction scores from the TUQ, the DP scores of the tasks recorded from the lab test.

Analysis of Variance (ANOVA) procedures were used to compare the average time of those in different dexterity level groups to complete the tasks. Bonferroni's test was used to do a pair-wise comparison among the means of the different groups when statistical significance was found in the ANOVA. The Welch F-ratio and results from the Dunnett T3 test were reported when the assumption of homogeneity of variance was violated. Pearson product-moment correlation coefficients were employed to measure the correlation among the time for participants to complete tasks, the satisfaction scores from TUQ, and the scores for level-of-difficulty of tasks. Statistical significance was set at the $p<0.05$ level.

6.3 RESULTS

6.3.1 Background of Participants

To control the scope and expenses of this in-depth study, 10 participants were recruited from the Pittsburgh area. Studies from human-computer interface (HCI) literature have found that 80% of usability problems can be found with only five subjects (Hertzum & Jacobsen, 2003; Lewis, 2006; Turner et al., 2006), with almost all high-severity usability problems being uncovered with only three subjects (Turner et al., 2006). The sample size of 10 participants in this study can be considered sufficient for discovering usability problems for persons with dexterity impairments. According to Faulkner (2003), 10 participants in a usability study may able to reveal 82% to 95% of usability issues.

Ten participants with varying levels of dexterity impairments were enrolled in this study. One of them decided to drop out after initial training for the apps. This participant who chose to drop has memory issues, and she was afraid to lose the device. The remaining nine participants ranged from18 to 55 years of age, including 6 men (67%) and 3 women (33%). Eight of them were persons with SB (89%); and one was had SCI (11%). As shown in Table 4, the majority of participants were 18-30 years old (67%). Only one participant's age was in the 41 – 55 range. They were all mobile phone users prior to this study, with four of them using smartphones with touch screen.

Table 4. Background of Participants

Question	P01	P02	P03	P04	P05	P06	P07	P08	P09
Age	31-40	18 - 30	18-30	18-30	18-30	31-40	18-30	41-55	18-30
Highest Education	Grad*	High School	High School	High School	High School	Under*	Under	Grad	Under
Gender	F	M	M	M	M	F	F	M	M
Regular Phone vs. Smartphone	Regular	Regular	Regular	Smart-phone	Smart-phone	Regular	Smart-phone	Smart-phone	Regular
Physical Keypad vs. Touch Screen	Physical	Physical & Touch	Physical	Touch	Touch	Physical	Touch	Touch	Touch
Mobile Phone experience (in years)	0 - 2	3 - 5	> 5	>5	> 5	0 - 2	> 5	> 5	0 - 2
Daily use (in minutes)	>60	<30	>60	>60	>60	<30	>60	>60	>60

*Grad: Graduate education; Under: undergraduate education.

Out of the nine participants, two (22%) spent less than 30 minutes per day using mobile phones; all others (78%) spent more than 60 minutes. All participants used their devices to make phone calls, and 89% commonly sent text messages. About 56% of the participants used their phone to play games and 44% to browse the Internet. Three out of the nine participants (33%) took photos using their devices. Thirty-three percent of the participants used the calendar on the smartphone for managing their daily activities, such as for recording work schedules. Three participants (33%) used their device to check email. Only two participants (22%) had experienced listening to music using their smartphones.

Participant 1 is the only one who had a general idea about mHealth. She indicated mHealth as “a way of keeping track of daily, normal activities with the use of a mobile phone or other electronic device.” No participants had previously used any kind of smartphone app to manage their health related activities, though participant 4 did use the alarm clock function to remind him to take his medications because he takes more than ten. Participants 3 and 8 were living with their family or relatives. All others were living in a residential nursing home. Either staff or family members reminded them about their medical daily routines.

6.3.2 Dexterity Levels

Nine participants were all right-hand dominant. Participants 2 and 8 were unable to perform the pegboard assessment test due to their dexterity limitations. Participant 2 had very limited movements of the arm and hand and almost no movement of the fingers. Participant 2’s cellphone device had a slide out physical keypad, but he likes to use a touch screen. Participant 8 had experienced a traumatic accident (SCI C-5) resulting in very limited movement of the arms, slight movement of the thumb and index figure, and an inability to hold or to pick up things. He accesses smartphone either using the side of his pinky or a stylus mounted to a special glove. Since they did not have any problem communicating with researchers, following directions to completing the vision test or using a smartphone, they were included in this study.

For the other participants, all four tests in the Purdue pegboard assessment, including the right-hand, left-hand, both-hands and assembly tests, were repeated three times. Table 5 shows the personal average for dexterity ability to complete each test. The score for right+left+both hand test was a mathematical sum from right-hand, left-hand and both-hands tests. As shown in

Table 5, all participants' right+left+both hand tests' scores were below –2 SD from the mean of general factory workers. However, 1, 5, 6, 7 9 tried picking up pins using both hands and dropping the pins in the holes at the same time to speed up their performance. This led to their obtaining scores for the both-hand test that were around average mean of general factory workers at 16.01.

Table 5. Results for Purdue Pegboard Assessment Test

PARTIC	Right Hand	Left Hand	Both Hands	R+L+Both
	Avg.=17.15 -2SD=13.57 -3SD=11.78	Avg.=16.01 -2SD=12.61 -3SD=10.91	Avg.=16.01 -2SD=12.61 -3SD=10.91	Avg.=46.76 -2SD=38.68 -3SD=34.46
P01	8.67	9.00	15.33	33.00
P02	0.00	0.00	0.00	0.00
P03	10.67	6.33	10.00	27.00
P04	8.67	5.00	10.00	23.67
P05	10.00	10.33	16.00	36.33
P06	9.33	9.67	16.00	35.00
P07	9.67	10.67	16.67	37.00
P08	0.00	0.00	0.00	0.00
P09	12.00	12.67	13.67	38.33

The result of right+left+both tests as the mathematical sum of other tests were utilized to group participants in varying dexterity conditions:

- Group 1, those with mild dexterity issues: Their scores for the right+left+both tests ranged from -2 SD to -3 SD below the generic mean of factory workers. This group included participants 5, 6, 7 and 9.
- Group 2, those with moderate dexterity issues: Their scores ranged below -3 SD from the generic mean of factory workers. This group included participants 1, 3 and 4.
- Group 3, those with severe dexterity issues: the participants who were not able to complete the Purdue pegboard tests were included in Group 3: participants 2 and 8.

6.3.3 Efficiency

After a one-week field trial, participants were introduced to the face-to-face lab tests. Figure 23 shows the average time spent on each task for each group of participants. Regardless of their dexterity levels, participants spent the least amount of time responding to medication alerts (Task 3). Task 1 (scheduling a medication alert) and Task 5 (responding to skincare alert) took longer for participants to finish. However, no significant time difference was found when comparing the three groups of participants with respect to complete tasks at $p>0.05$ level, $F(2, 12)=0.186$, $p=0.833$.

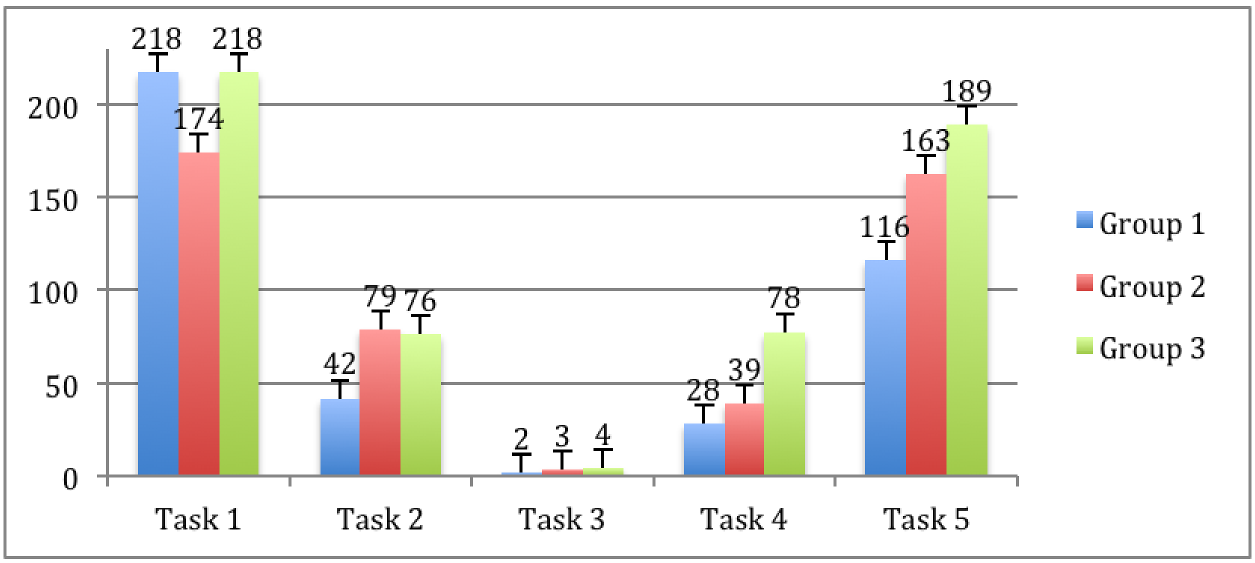


Figure 23. Group Average Time for Each Task, in seconds

Table 6 shows the time each participant spent on tasks. Participant 6 from group 1 spent about 485 seconds scheduling a new medication. Rather than click "+" to add a new medication, Participant 6 clicked on the existing medication list and tried to modify the schedule first then continued with the activity to add new. Participant 2 from group 3 with severe dexterity impairments spent the longest time to complete all tasks. However, participant 8 was able to perform at a level closer to those in group 2 by using stylus.

Table 6. Time for Participants to Complete Tasks*

	PARTIC	Task 1	Task 2	Task 3	Task 4	Task 5	Total	Group Avg. (SD)
Group 1	P05	193	35	2	31	259	520	81 (115.6)
	P06	485	66	1	48	82	682	
	P07	90	24	2	20	87	224	
	P09	104	42	3	13	36	198	
	Average	*218.00*	*41.75*	*2.00*	*28.00*	*116.00*	*406.00*	
Group 2	P01	194	152	3	29	258	635	92 (81.3)
	P03	163	54	5	40	80	341	
	P04	164	31	2	49	151	379	
	Average	*173.67*	*79.00*	*3.33*	*39.33*	*163.00*	*451.67*	
Group 3	P02	305	115	5	120	251	797	113 (101.1)
	P08	131	37	3	35	127	333	
	Average	*218*	*76*	*4*	*77.5*	*189*	*565*	
Total Avg. (SD)		203 (122.8)	62 (43.6)	3 (1.4)	43 (31.3)	148 (87.1)	458 (210.9)	120 (59.1)

** in seconds.*

6.3.4 Effectiveness

As shown in Tables 7 – 11, participants did complete all five tasks, covering all activities in the MyMed and Skincare apps. Specifically, the nine participants performed 361 steps to complete all of the tasks. Thirty-nine errors were identified among all of the participants, resulting in an error rate of 10.8%.

Table 7. Task 1 – Schedule Medication Alert

PARTIC	Total Steps	Total Mistakes	Error rate
P01	15	2	13.33%
P02	17	3	17.65%
P03	18	0	0.00%
P04	16	1	6.25%
P05	16	1	6.25%
P06	16	2	12.50%
P07	16	2	12.50%
P08	16	1	6.25%
P09	16	0	0.00%
Total	*146*	*12*	*8.30%*

Table 8. Task 2 – Modify Medication Alert

PARTIC	Total Steps	Total Mistakes	Error rate
P01	8	1	12.50%
P02	8	2	25.00%
P03	8	0	0.00%
P04	8	3	37.50%
P05	8	1	12.50%
P06	8	1	12.50%
P07	8	2	25.00%
P08	8	2	25.00%
P09	8	2	25.00%
Total	*72*	*14*	*19.44%*

Table 9. Task 3 – Respond to Medication Alert

PARTIC	Total Steps	Total Mistakes	Error rate
P01	1	0	0.00%
P02	1	0	0.00%
P03	1	0	0.00%
P04	1	0	0.00%
P05	1	0	0.00%
P06	1	0	0.00%
P07	1	0	0.00%
P08	1	0	0.00%
P09	1	0	0.00%
Total	*9*	*0*	*0.00%*

Table 10. Task 4 – Schedule Skincare Alert

PARTIC	Total Steps	Total Mistakes	Error rate
P01	6	0	0.00%
P02	6	1	16.67%
P03	6	0	0.00%
P04	6	1	16.67%
P05	6	0	0.00%
P06	6	0	0.00%
P07	6	0	0.00%
P08	6	1	16.67%
P09	6	0	0.00%
Total	*54*	*3*	*5.56%*

Table 11. Task 5 – Respond to Skincare Alert

PARTIC	Total Steps	Total Mistakes	Error rate
P01	10	1	10.00%
P02	8	3	37.50%
P03	10	0	0.00%
P04	10	2	20.00%
P05	10	1	10.00%
P06	8	0	0.00%
P07	8	1	12.50%
P08	8	1	12.50%
P09	8	1	12.50%
Total	*80*	*10*	*12.78%*

The tasks for scheduling a medication alert (Table 7) and responding to a skincare alert (Table 11) were the most complicated because more steps were involved, resulting in a relatively higher error rate at 8.3% and 12.78%. On the other hand, only a single click on the alert screen was required for a user to respond to a medication alert, no mistakes were identified.

Table 12. Group Comparison of Error Rate

	PARTIC	Task 1	Task 2	Task 3	Task 4	Task 5	Avg.	Group Avg.
Group 1: Mild	P05	6.25%	12.50%	0.00%	0.00%	10.00%	5.75%	
	P06	12.50%	12.50%	0.00%	0.00%	0.00%	5.00%	
	P07	12.50%	25.00%	0.00%	0.00%	12.50%	10.00%	
	P09	0.00%	25.00%	0.00%	0.00%	12.50%	7.50%	7.06%
Group 2: Moderate	P01	13.33%	12.50%	0.00%	0.00%	10.00%	7.17%	
	P03	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
	P04	6.25%	37.50%	0.00%	16.67%	20.00%	16.08%	7.75%
Group 3: Severe	P02	17.65%	25.00%	0.00%	16.67%	37.50%	19.36%	
	P08	6.25%	25.00%	0.00%	16.67%	12.50%	12.08%	15.72%
	Average	*8.30%*	*19.44%*	*0.00%*	*5.56%*	*12.78%*	*9.22%*	*9.22%*

As shown in Table 12, group 3 with severe dexterity impairments had a higher rate of mistakes. According to a one-way ANOVA, the error rate difference was marginally significant across the three groups at individual task level at $p<0.08$ (n=9 participant x 5 tasks=45), $F(2, 42)=2.722$, $p=0.077$. A slightly positive correlation was found between the numbers of steps to complete a task and error rate ($r=0.25$, $p=0.049$, $n=45$) using a Pearson product-moment correlation coefficient. This correlation was significant at $p<0.05$ level. In addition, a significant negative correlation was found ($r=-0.348$, $p=0.019$, $n=45$) between mistakes and dexterity score (R+L+Both). This means people who have lesser dexterity might have more problems to complete tasks.

After adding the weighted DP score to each mistake, participants experienced more problems completing task 1 – scheduling a new medication, task 2 – modifying a medication alert, and task 5 – responding to a skincare alert (Table 13). However, no significant difference was identified among the three groups when comparing the DP using an ANOVA at $p>0.05$ level, $F(2, 42)=0.033$, $p=0.967$. A slightly negative correlation was identified between subjects' dexterity levels (R+L+Both) and their DP based on Pearson correlation, ($r=-0.037$, $n=45$); but this coefficient was not significant, p=0.812. On the other hand, a significant correlation was found between the numbers of steps and DP at $p<0.01$ level, r=0.554, n=45, p=0.000. Results from Pearson correlation also suggest an increase in error rate might significantly increase DP for users in completing tasks at $p<0.01$ level, r=0.642, n=45, p=0.000).

Table 13. Overview of Difficulty-on-Performance

	PARTIC	Task1	Task2	Task3	Task4	Task5	Avg. (SD)
Group 1: Mild	P01	5	2	0	0	4	2.20 (2.28)
	P02	4	2	0	1	3	2.00 (1.58)
	P03	0	0	0	0	0	0.00 (0.00)
	P04	4	7	0	1	2	2.80 (2.77)
Group 2: Moderate	P05	4	4	0	0	4	2.40 (2.19)
	P06	7	3	0	0	0	2.00 (3.08)
	P07	4	2	0	0	3	1.80 (1.79)
Group 3: Severe	P08	1	2	0	1	1	1.00 (0.71)
	P09	0	2	0	0	1	0.60 (0.89)
	Total	*29*	*24*	*0*	*3*	*18*	*14.80 (12.79)*

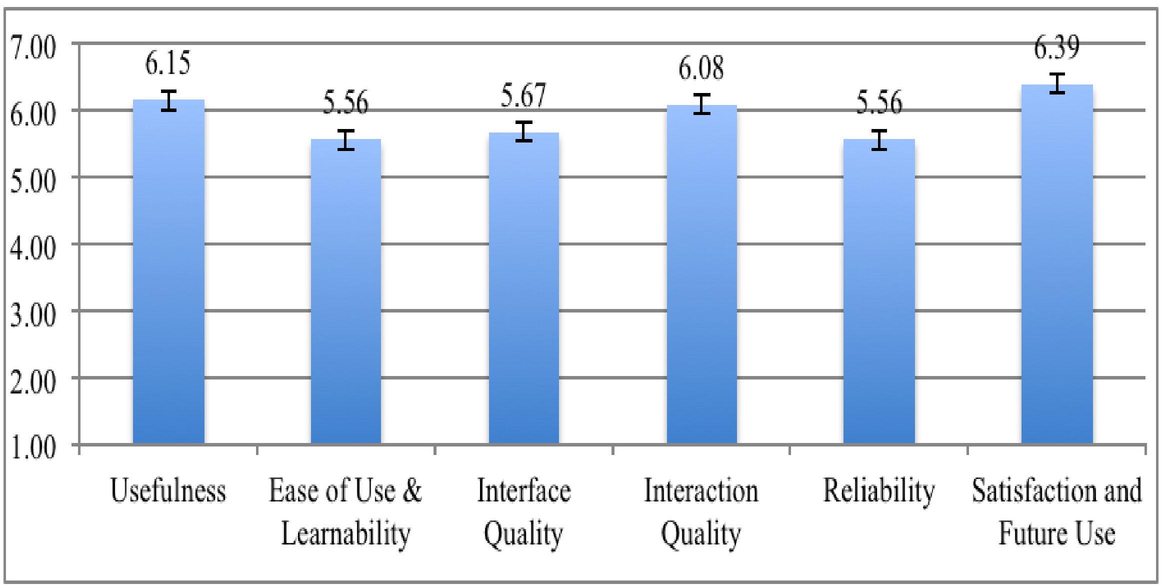
Table 14 shows the detailed list of the mistakes and the weighted DP scores. User frustrations were identified regarding text entry and accessing buttons (Type A mistakes, 8 out of 39 errors, 21%). The main cause of user difficulty was that fingers were easily sliding off buttons. The remaining 31 errors (79% of 39) were related to participants' familiarity with apps (Type B). Participants were able to self-correct about 51% of mistakes (n=20) without any help (DP=1). They also corrected 8 mistakes (about 21%) after a one-sentence reminder from the researcher (DP=2). The remaining 11 mistake required more assistance from the researchers (5 mistakes: DP=3; 6 mistakes: DP=4).

Table 14. List of Mistakes and Difficulty-on-Performance

#	Task	Description of Mistake	DP	Total DP
P01	Schedule a medication alert	Saved without scheduling an alert (Type B)	3	11
		Forgot to save alias & notes (Type B)	2	
	Modify a medication alert	Forgot to save alias & notes (Type B)	2	
	Respond to skincare alert	Saved directly, forgot to check "problem identified." (Type B)	4	
P02	Schedule a medication alert	Forgot to click "+" to add a new item (Type B)	1	10
		Difficulty to type information in "Alias" (Type A)	1	
		Forgot to save alias & notes (Type B)	2	
	Modify a medication alert	Difficult to change the alert time (Type A)	1	
		Difficult to click "save" button (Type A)	1	
	Respond a skincare alert	Difficult to click "save" button in the alert screen (Type A)	1	
		Accidentally, clicked to retake picture (Type A)	1	
		Difficult to click "save" after recording a problem (Type A)	1	
	Schedule a skincare alert	Difficult to change the alert time (Type A)	1	
P04	Schedule a medication alert	Forgot to save the alert (Type B)	4	14
	Modify a medication alert	Forgot click on medication item to modify (Type B)	2	
		Tried to add a new schedule (Type B)	3	
		Forgot to save alias & notes (Type B)	2	
	Respond a skincare alert	Saved directly, forgot to check "problem identified." (Type B)	1	
		Forgot to click "+" to add new (Type B)	1	
	Schedule a skincare alert	Forgot to click on "Time" to modify the alert. (Type B)	1	
P05	Schedule a medication alert	Forgot to save the alert (Type B)	4	12
	Modify medication alert	Forgot to save alias & notes (Type B)	4	
	Respond skincare alert	Saved directly, forgot to check "problem identified." (Type B)	4	
P06	Schedule medication alert	Forgot to click "+" to add new, modified the existing medication instead (Type B)	4	10
		Forgot to save alias & notes (Type B)	3	
	Modify medication alert	Add a new schedule instead (Type B)	3	
P07	Schedule medication alert	Saved without scheduling an alert	2	9
		Forgot to save alias & notes (Type B)	2	
	Modify medication alert	Long thinking before clicked on medication item to modify (Type B)	1	
		Long thinking before clink on time to change the alert (Type B)	1	
	Respond skincare alert	Clicked on the listed item rather than "+" (Type B)	3	
P08	Schedule medication alert	Forgot to save alias & notes (Type B)	2	6
	Modify medication alert	Long thinking before choosing "modify" from the option menu (Type B)	1	
		Forgot click on medication item to modify (Type B)	1	
	Respond a skincare alert	Did not slide up to finish the survey. Selected to retake picture rather than save button (Type B)	1	
		Clicked save button twice (Type A)	1	
P09	Modify a medication alert	Long thinking before clicked on medication item to modify (Type B)	1	
		Long thinking before choosing "modify" from the option menu (Type B)	1	3
	Respond a skincare alert	Clicked on listed item, but self-realized (Type B)	1	1
		Total DP Score	75	75

6.3.5 Users' Satisfaction

The average TUQ score for all participants was 5.9 (out of 7 point). As shown in Figure 24, participants were satisfied with the iMHere apps and would consider using them in the future (average score: 6.39). When looking toward further improvements, the sections for "ease of use & learnability," "interface quality," and "reliability" received scores lower than 6 (average scores: 5.56, 5.67 & 5.56).



SD: 0.75 vs. 0.60 vs. 0.47 vs. 0.54 vs. 0.81 vs. 0.50 vs. 0.40

Figure 24. TUQ Factors and Scores

Figure 25 illustrates the average usability scores for each of the three groups. Group 2 participants gave higher scores across all six factors of usability when compared with groups 1 and 3. Participant 8, particularly, gave the lowest score, 2, for question 17, "the system gave error messages that clearly told me how to fix problems," under the reliability factor. Participant 8 thought the "apps could be more instructive" and it is better to "avoid typing, because I cannot type without stylus." Participant 2 with more severe impairment didn't think he could use the apps effectively because of the target's size – his fingers were always sliding off of the buttons.

However, no significant difference was identified among the three groups when comparing the TUQ factor scores using an ANOVA at $p>0.15$ level, $F(2, 15)=1.96$, $p=0.175$, n=3 group x 6 factors=18.

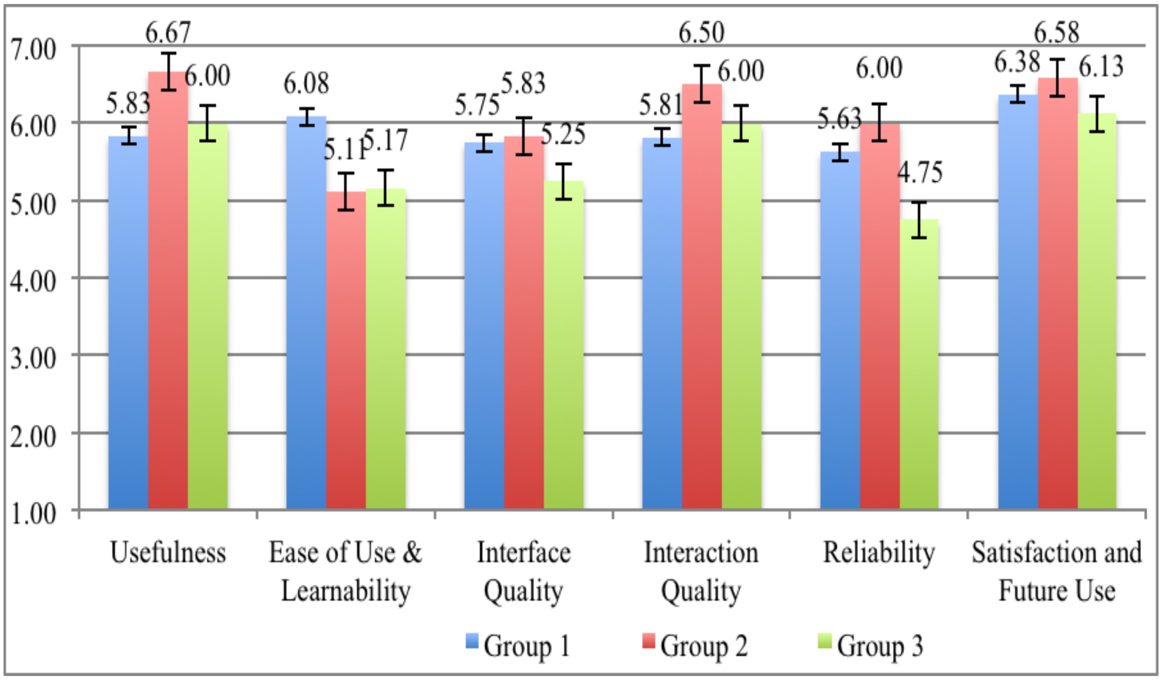


Figure 25. Comparison of TUQ scores

6.4 DISCUSSION

According to Pearson correlation, users with a higher degree of dexterity impairment demonstrated more problems in task completion. These particular users' fingers easily slid off buttons. The remaining errors were related to participants' familiarity with apps. A larger amount of steps for task completion is not necessary associated with more user errors, but it was shown to increase the difficulty-on-performance.

The original iMHere apps had certain features to make them more accessible. For instance, participants highlighted the usefulness of colors. Green and red colors were utilized to indicate the status of whether or not a medication was scheduled. When participants 1 & 7 completed the task of adding a new medication without scheduling an alert, they noticed and self-corrected the problem after seeing a red color bar in the medication list. Moreover, participants 1, 2, 3, 5, 8 indicated that using colors to separate body parts helped patients to correctly specify the location of problem skin areas.

However, the following accessibility features were not sufficient to enable individuals with dexterity impairments full access to the program:

1) Pop-up notifications to instruct patients on how to complete the current step, such as saving a medication alert or sliding up to finish the skincare survey before saving. Participants 4, 5 & 8 closed the dialog directly without fully comprehending the information.
2) Use of a consistent design, such as the same image icon, words, and layout being used consistently across all screens with the same activities, such as scheduling an alert within different apps. Users who learned to use one app should theoretically not have had problems using other apps in the iMHere system. However, participant 5 was concerned that he would forget which app he is using if the activity has been interrupted, since the screens for scheduling an alert look same in MyMeds and SkinCare apps.

Based on participants' suggestions, several important findings from this study reveal ways to improve accessibility in general:

1) Thematic colors: Participants highlighted the usefulness of the colors mentioned above. Participant 5 suggested that using color to separate the apps would easily let them know which app they are using.
2) Instructive guidance: About 77% out of 39 mistakes (n=30) that were encountered by participants were related to participants' familiarity with apps. About 51% of these mistakes were self-corrected without any help. Thirteen mistakes were corrected after one (8 mistakes) or two sentences assistance (5 mistakes). For instance, participants forgot to click the "plus" sign to add a new schedule, forgot to save data, or saved data without completing a survey. A short one-sentence reminder for providing directional guidance might be useful to prevent these types of mistakes.
3) Simpler cognitive process: Participants 4, 5 & 6 suggested that streamlining the cognitive process of tasks and reducing the layout complexity on one screen may help to improve accessibility. Participants 2, 7, 8 & 9 suggested that offering fewer functions on such a small screen may help to reduce confusion about what do to next.
4) Alternative camera button: Subjects with severe dexterity impairments (participants 2 & 8) needed help from a family member or clinical staff to take a photo of their problem skin area because they were unable to hold a Smartphone. Participants 1, 4, 7 were not very comfortable using the in-screen camera button, especially when the skin problem was located in an area inconvenient to access. Manufactures are not providing a physical camera button anymore; therefore strategies such as binding the camera function to a physical button or adding a time delay to the camera would be possible appropriate ways to improve accessibility.

Other suggestions were related to participant's preferences to use mHealth apps. The following findings were associated with improving users' experiences through personalization:

1) Participants from moderate to severe groups (group 2 & 3) commented on the button size. They would prefer to have larger buttons.
2) Participants 3 & 5 indicated that they might be more comfortable with dark text on a white background.
3) Participants 4, 6 & 9 would like to change the background picture to make the app more personalized.

In general, users expressed the desire to have simpler apps, meaning ones that make processes easier. Apps on Smartphones serve as a data point of input (POI) for patients. Accessibility to apps is essential for persons with dexterity impairments to perform their medical-related activities and to report and communicate with their clinicians. Identifying their needs and preferences with respect to using iMHere apps in study 1 was our first step in developing strategies for implementing accessible apps. The development of accessible mHealth apps is continued in study 2.

7.0 STUDY 2: DESIGN AND DEVELOPMENT

7.1 INTRODUCTION

The goal of this study was to design and develop a usable and accessible system for the approximately 4.04 million adults in the US with dexterity impairments (Adams, Martinez, & Vickerie, 2010). Persons with dexterity impairments have expressed the desire to have simpler apps with easier processes (Yu, Parmanto, & Dicianno, 2013). How to meet persons with dexterity impairments' needs and desires is a challenge that once met can enhance the use of mHealth for self-care.

A list of accessibility issues was identified in study 1 (Chapter 6). Particularly, there was a chance for an increase in user mistakes when a participant had a large finger or a finger that easily slides off buttons. Participants also identified frustrations regarding text entry and accessing buttons, which can be difficult due to the small size of keys/buttons on small screens. Besides that, participants suggested the ability to change the display text size would be preferred for obtaining information. Some of them would prefer to have dark text on a white background and vice versa. They also expressed interest in being able to set different background pictures to make the app more personalized. These possible issues to accessibility and the suggestions related to user interface (UI) could be mitigated with better app design and development. We believed that accessibility of mHealth could be enhanced with user-centered UI design and development (*Hypothesis*$_2$).

The development approach to accessibility was carried out through two primary layers of the UI: physical presentation and navigation. Physical presentation is important to ensure basic accessibility for users, including the use of widgets (such as the size and the contrast of text and the use of icons as the basic elements in building accessible UI presentation). The use of a variety of colors and graphic elements is not necessary but might be important to providing good visual cues, helping users to understand content, and enhancing their experiences to interact with smartphone apps.

While physical presentation is the foundation for accessibility, navigation addresses accessibility from the efficiency perspective. The navigation components include activity flow and layout order. A simple and straightforward user interface is important in terms of accessibility for users with dexterity impairments as well as users in general. Activity flow should be focused on cognitive processes. The activity flow designed with the cognitive abilities of the user in mind can help to achieve a smoother activity flow for a particular user to complete a task. Layout order is important for efficiency. Highly related information presented consistently in proximity makes it easier for users to understand and follow the contents on a screen. Moreover, the ability to customize physical presentations and to detect shortcuts within activity flows—based on users' performances to eliminate unneeded steps—would be the optimal solution to enhance accessibility (Yu et al., 2013).

The main objective of this study was to develop an infrastructure to support the centralized configuration of UI elements related to physical presentation, including text, buttons/icons and themes, to enhance accessibility for persons with dexterity impairments. A revisioning and redesign of the abovementioned elements were essential to creating an informative and useful UI for our population on a smartphone screen. By categorizing the abovementioned essential UI elements into a specific group, users were allowed to modify its attributes, including size and color that might affect users' experience with the mHealth apps on a small screen.

7.2 METHODS

7.2.1 Study Design

We developed the capability for users to customize different settings allowing users to choose which apps they wish to use, to change the background and text color, to change the text size, and to set button size. Additional functions to simplify the navigation process and to enhance the interaction with users were also added, such as using the volume control button to take a picture and the ability to take a photo of a pill or medication bottle to upload into their medication schedules. A usability study was conducted after this development.

Participants from study 1 were included in this usability study. Inclusion criteria were 18–64 years of age, has trouble moving or using their fingers, has the potential for skin breakdown, and uses at least one prescription or non-prescription medication. Exclusion criteria included vision, hearing, or speech problems that entirely precluded the use of a smartphone. The right+left+both score from the Purdue Pegboard Assessment (Lafayette Instrument) from study 1 represents participants' dexterity levels.

7.2.2 Study Procedure

The accessible design and development procedures were focused on two iMHere smartphone apps: MyMeds for medication management and Skincare for skin monitoring and reporting of skin breakdown. A laboratory-setting evaluation with an in-depth interview was conducted after a one-week field trial. A "think aloud" method was utilized to gain comprehensive knowledge of participants' experiences. It required them to describe aloud whatever they were looking at, thinking, doing and feeling as they performed the tasks. The following six tasks were included in this lab-test:

- Task 1 – Scheduling a new medication alert that includes searching for and finding the correct medication and setting up a medication schedule;
- Task 2 – Modifying a medication reminder, which includes changing the alert time for a medication;
- Task 3 – Responding to a medication alert, which includes indicating he/she took a medication;
- Task 4 – Scheduling an alert to remind one to check the skin for any issue or problem;
- Task 5 – Responding to a skincare reminder, which involves taking a picture and describing the issues by answering survey questions;
- Task 6 – Setting personalized configurations for UI presentations, including choosing a preferred apps list, the reading size of text, and the target size for easier interaction.

7.2.3 Measurements

The time it took each participant to complete individual tasks was recorded. After performing the tasks, participants were asked to complete the modified TUQ (Chapter 5) to reveal their level of satisfaction with the iMHere apps. The TUQ utilizes a seven-point Likert scale to measure usability, with the value of one (1) as least usable and seven (7) as most usable (Parmanto et al., 2010). This was followed by an in-depth interview and a semi-structured questionnaire to obtain the participants' feedback and impressions regarding the iMHere apps.

7.2.4 Statistical Analysis

The sum and average times to complete tasks were utilized to measure participants' performance. Standard deviation was calculated to reveal the dispersion patterns of the abovementioned variables. The results from study 1 (Chapter 6) were used in this study for comparison purposes. An unequal variances t-test was utilized to explore the difference in the time for completing all tasks before and after the intervention. Person's Correlation Coefficient (PCC) was utilized to measure a linear association between the individual-based TUQ scores and the error rate encountered by each participant.

7.3 RESULTS

7.3.1 Background of Participants

All nine participants from study 1 enrolled in study 2. Three were lost to follow up after four months washout period, e.g., changed the phone number or moved to a different place. Only six participants completed study 2. Five participants had SB; one had SCI. As shown in Table 15, their ages ranged from 18-55 years, including two females (33%), and four males (67%). Four participants were smartphone users, and two used regular mobile phones with a slide-out keypad. The lower the right+left+both score of the participant, the higher degree of dexterity impairment. All of the participants had stopped using iMHere apps for more than five months before this study to minimize the learning effects that might carry over from study 1.

Table 15. Background Information

	P01	P03	P04	P05	P07	P08
Age	31-40	18-30	18-30	18-30	18-30	41-55
Gender	F	M	M	M	F	M
Mobile phone user	Yes	Yes	Yes	Yes	Yes	Yes
Smartphone	No	No	Yes	Yes	Yes	Yes
Pegboard score: Right+Left+Both	33	27	23.67	36.33	37	0
Type of Disease	SB	SB	SB	SB	SB	SCI

7.3.2 Development Results

Ten accessibility features aimed at enhancing users' experience with the iMHere app were implemented in this study. We asked participants to order these features from 1 to 10, with 1 being the most important to them and 10 being the least important to them. Table 16 shows the number of individuals assigning high (1-3, very important), medium (4-7, important but not essential), and low (8-10, less important) ranks for each feature.

Table 16. Ranked Preferences

#	Features	P01	P03	P04	P05	P07	P08	No. 1 – 3	No. 4 – 7	No. 8 – 10
1	Customized application list	1	10	6	7	2	9	2	2	2
2	Customized text display size	2	3	8	10	8	4	2	1	3
3	Customized theme (background with text color)	10	4	10	5	9	8	0	2	4
4	Customized Button Size (from finger tip size)	7	5	2	9	7	2	2	3	1
5	Customized keyboard	3	6	7	8	10	1	2	2	2
6	Ability to take a picture of pill or med bottle	6	1	5	2	4	5	2	4	0
7	Matched color for application name to the separator of action bar	9	7	9	3	6	10	1	2	3
8	Short cut for navigation	8	8	1	4	3	7	2	2	2
9	Text guide	4	2	3	6	5	6	2	4	0
10	Voice guide	5	9	3	1	1	3	4	1	1

1) The first feature we examined was the customized application list, which provides the ability for a user to hide or show a selected app from the home screen (Figure 26). Four participants (about 67%) thought this feature was important in order to hide the TeleCath and BMQs apps, because they did not need to catheterize the bladder (TeleCath) or do bowel management (BMQs). This feature made the system simpler and more appropriate for personal use.

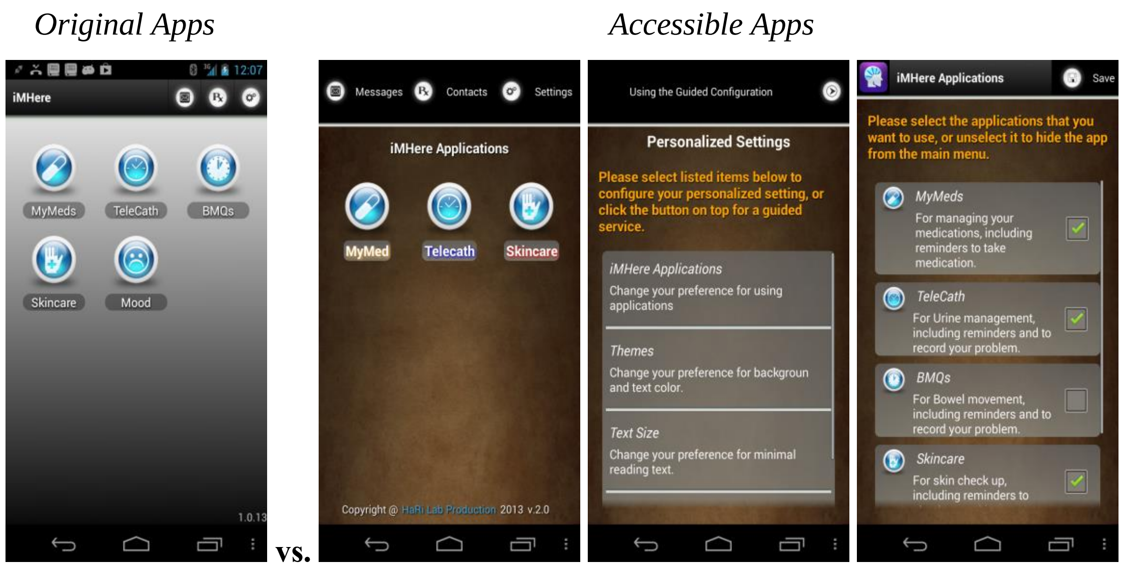


Figure 26. Customizing Application List

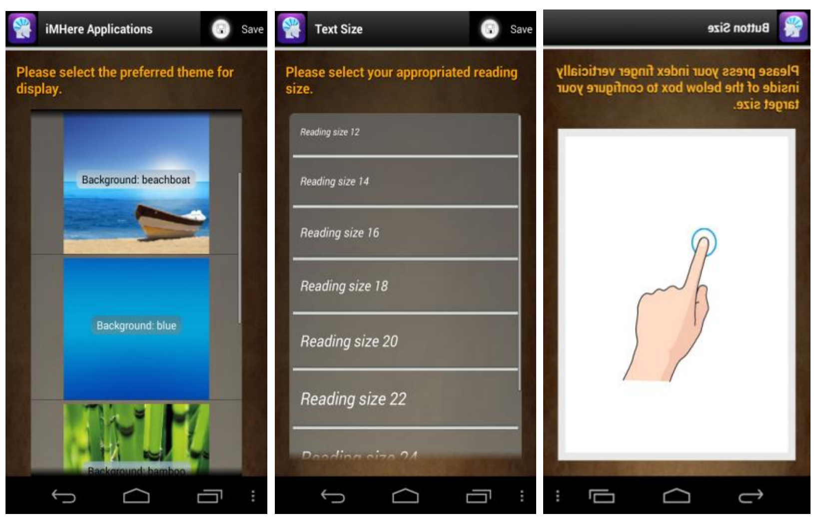


Figure 27. Personalized Setting

2) The second feature, size of display text, was specified as the minimal and comfortable reading size for a particular user (Figure 27). It was identified as the foundation for all other configuration parameters during the redesign process. The size, color, bold and italic versions of title_text, attention_text and warning_text were predefined in the mHealth apps relative to the display text. Three participants (50%) thought using customized text size was important:

Participant 1 ranked it as No. 2, participant 3 ranked it as No. 3, and participant 8 ranked it as No. 4.

3) The third feature examined was a customized theme (Figure 27). The new customized theme feature allowed the user to select his/her preferred background and text color. Though all of our participants liked to have this ability, participants 1, 4, 7 and 8 (67%) thought this was more about personal choice and not necessary for improving the accessibility of apps, ranking it No. 10, No. 10, No. 9 & No. 8, respectively.
4) With respect to customizing button size, the system asked participants to press their index finger or the one likely to be used with apps to record their fingertip size (Figure 28). This actual touch size was used as the minimum target size for buttons/icons in the accessible design. About 83% of participants (5 out of 6) thought this feature was important. Participants 4 and 8, with a higher degree of dexterity impairments, ranked it as the second most important accessibility feature for them. For this group of users, touching and holding on a small area might be problematic due to the decreased flexibility and sensitivity of the fingers. As might be expected, participants 1, 5 and 7, whose Pegboard scores were above 30, gave a lower rank to this feature (No. 7, No. 9 & No. 9, respectively).
5) As seen in Figure 28, we designed a customized keyboard with softer keys, larger key sizes and preconfigured numbers and words specifically for entering dosage information when scheduling a new medication. This customized keypad was designed to reduce the number of required touches on the smartphone screen. When using the customized keypad to enter "2 tablets," for instance, the users needed only to touch "2" and "tablet." In contrast, a traditional keypad requires at least 8 touches to enter the same information: holding down on "W" to get "2," space bar, and the letters of the word "tablet." Four out of six participants (67%)

identified this feature as important for them. In particular, participant 8, with severe dexterity impairments, ranked this as the most important feature.

Regular Keypad *Customized Keypad*

Figure 28. Keypads for Entering Text

6) Two out of six participants (33%) ranked the ability to take a picture of a pill or bottle as one of the most important features for them (No. 1 vs. No.2). Particularly, participant 5 needed to take more than 10 medications on a daily basis; he indicated that the alert with a pill or bottle image (Figure 29) would be very helpful for him to verify he was taking the correct medication. The remainder thought this feature was important but might not be essential to improve the accessibility of mHealth, ranking it No. 4 to No. 6.

Original *Accessible*

Figure 29. Medication Reminder

7) In study 1, participants highlighted the usefulness of colors to indicate the status of whether or not a medication is scheduled, green vs. red. As suggested by participants in study 1, color-

coding was utilized in the accessible design to indicate the apps and their activities. As shown in Figure 30, the title for the SkinCare app was highlighted in red. All screens under the SkinCare app had a red bar to remind the user of the current app. This strategy also applied to MyMeds app, with orange color being used. Participant 5 indicated this feature was very important for him to know which app he was using, ranking it as No. 3. Participants 3 and 6 thought this feature was important but might not be essential. Participant 7 thought this feature might be benefit users with cognitive issues.

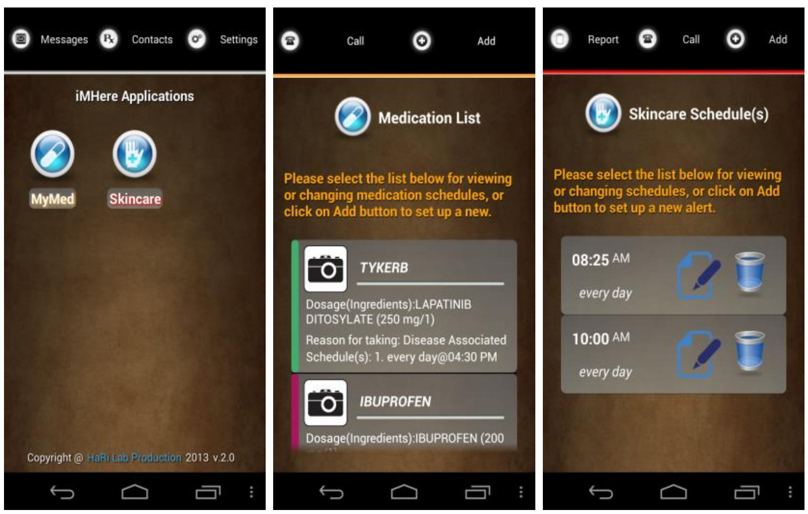


Figure 30. The Use of Color-coding at Application Level

8 & 9) Text & voice guidance was also utilized in the accessible design for continuity of use and training purposes. The text in orange shown in Figure 31 was the self-training instructional notes. Participants 3 and 4 ranked the text guidance as a very important feature to them (No. 2 & No. 3). The remainder thought the text guidance was important but not essential (ranking it as No. 4 to No. 6). Using text-to-speech technology, the users were able to listen to the text guidance in the form of audio output. Participants 4, 5, 7 and 8 (about 67%) thought this ability was very important (ranking it as No. 3, No. 1, No. 1 & No. 3). All participants liked to

have voice and text guidance work together; Participant 4, however, thought the voice guidance might be annoying in certain circumstances, such as in a movie theater.

10) Additionally, the concept of personalization was applied to the navigation levels. About 33% of participants (2 out of 6) indicated the ability to create shortcuts in navigation was very important for them: Participant 1 ranked it as No. 1, participant 5 ranked it as No. 3. Participants 5 and 8 thought this feature was important but not essential (ranking it as No. 4, and No. 7, respectively). The shortcuts were applied and affected user's experiences in the following contexts:

a) The system would check the database for personalized settings first (Figure 31). If no personalized settings were found, the system would lead the new user to set his/her preferences before going to the home screen (a list of apps).

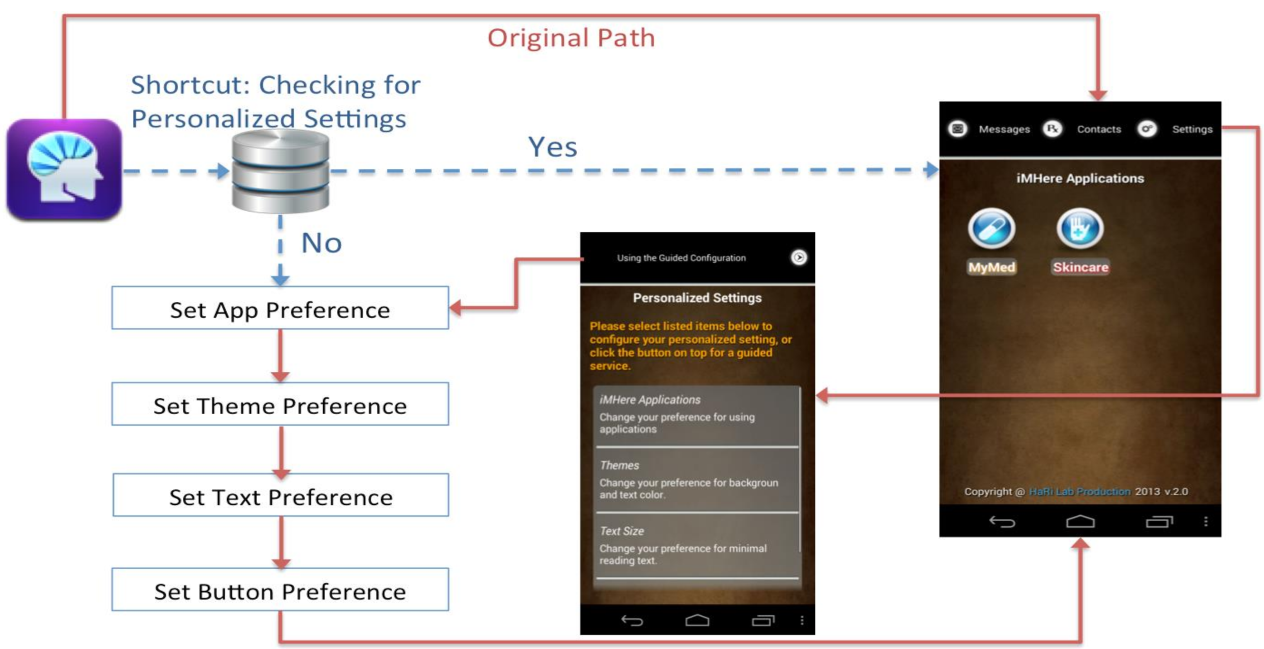


Figure 31. Navigation for Personalized Configuration

b) Shortcuts were also applied to the activities for scheduling a medication alert or scheduling a skin check alert. As shown in Figures 32 & 33, this particular app would check the local database for the current schedule list. If no schedules were found, the app would automatically direct the user to set up a new one.

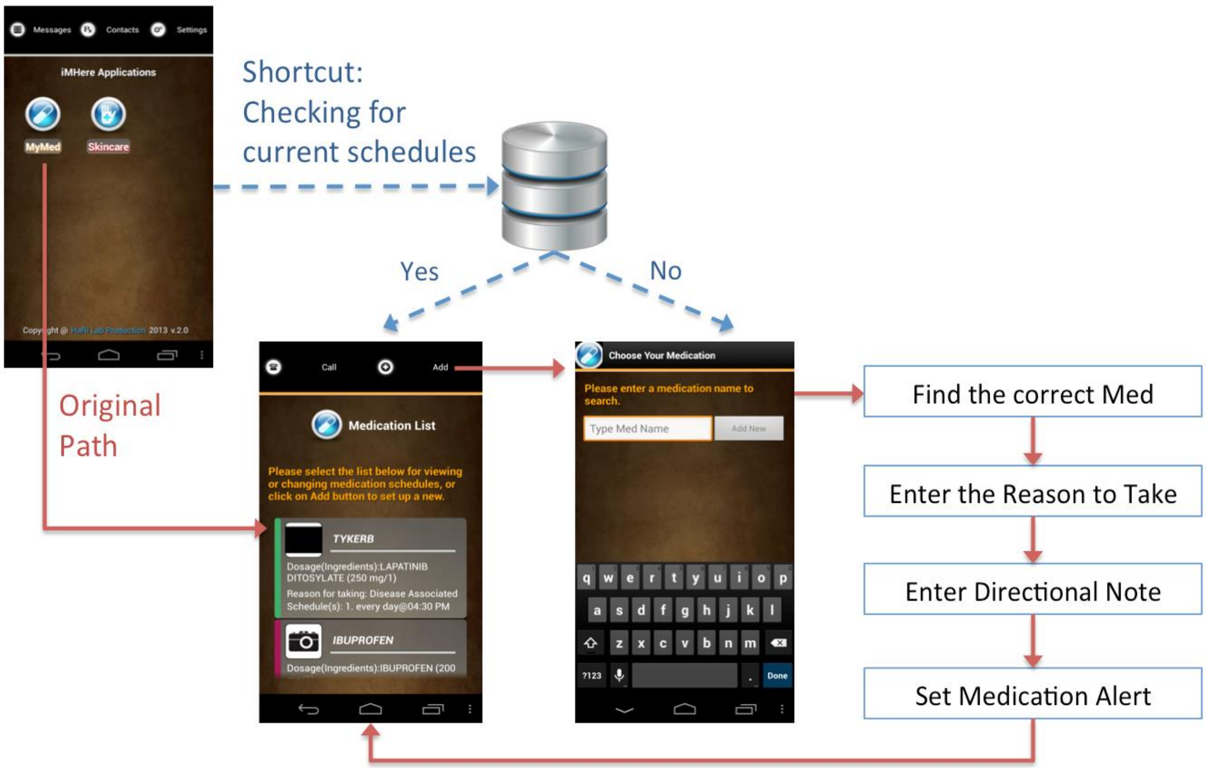


Figure 32. Navigation for Scheduling a New Medication

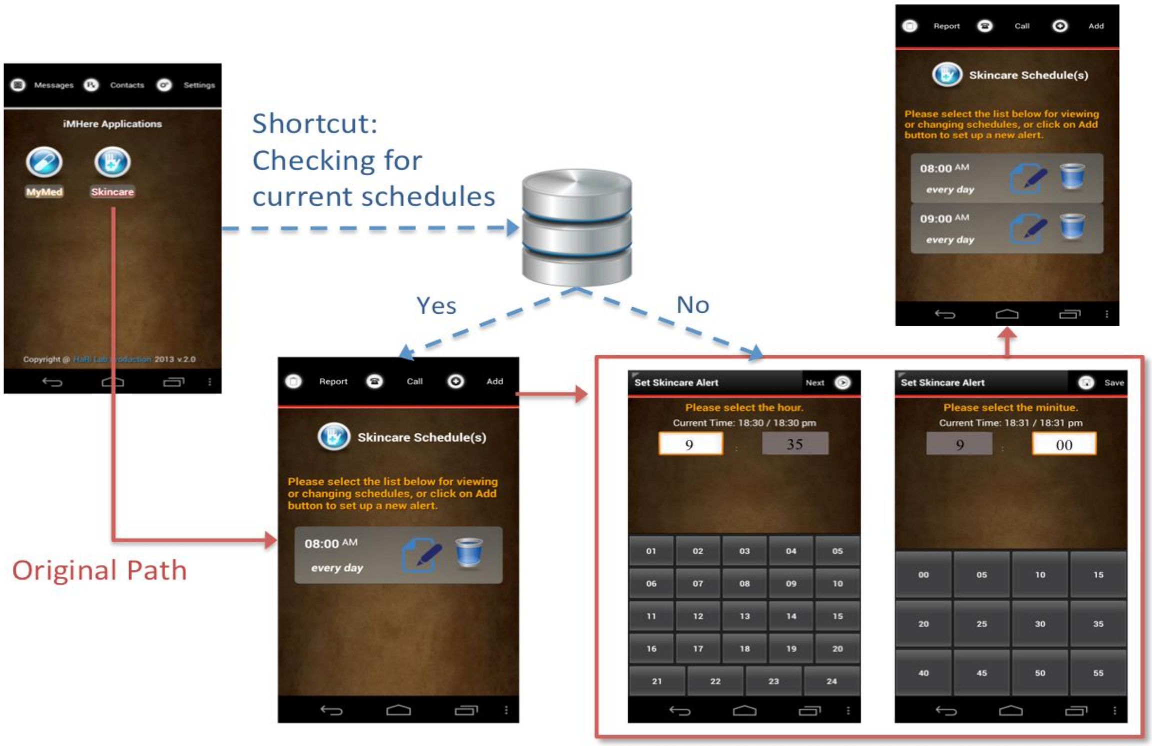


Figure 33. Navigation for Scheduling a Skin Check

c) As shown in Figure 34, three options were listed in the alert screen for a user to respond to a skin checkup alert. A user could report to say no problem identified, to add a newly affected skin area, or to update the condition of an existing problem. If a user selected to add a new record, he/she would be directed to the screen with a body part image to indicate the location. If a user chose to update the condition of the existing problems, he/she would see the list of affected skin areas; then, the user could select the particular problem and continue with the steps to track/update the changes.

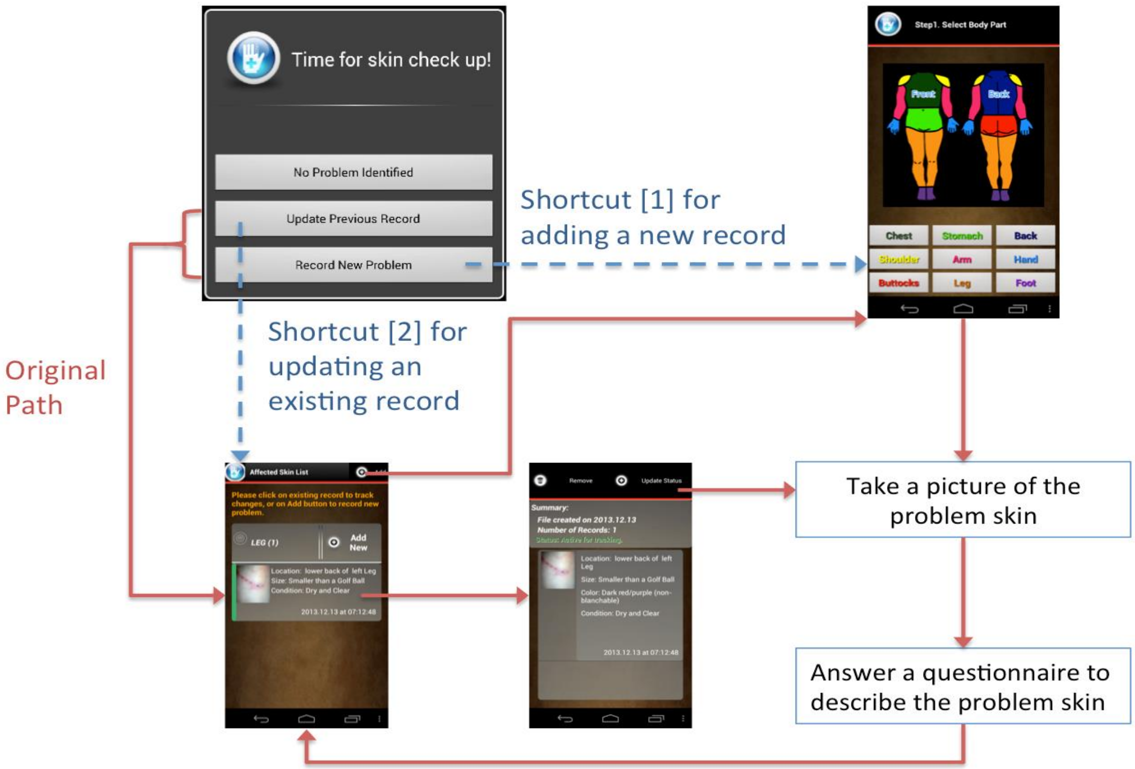


Figure 34. Navigation for Reporting a Skin Problem

In addition to the abovementioned features, several strategies were also implemented to improve users' experience with iMHere apps. First, because text entry with small and tight keys on a smartphone could be an arduous activity for users, especially for persons with higher level of dexterity impairments, multiple/single choice questions were utilized in the accessible apps to reduce the burden of typing on a smartphone screen. For example, a list of reasons to take a medication and the directions for intake were provided on the small screen (Figure 35). All participants found it was easy to make a selection rather than enter long lines of text. However, text entry should always be an option in the list if a user selects "other" and wants to answer in more detail.

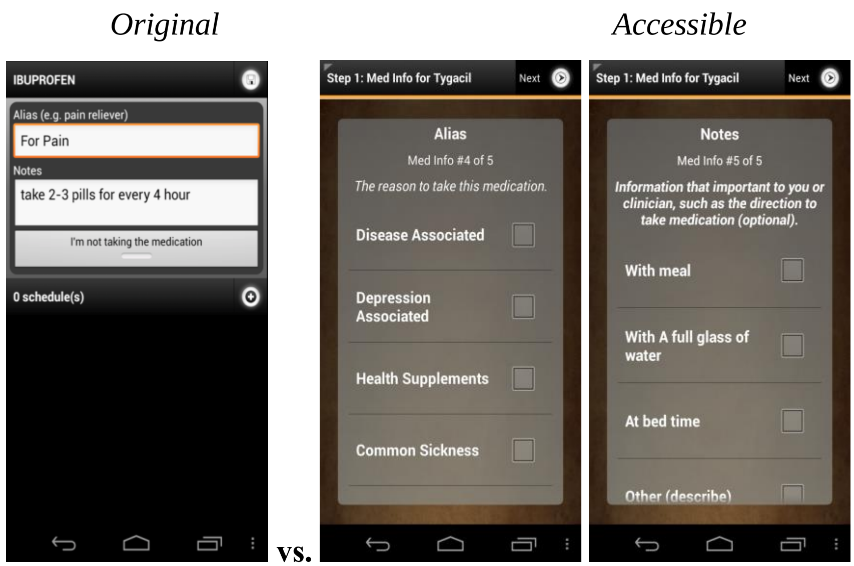


Figure 35. Strategy to Eliminate Text Entry

Second, the volume button was reassigned as the camera button. Participants indicated this change would be especially helpful when the skin problem being photographed was located in an inconvenient area. Participant 8 was not able to use a smartphone to take pictures because a severe level of dexterity impairments; the family member that helped him by taking the pictures, however, also preferred the physical button rather than the in-screen button for taking pictures.

Third, a self-directed questionnaire was utilized in the redesigned apps to simplify the cognitive procedures of tasks. The example shown in Figure 36 illustrates the redesigned apps displayed one question at a time. Compared with the regular format used in the originally designed apps, each question in the accessible design had a larger display space. Moreover, a short description (orange text) could be included in the small screen to help users to understand the question. The system automatically directs to the next question after a user makes a selection in a single-choice question. For multiple-choice questions or questions that require entering text, a user had to touch "Next" to continue. Generally, only 8 touches were needed for a user to complete the survey for recording a skin problem in the redesigned app. Because additional touches were required to enable options in drop-down list or pop-up windows, about 14 touches were required for a user to finish the same survey in the app as originally designed.

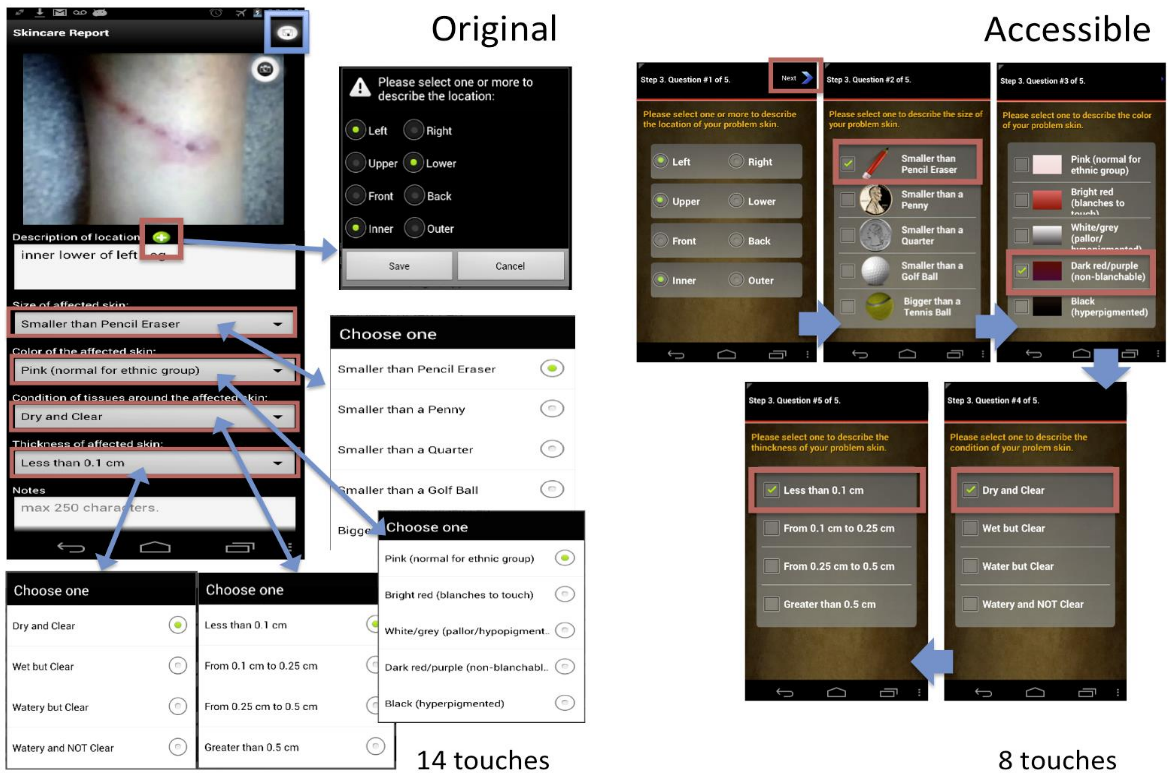


Figure 36. Regular Form Format vs. Self-Directed Service

Table 17. Comparison of the Total Numbers of Touches

Tasks	Original Apps	Redesigned Apps	Difference	Effort
Schedule med alert	20	11	-9	-45%
Modify med alert	9	6	-3	-33%
Respond to med alert	1	1	0	0%
Schedule a skin check	6	5	-1	-17%
Report a new skin problem	18	13	-5	-28%
Average	*11*	*7*	*-4*	*-25%*

Table 17 shows a comparison of the minimum number of touches for a user to complete tasks in the original and the redesigned apps. As explained in Chapter 5, scheduling a new medication and reporting newly affected skin were the most complicated tasks. More touches were required for a user to complete these two tasks whether using the original or the redesigned apps. At least 20 touches were needed for a user to schedule a new medication in the original app. This number dropped by about 45% to 11 touches using the redesigned app. About 18 touches were required for a user reporting a new skin problem in the original app; about 13 touches were needed to complete the task in the redesigned app, a reduction of about 28%. By eliminating the use of pop-up windows with options to modify or remove the selected medication or schedule, the effort for a user to modify a medication alert was reduced by about 33% to 6 touches.

Overall, a user's effort to complete tasks using the redesigned app was reduced by about 25% on average. A t-test was conducted to compare the minimum number of touches that required a user to complete individual tasks using the original apps and the redesigned apps. There was a marginally difference in the number of touches using the original apps ($M=8.04$, $SD=3.60$) and the redesigned apps ($M=4.82$, $SD=2.14$) conditions at the $p<0.09$ level; $t(4)=2.25$, $p=0.088$. Participants found the flow in the redesigned apps was easier to understand and to follow.

7.3.3 Usability Test Results

Six participants completed five tasks in the usability tests. Table 18 shows the average time in seconds for all participants to complete tasks. Regardless of the type of apps, they spent the most time on the tasks for scheduling a medication and reporting a new skin problem. Except task 3, participants' speed in completing other 4 tasks with the redesigned apps improved more than 56% over their speed when using the original iMHere apps. A paired t-test revealed a marginally significant difference between the average time to complete tasks ($n=5$) using the original apps

(M=5.86, s=0.396) and the redesigned apps at the p<0.06 level, M=91.7, SD=81.8, t(4)=2.64, p=0.057.

Table 18. Comparison of the Average Time to Complete Tasks

#	Tasks	Original Apps		Redesigned Apps		Time Difference	
		Avg. sec.	**SD**	**Avg. sec.**	**SD**	**Sec.**	**%**
1	Schedule Med Alert	203.2	122.8	89.2	49.5	-114.1	-56.1%
2	Modify Med	61.8	43.6	18.8	5.6	-43.0	-69.5%
3	Respond to Med Alert	2.9	1.4	2.7	1.0	-0.2	-7.7%
4	Schedule Skin Check	42.8	31.3	15.7	4.5	-27.1	-63.4%
5	Report New Skin	147.9	87.1	61.3	22.5	-86.6	-58.5%
	Average	*91.7*	*57.2*	*35.9*	*16.5*	*-54.2*	*-59.1%*

As shown in Table 18, one task only showed a small improvement in terms of time to complete: responding to a medication alert (7.7%). The speed in this case was very close because this task involved only a single click on the alert screen for both the original and redesigned apps. The main difference was that more detailed medication information was presented in the redesigned apps, with directional notes and images of the medication (pills or bottles). By using the redesigned app, participants were able to verify the pill or bottle with the image to assist them in taking the correct medication.

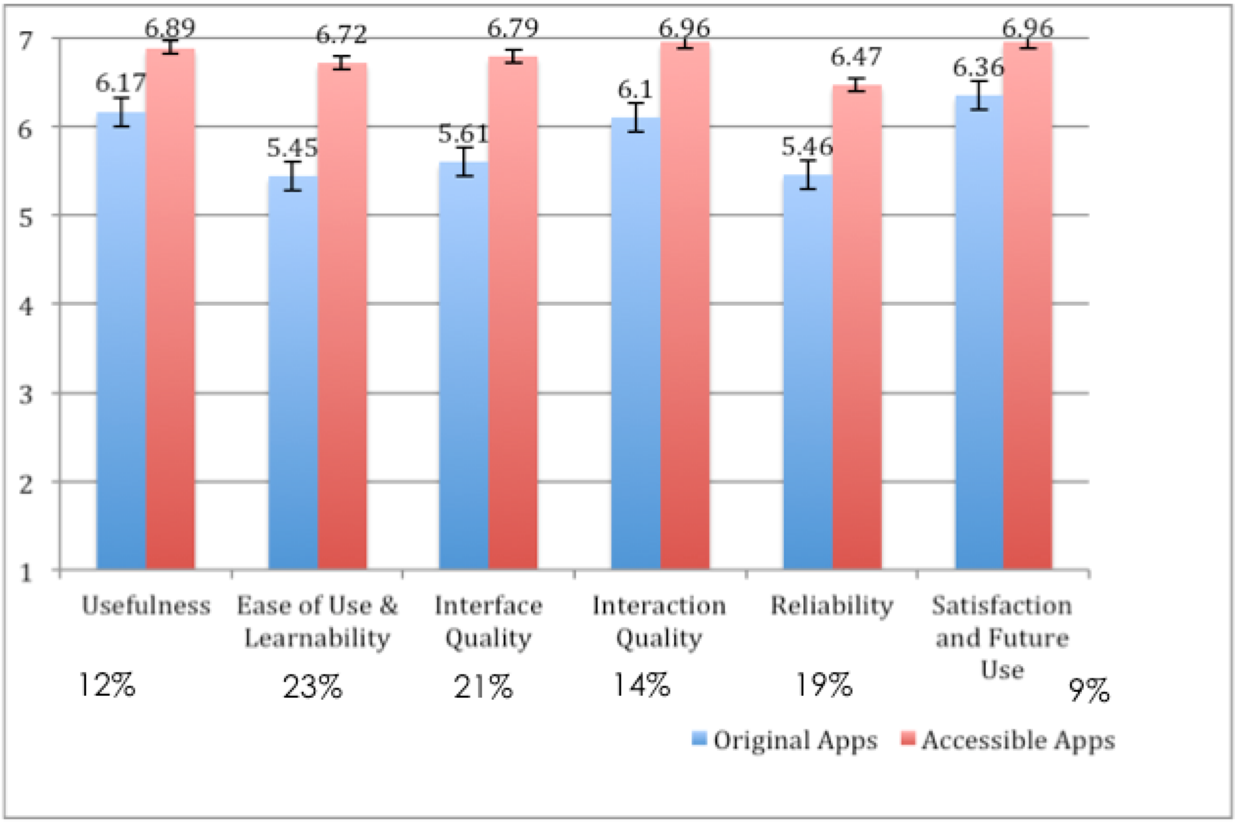


Figure 37. TUQ Factors & Scores

When comparing the average TUQ score from this study with that of study 1 (Chapter 6), users' satisfaction improved from 5.86 (out of 7 points) for the originally designed apps to 6.80 for the redesigned apps (Figure 37). Improvements are highlighted in the sections for "ease of use & learnability," "interface quality," and "reliability" (more than 15% improvements). An unequal variances t-test revealed a significant difference between the mean TUQ score from study 1 ($M=5.86$, $SD=0.396$) and this study ($M=6.80$, $SD=0.187$), $t(7.098)=-5.23$, $p<0.01$.

Table 19 shows the average time in seconds for each participant to complete tasks and their TUQ scores. A t-test was conducted to compare the TUQ scores in study 1 (original apps) and study 2 (redesigned apps). There was a significant difference in the TUQ scores for the original apps ($M=6.08$, $SD=0.42$) and the redesigned apps ($M=6.85$, $SD=0.16$) conditions; $t(5)=4.37$, $p=0.007$. A highly significant difference was also identified between the average time for users to complete tasks in the original apps (M=82, SD=29.34) and in the redesigned apps (M=35, SD=10.94); t(5)=-4.58, p=0.006. Using Pearson correlation, a positive correlation was found between the TUQ scores and the average time for each participant to complete tasks in the redesigned apps; this correlation was significant at the p<0.05 level, r=0.867, n=6, p=0.025.

Table 19. TUQ Scores and Average Time to Complete Tasks

		P01	P03	P04	P05	P07	P08
TUQ Score (SD)	Original	6.55 (0.69)	6.35 (0.88)	5.55 (0.89)	6.10 (0.72)	6.35 (0.49)	5.60 (1.14)
	Accessible	6.90 (0.31)	7.00 (0.00)	6.89 (0.32)	7.00 (0.00)	6.60 (0.50)	6.70 (0.47)
Avg. Time* (SD)	Original	127.20 (108.69)	68.40 (59.41)	79.40 (73.38)	104.00 (114.50)	44.60 (40.94)	66.60 (58.56)
	Accessible	33.50 (24.63)	38.00 (22.79)	38.83 (29.92)	53.00 (69.68)	22.17 (21.71)	26.50 (27.29)

** in seconds*

Table 20. Comparison of the Error Rates

Participant	Original Apps	Redesigned Apps
P01	7.17%	0.00%
P03	0.00%	0.00%
P04	16.08%	0.00%
P05	5.75%	0.00%
P07	10.00%	0.00%
P08	12.08%	0.00%
Average	8.51%	0.00%

As shown in Table 20, no mistakes were identified during the lab test in study 2 after one-week field trial. The error rate using the redesigned apps (M=0, SD=0; t(5)=3.76, p<0.02) was significantly decreased from that when using the original apps (M=8.51, SD=5.55).

7.4 DISCUSSION

Scores from the TUQ indicated that the redesigned apps developed in this study were viewed positively (6.80 out of 7 points, 97%). Users' satisfaction with using the redesigned apps showed a significant increase ($p<0.01$). Pronounced improvements were noted for the factors "ease of use & learnability" (5.45 on the original iMHere design vs. 6.72 on the redesigned apps), "interface quality" (5.61 vs. 6.79) and "reliability" (5.46 vs. 6.47). By utilizing the accessibility strategies related to physical presentation and navigation, the average time to complete the aforementioned tasks was reduced by about 60% in the redesigned apps.

Six out of 10 accessibility features (Section 7.3.1) were aimed to improve the quality of services through personalization. Those include the abilities 1) to select or hide apps from iMHere home screen, 2) to change text display size, 3) to change the theme of display, including background and text color, 4) to personalize the button size, 5) to use custom keyboard for text entry avoiding the switches between the QWERTY and numeric keypads, 6) to detect and provide shortcut for simplifying the cognitive process of tasks. The remaining four features and three accessibility strategies were related to improving the accessibility in general.

Besides the aforementioned, participant 8 liked the ideal of replacing text entry with multiple/single choice questions – "I have problems to enter text using stylus. Making a selection from the list is much easier." Except for participant 8, who was unable to hold a smartphone, all other participants liked being able to use the volume control button to take a picture. Additionally, participants 3, 4, 7, & 8 indicated the flow was easier to understand and to follow as a result of offering fewer functions on one screen and a self-directed questionnaire. Moreover, all the participants preferred expressed a preferences for having both text and voice guidance.

When we asked participants' preferences with regards to using the original or redesigned apps, all six participants expressed that they preferred to use the redesigned apps. However, a limited number of participants were involved in this redesign and development procedures. More participants with various levels of dexterity impairments will be included in the next study to verify user's acceptance and preference with respect to the redesigned apps.

8.0 STUDY 3: EVALUATION

8.1 INTRODUCTION

The overall goal of this study is to evaluate user's acceptance and preference with regards to the redesigned apps from study 2 for patients with dexterity impairments. As the smartphone becomes ubiquitous, mHealth is a viable technology to empower individuals to engage in preventive self-care.

The needs of accessibility for users with dexterity impairments to obtain access equal to those without disabilities were identified in study 1 using iMHere apps. Two of the most complicated apps in terms of steps to complete tasks were a focus of study 2. Those include MyMeds app for medication management, and SkinCare app for monitoring and reporting of skin breakdowns. In study 2, we approached the accessibility and usability through personalization of two primary layers of the user interface (UI): physical presentation and navigation. However, a limited number of participants were involved in the redesign and development procedures (study 2). More participants with various chronic conditions were included in this study (study 3). We expected that the personalized and accessible designs from study 2 are more accessible and usable for users with dexterity impairments ($Hypothesis_3$).

8.2 METHODS

8.2.1 Study Design

This descriptive and observational study concentrated on examining the accessibility of mHealth apps, including the original apps from the iMHere system and the redesigned apps from study 2. As with study 2, two of the most complicated apps were evaluated here:

- The MyMeds app requires the user to search for and find the correct medication, enter the reason for taking this medication, set up a medication schedule, and respond to medication reminder(s).
- The SkinCare app allows the user to set up skin checkup schedules, to respond to skin check reminders, and to record the affected skin.

The tests were conducted in a lab environment, either at the Department of Health Information Management or at a site of the subject's choosing, i.e., home or office. During the evaluation, participants were asked to spend approximately 120 minutes with both apps.

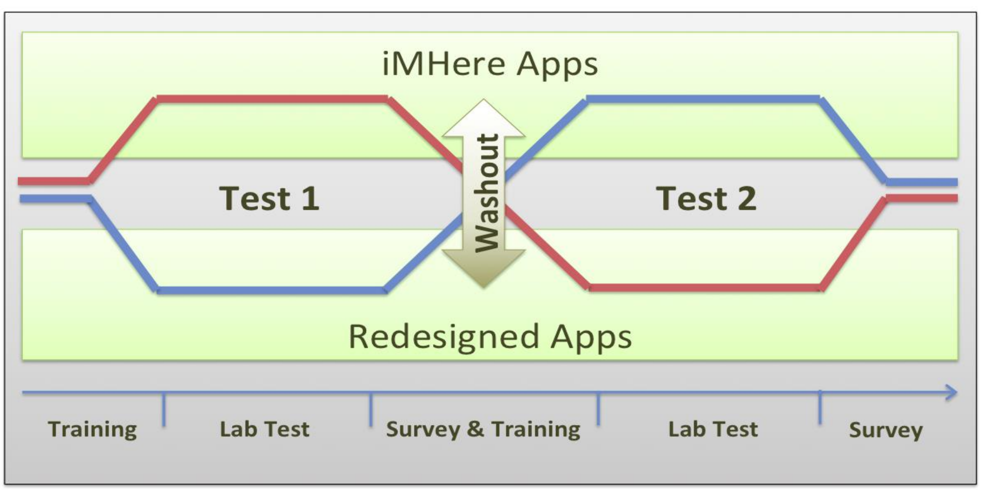


Figure 38. Cross-over Design

In order to compensate for the limited size of the subject pool and to control individual variability, a within-subject crossover design (Nielsen, 1994) was utilized in this study. This crossover design has been popularly used to evaluate the usability of systems (Bunker, 2005; Hackett, 2007; Saptono, 2011; Scotch, Parmanto, & Monaco, 2008; Zeng, 2004). Participants were randomly assigned to different arms of the test that use the original or redesigned apps (Figure 38). Because participants serve as their own matched control, this repeated measurement could yield a more efficient comparison of tests. The training time before the second test served as the washout period to minimize the carry-over effects.

Inclusion criteria were 18 to 64 years of age, has trouble moving or using their fingers, has the potential for skin breakdown, and uses at least one prescription or non-prescription medication. Exclusion criteria included vision, hearing, or speech problems that entirely precluded the use of a smartphone. The right+left+both score from the Purdue Pegboard Assessment (Lafayette Instrument) was collected to represents participants' dexterity levels.

8.2.2 Study Procedure

First, a background questionnaire (Appendix G) was collected from participants to gather their baseline information, such as their experiences with a mobile phone. Second, participants were asked to follow the steps below to complete study 3:

1) A face-to-face orientation was conducted after the questionnaire was filled out. Two (2) apps were introduced: the medication management app and the skincare app. The activities in the medication app include scheduling and responding to medication reminder(s). The activities in the skincare app include scheduling a daily alert for a skin checkup and recording skin problems. During the orientation, participants were trained to

perform the tasks for each of the apps. A trial medication bottle and a mock skin problem image were used in this training and for the tasks in next step.

2) Participants were asked to perform a set of tasks using the smartphone apps after the orientation. The think aloud method for product design and development (Lewis, 1982) was utilized here to gain comprehensive knowledge of participants' experiences, including their frustration. For instance, participants were asked to verbally describe their intentions and actions to the researcher as they performed the following tasks:

    - Task 1 – Schedule a new medication: participants had to locate the correct medication, add more information about their regimen such as their reason for taking the medication, and set up a reminder.
    - Task 2 – Modify a medication reminder: participants had to change the alert time for a medication.
    - Task 3 – Respond to a medication alert: participants had to indicate he/she took a medication.
    - Task 4 – Set up a schedule to check skin: participants were required to set a daily alert skin checkup.
    - Task 5 – Modify an alert for skin check: participants had to change the alert time for a medication.
    - Task 6 – Report a skin issue: participants were required to respond to reminders, take a picture, and fill out a form describing the affected skin, including location, color, size, depth, and tissue condition.
    - Task 7 – Update/track the change of an existing skin issue: participants were required to respond to reminders, take a picture, and fill out a form describing the affected

skin, including location, color, size, depth, and tissue condition.

- Task 8 – Setting personalized configurations for UI presentations: participants were asked to record a preferred apps list, the background, the reading size of text, and the target size for easier interaction. This task was only conducted for the redesigned app.

3) After the tasks, participants were asked to complete the modified TUQ (Appendix H) and Personal Preferences and Ease-of-use Questionnaire (Appendix J) to reveal their levels of preferences with regards to the accessibility features and the ease-of use for regards to specific tasks.

Participants had to repeat the abovementioned step 1 – 3 for testing the apps with different designs. Task 8 for configuring personalized settings was only performed when a participant was testing the redesigned apps. By using the crossover design, participants were blind to the type of design they were testing. The data instruments collected during these tests are described next.

8.2.3 Measurements

A mixed-method of qualitative and quantitative research in the form of a descriptive study was conducted to examine the individuals' preferences in terms of the usability and accessibility of mHealth apps. Quantitative data, particularly, was collected from participants' performances using the following measurements:

- *Time to complete each task.* The time for a participant to complete each task was measured to compare the efficiency of different designs.
- *Number of mistakes, error rate & success rate.* Possible mistakes were identified

when a participant has a problem to finish a task. Error rate was calculated as the sum of mistakes divided by the total steps to complete a task. The task completion success rate was calculated as 1- error rate.

- *Mistake recovery.* Step-by-Step Observation Notes (Appendix F) was used in study 3 to record the status of mistake recoveries, i.e., whether the participant was able or not able to correct the mistake. The corresponding weights were added to describe the difficulty-on-performance (DP) for a participant for mistake recovering: 1—solved the problem without any help; 2—needed help in one sentence; 3—needed help in two to four sentences; 4—unable to solve the problem. As described in Chapter 6, the DP score was calculated as the sum of weighted scores. A lower DP score indicates better and easier performance on the task.

Additionally, qualitative data were collected before or after participants performed the tasks using the following surveys:

- *Background questionnaire.* This questionnaire was used to gather the baseline information of participants at the beginning of the tasks. As shown in Appendix G, the information collected included participants' demographic information, their experience with mobile phones, and their knowledge with of mHealth.
- *Telehealth Usability Questionnaire* (TUQ*).* Twenty-one questions from TUQ were modified to explore the usability issues for mHealth system (Appendix H) was collected after participants completed the tasks on the original or redesigned apps. The modified TUQ was aimed at obtaining a more comprehensive understanding of the factors of usefulness, ease of use and learnability, interface quality, interaction quality, reliability, satisfaction and future use (Parmanto et al., 2010). A seven-point

likert scale was used in TUQ with the value of one (1) as least usable and seven (7) as most usable.

- *Personal Preferences and Ease-of-use Questionnaire.* As shown in Appendix I, this questionnaire was collected after participants completed the tasks on the original or redesigned apps. The participant had to indicate how easy or difficult each task was to perform. Additionally, for the ten accessibility features implemented in the redesigned apps, participants were asked to indicate the importance of each feature to the accessibility. The value of one (1) meant most important to them and ten (10) was lest important to them.

In general, the abovementioned quantitative data were used to assess the efficiency and effectiveness of the different designs for participants to complete tasks. The qualitative data collected from the surveys were more related to exploring participants' satisfaction and their preferences with respect to using mHealth apps. We compared the results of the quantitative and qualitative data of participants' performances for both the original and redesigned apps in order to explore the efficiency of the design.

8.2.4 Statistical Analysis

The sum and average times to complete tasks were utilized to measure participants' performance. Standard deviation was calculated to reveal the dispersion patterns of the abovementioned variables. An unequal variances t-test was utilized to explore the difference in the time for completing all tasks using the original iMHere and the redesigned apps from study 2. Pearson's Correlation Coefficient (PCC) was utilized to measure a linear association between the individual-based TUQ scores and the error rate encountered by each participant.

8.3 RESULTS

A total of 28 participants were recruited from Pittsburgh, PA and the surrounding areas (Figure 39). Using the binomial probability formula (Sauro, 2011), the sample size needed is based on the change of seeing the problem and its occurrence: *sample size = log (1-chance of detecting) / log (1-probability of occurring).* Since the sample size of 22 participants gives us a 90% chance to identify problems that impact 10% or more of the users (Sauro, 2004), 28 participants can be considered sufficient for discovering usability problems for persons with dexterity impairments.

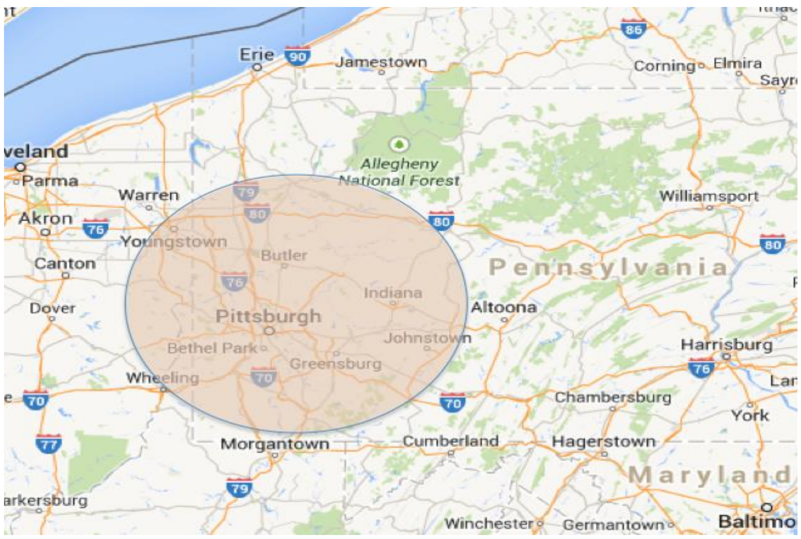


Figure 39. Coverage Areas for This Study

Three out of the 28 participants were not qualified to participate. The first participant was a blind user. The second participant's pegboard assessment score was higher than the general mean of factory workers. The third participant could not use a smartphone because of too severe dexterity and vision limitations. Additionally, one participant decided to drop out because of her busy schedule at the beginning of study 3. As a result, 24 participants (8 females and 16 males) completed this study. Their ages ranged from 18 to 64 years, with an average of 28 years (SD=6.28).

8.3.1 Background of Participants

As shown in Table 21, 14 of the 24 participants were persons with SB (58.33%); five were persons with SCI (20.83%); and five (21%) were persons with other types of chronic conditions, such as CP (3 participants), MD (1 participants) and Cerebellum Atrophy[6] (CA, 1 participant). Twenty-two out of 24 participants were right-hand dominant (88%). All participants except for participants 1, 4 & 23 were smartphone users. About 83% (n=20) of the participants spent more than 60 minutes on a smartphone daily. Five participants (about 21%) finished graduate study. Two participants (8%) were in college education. All other participants (n=17, about 71%) received high school or equivalent education.

[6] Cerebellar atrophy is a degeneration of the cerebellum, a section of the brain responsible for balance, voluntary muscle movements, and posture. People with damage to the cerebellum can experience poor muscle control, and trouble speaking or swallowing (wiseGeek).

Table 21. Background of Participants

#	Age	Gender	Highest Education	Chronic Condition	Regular vs. Smart phone	Physical vs. Touch Keypad	Years of use	Daily Usage (in minutes)	Participated in prior studies
P01	36	F	Graduate	SB	R	Physical	<2	>60	Yes
P02	25	F	College	SB	S	Touch	>5	>60	No
P03	27	M	High Sch.	SB	S	Touch	3-5	<30	Yes
P04	25	M	High Sch.	CP	No	No	0	0	No
P05	20	M	High Sch.	SB	S	Touch	>5	>60	Yes
P06	25	M	High Sch.	SB	S	Touch	3-5	>60	Yes
P07	33	F	High Sch.	SB	S	Touch	<2	>60	No
P08	33	F	High Sch.	SB	S	Touch	<2	>60	No
P09	37	M	High Sch.	CP	S	Touch	<2	>60	No
P10	25	M	High Sch.	SB	S	Touch	>5	>60	No
P11	23	M	High Sch.	SB	S	Touch	<2	>60	No
P12	19	M	High Sch.	SB	S	Touch	<2	>60	No
P13	32	M	High Sch.	SB	S	Touch	<1	>60	No
P14	23	F	High Sch.	CA	S	Touch	<2	>60	No
P15	28	F	High Sch.	SB	S	Touch	>5	>60	Yes
P16	23	M	High Sch.	SCI	S	Touch	3-5	30-60	No
P17	30	F	Graduate	MD	S	Touch	>5	>60	No
P18	31	F	Graduate	SCI	S	Touch	>5	>60	No
P19	31	M	Graduate	SCI	S	Touch	>5	>60	No
P20	33	F	High Sch.	CP	S	Touch	3-5	>60	No
P21	28	M	High Sch.	SB	S	Touch	0-2	>60	No
P22	36	M	High Sch.	SCI	S	Touch	0-2	>60	No
P23	22	M	College	SB	R	Touch	0-2	>60	Yes
P24	28	M	Graduate	SB	S	Touch	>5	30-60	Yes

Seven of the 24 participants (about 29%) had tested the original and/or redesigned apps in prior studies (study 1 and/or 2). However, as mentioned above, they had stopped using our mHealth apps for at least four months before participating in this study to minimize the learning effects that might carry over from their previous experiences. Participants 1, 3, 6 & 15 remembered around 5% of the process in the original apps from study 1 and about 10 % of the redesigned apps from study 2. Participants 5, 23 & 24 had completely forgotten how to use these apps. All of the other participants (about 71%) were new to our mHealth apps.

8.3.2 Dexterity Levels

As shown in Table 22, all of the participants' Pegboard assessment scores (right+left+both hand test) were -1SD below the 46.76 generic mean of factory workers (M=25.30, SD=15.53). Based on their scores, participants were categorized into the following three groups reflecting their dexterity levels:

- Group 1, those with mild dexterity issues: the 8 participants in this group had scores for the right+left+both tests ranging from -1SD to -3SD below the generic mean of factory workers (score: 42.72 – 34.46).
- Group 2, those with moderate dexterity issues: the 12 participants in this group were able to complete the pegboard assessment test, but their scores were -3 SD below the generic mean of factory workers (score < 34.46).
- Group 3, those with severe dexterity issues: the 5 participants in this group were not able to perform the pegboard assessment test (score = 0) because of their difficulty picking up small objects.

Table 22. Results for Purdue Pegboard Assessment Test

PARTIC	Right Hand Mean=17.15 -1SD=15.36 -3SD=11.76	Left Hand Mean=16.01 -1SD=14.31 -3SD=10.91	Both Hands Mean=13.37 -1SD=14.31 -3SD=10.91	R+L+Both Mean=46.76 -1SD=42.72 -3SD=34.46	Group #
P01	9	9	15	33	2
P02	12	9	15	36	1
P03	0	0	0	0	3
P04	0	0	0	0	3
P05	5	9	10	24	2
P06	10	10	16	36	1
P07	12	13	17	42	1
P08	7	9	14	30	2
P09	0	0	0	0	3
P10	10	10	19	40	1
P11	10	11	11	32	2
P12	8	12	13	33	2
P13	11	12	19	42	1
P14	3	4	3	10	2
P15	11	8	10	28	2
P16	0	0	0	0	3
P17	5.3	7	9	22	2
P18	3	4	3	10	2
P19	13	13	16	42	1
P20	7	0	0	7	2
P21	9	10	13	32	2
P22	9	11	18	38	1
P23	12	13	14	38	2
P24	0	0	0	0	3
Average (SD)	7.40 (4.97)	6.78 (4.38)	9.79 (7.09)	23.94 (15.96)	

The results collected from the participants' studies were analyzed from the perspective of usability that include efficiency, effectiveness and satisfaction (Dix, 2009). This group-based analysis is used in the following section to explore and compare the efficiency of task completion.

8.3.3 Efficiency

Each participant completed 15 tasks including seven tasks on the original apps and eight tasks on the redesigned apps. Using the crossover study design, 12 participants (50%) tested the original iMHere apps first, then the redesigned apps. Twelve (12) participants tested the redesigned apps first and then the original ones. About 15 minutes was allotted for training and practicing time before the second test to serve as the washout period. Since task 8 for configuring a personalized setting was only performed when using the redesigned apps, task 8 was excluded in the following comparison of time to complete tasks.

Table 23 shows the average time in seconds for all participants to complete tasks 1 – 7 using the different apps. The average time for the 24 participants to complete tasks 1 – 7 in the original apps was about 48 seconds (Table 24). This time dropped by 35% to 31 seconds using the redesigned apps. Their speed in completing the tasks for scheduling and modifying a medication, scheduling a skin check and reporting a new skin problem with the redesigned apps improved more than 30% over their speed using the original apps. According to the t-test, there was a significant difference in the time for the 24 participants to complete tasks using the original ($M=48.37$, $SD=38.87$) and the redesigned apps ($M=31.27$, $SD=23.92$); $t(167)=10.33$, $p<0.001$, $n=24$ participants x 7 tasks = 168.

Table 23. Comparison of the average time to complete tasks

Tasks	Original Apps		Redesigned Apps		Time Difference	
	Avg. sec.	SD	Avg. sec.	SD	Sec.	%
Schedule a medication alert	110.54	36.11	68.88	21.35	-40.7	-37.14%
Modify a medication alert	39.62	15.63	25.14	11.31	-13.92	-35.64%
Respond to a medication alert	4.21	3.23	4.29	2.96	-0.08	1.90%
Schedule skin check	25.26	10.91	16.73	6.46	-8.53	-33.77%
Modify a skincare alert	21.78	9.26	16.47	9.75	-5.31	-24.38%
Report a new skin problem	81.17	18.41	48.51	11.57	-32.66	-40.24%
Track the changes	56.01	15.06	38.85	10.79	-16.62	-29.96%
Average	*48.37*	*15.52*	*31.27*	*10.60*	*-17.05*	*-34.96%*

Table 24. Group comparison of the average time to complete tasks

Tasks	Original Apps		Redesigned Apps		Time Difference	
	Average (in sec.)	SD	Average (in sec.)	SD	Seconds	%
Group 1	44.55	8.00	30.69	5.74	-13.87	-31.12%
Group 2	47.87	11.39	28.77	6.49	-19.11	-39.91%
Group 3	54.90	14.15	32.82	11.44	-22.08	-40.22%
Average	49.11	5.28	30.76	2.03	-18.35	-37.37 %

As shown in Table 24, participants with severe dexterity issues, those from group 3, needed 55 seconds on average to complete the tasks using the original apps. Their time to complete tasks improved about 40% using the redesigned apps (22 seconds), which was the largest improvement among three groups. The speed of participants with mild (group 1) and moderate dexterity impairments (group 2) to complete these tasks with the redesigned apps improved more than 30%. There was a significant time difference was found when comparing the three groups of participants with respect to complete tasks at the $p<0.02$ level; $t(2)=7.64$, $p=0.017$.

The activities in task 8 for configuring a personalized setting include choosing which app participants wish to use, changing the background and text color, changing the text display size and choosing the button/target size. About 36 seconds (SD=9.00) on average was needed for participants to complete this task. Specifically, participants with mild dexterity issues (Group 1) spent 32.78 seconds (SD=7.07) to finish the abovementioned activities in task 8. Participants with moderate (Group 2) and severe (Group 3) dexterity issues spent 34.38 and 42.19 seconds to complete the same activities (SD=9.98 vs. SD=6.67), respectively. According to an ANOVA, no significant time difference was found when comparing the three groups of participants with respect to configuring personalized settings at the $p>0.05$ level, $F(2, 21)=1.94$, $p=0.17$.

As mentioned above, both experienced and inexperienced users were included in this study. The overall average time in seconds for each group of participants to complete tasks using the original and redesigned apps are shown in Table 25. According to a paired t-test, no significant difference in time was identified between the experienced (N=7, M=49.00, SD=36.59) and inexperienced participants (N=17, M=47.95, SD=37.35) when using the original apps at the $p>0.05$ level, $t(6)=0.76$, $p=0.48$. In addition, no significant difference in time was identified between the experienced (N=7, M=31.57, SD=23.80) and inexperienced participants (N=17, M=31.14, SD=21.65) when using the redesigned apps at the $p>0.05$ level, $t(6)=0.29$, $p=0.78$. After the four-month washout period, the experienced participants might not benefit from their prior experiences in terms of time efficiency.

Table 25. Comparing the average time for experienced and inexperienced participants

Tasks	Original Apps		Redesigned Apps	
	Experienced (SD)	Inexperienced (SD)	Experienced (SD)	Inexperienced (SD)
1. Schedule a medication alert	109.04 (49.15)	111.16 (31.85)	74.09 (36.49)	66.73 (15.84)
2. Modify a medication alert	46.05 (19.48)	36.98 (12.85)	21.40 (12.08)	26.68 (12.08)
3. Respond to a medication alert	4.17 (1.64)	4.23 (1.64)	3.86 (1.25)	4.46 (3.35)
4. Schedule skin check	25.43 (15.76)	25.19 (9.38)	16.45 (7.11)	16.85 (6.57)
5. Modify a skincare alert	21.19 (10.06)	22.02 (9.52)	18.35 (13.10)	15.69 (7.98)
6. Report a new skin problem	81.12 (17.82)	81.19 (18.15)	47.64 (12.74)	48.86 (12.01)
7. Track the changes	56.02 (15.21)	54.90 (17.82)	39.19 (9.16)	38.71 (11.99)

8.3.4 Effectiveness

The effectiveness of performance was measured by examining the steps to complete the task, number of mistakes made, the error rate, and mistake recovery. Mistake recovery was identified as the ability of participants to overcome mistakes and to complete the tasks. Figure 40 shows the average steps for each participant required completing tasks 1 – 7 when using both the original and the redesigned apps. At least 68 steps (15+8+1+6+7+20+11) were required for a participant to complete task 1 – 7 using the original apps. This number dropped about 25% to 49 steps (11+6+1+5+5+13+8) using the redesigned apps. Regardless of the type of app, more steps were required for scheduling a medication and reporting a new skin problem. A t-test revealed that the steps for a participant to complete tasks in the original (M=9.71, SD=6.26) and the redesigned apps (M=7.00, SD=4.04) were significantly different at the $p<0.03$ level, $t(6)=3.14$, $p=0.02$.

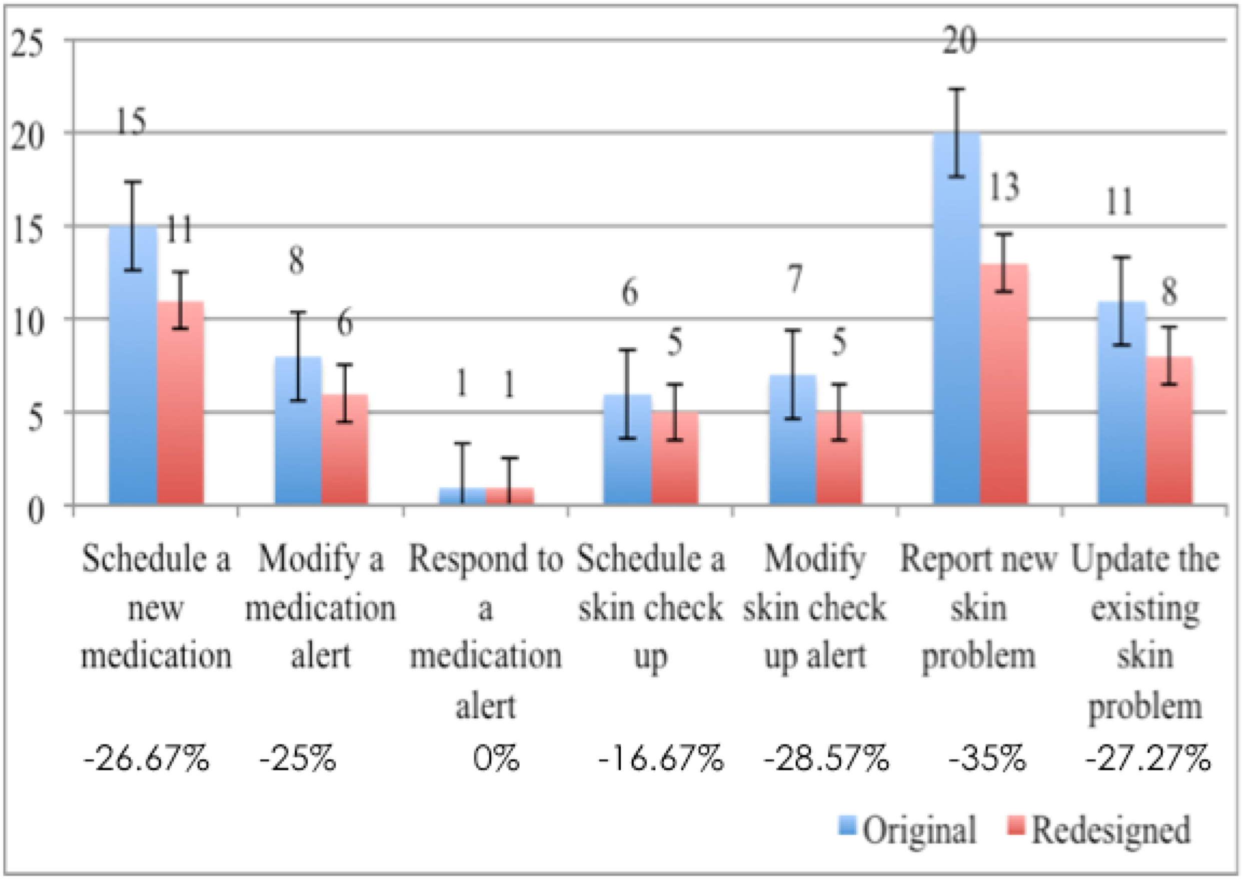


Figure 40. Number of steps for participants to complete tasks

Table 26 shows the total number of steps for participants to complete tasks, the total number of mistakes that confronted the participants, the calculated error rate and the total DP score recorded when all participants performed tasks 1 – 7. As the table shows, the error rate for participants to complete tasks 1-7 using the original apps was about 6%. This number dropped to 1% using redesigned apps. According to the t-test, this difference was significant at the $p<0.05$ level; $t(6)=2.71$, $p=0.035$.

Table 26. Comparison of total steps, mistakes, and error rate

Tasks	Original Apps				Redesigned Apps			
	Total Steps	Total Mistakes	Error Rate	Total DP	Total Steps	Total Mistakes	Error Rate	Total DP
Schedule a new medication	360	32	9.28%	69	264	4	1.52%	8
Modify a medication alert	192	21	10.87%	41	144	2	1.39%	4
Respond to a medication alert	24	0	0.00%	0	24	0	0.00%	0
Schedule a skin check	144	5	2.90%	9	120	0	0.00%	0
Modify skin check alert	168	6	3.11%	12	120	3	2.50%	5
Report new skin problem	480	13	2.61%	21	312	4	1.28%	8
Update the existing skin problem	264	16	5.93%	36	192	3	1.56%	5
Total	*1632*	*93*	*5.70%*	*188*	*1176*	*16*	*1.36%*	*30*

Specifically, 93 total mistakes were identified throughout the participants' tests using the original apps. Thirty-two of these mistakes (34.41%) occurred when participants tried to schedule a new medication. Twenty-one mistakes (22.58%) were associated with the task of modifying a medication alert. Sixteen mistakes (17.20%) were found for updating the condition of an existing skin problem. Thirteen mistakes (13.98%) were related to report a new skin problem. Six mistakes (6.45%) were associated with the task to modify a skin check alert and 5 mistakes (5.38%) were identified when scheduling a skin check. No mistakes were identified when participants responded to a medication alert.

Sixteen (16) mistakes, on the other hand, were identified when participants used the redesigned apps (Table 26), with an 82.80% drop rate. Four (25%) mistakes were associated with the task of scheduling a new medication. Two mistakes (12.5%) occurred when participants tried to modify a medication alert. Ten mistakes (62.5%) occurred related to the activities on SkinCare app: 3 mistakes when participants tried to modify a skin check alert, 4 when they reported a new skin problem, and 3 when they updated the condition of an existing skin problem. No mistakes were identified using the redesigned apps for the tasks of responding to a medication alert, scheduling a skin check, or configuring personalized settings. The total number of mistakes for participants to complete tasks 1 – 7 using the redesigned apps (M=0.63, SD=1.13) was significantly lower than for the original apps (M=3.88, SD=2.66) at $p<0.001$ level; $t(23)=6.352$, $p=0.000$.

The DP scores were also calculated for each task to describe the difficulty-on-performance (DP) preceding task completions (Table 26). The total DP score for participants to complete tasks 1 – 7 using the redesigned apps (M=4.29, SD=3.30) was significantly lower than that for the original apps (M=26.86, SD=23.65) at $p<0.05$ level; $t(6)=2.77$, $p=0.032$. This difference was more significant when analyzing at the individual level for using the original apps (M=7.71, SD=5.90) and the redesigned apps (M=1.17, SD=2.33), $t(23)=6.193$, $p<0.001$.

Moreover, the success rate was calculated as the opposite of the error rate. The overall success rate for participants to complete tasks 1 – 7 was 94.30% using the original apps and 98.64% using the redesigned apps. Though the success rate on average for participants to complete tasks in both apps was around 95%, the quality of performance varied for each of the tasks, as described below:

<u>Task 1) Schedule a new medication</u>: The success rate for completing task 1 was improved from 91.11% when using the original app to 98.48% when using the redesigned app.

a) Original apps – About 21% (n=5) of participants were able to complete task 1 using the original app without mistakes. Problems that confronted the other participants were identified during the following activities:

- Six participants experienced problems in locating the plus symbol for adding a new medication. Participant 12 and 23 were able to self-correct this issue without any assistance from the researcher (DP=1). Participants 4, 5, and 14 received one sentence of assistance in order to correct the mistake (DP=2). Participant 22, however, needed assistance in two sentences (DP=3).
- Four participants saved a medication without scheduling an alert. Participants 7 was able to self-correct the mistake with one sentence assistance (DP=2). Participants 2, 19 and 20 received a two-sentence reminder (D=3).
- Seven participants experienced problems in locating the plus symbol for adding a new schedule. Participant 13 was able to self-correct the problem without any help from the researcher (DP=1). Participants 17, 18, 21 & 23 received one sentence of assistance from the researcher (DP=2). Participants 4 & 22 needed assistance in two sentences to solve the problem (DP=3).
- Thirteen participants forgot to save an alias & notes for completing the task to schedule a new medication. Participants 5, 13 & 17 were able to self-correct the mistakes without any assistance (DP=1). Participants 2, 4, 6, 12, 14, 21, 22 & 23 received one-sentence assistance (D=2). Participants 3 & 8 were able to self-correct this issue with assistance in two sentences (DP=1).
- The researcher reminded participant 8 in two sentences to select a medication from the medication list that showed on the smartphone screen (DP=2).

b) Redesigned apps – About 83% (n=20) participants were able to complete this task without mistakes. The remaining four participants (P4, P9, P12 & P18) made one mistake while trying to schedule a new medication alert, but they were able to finish the task with one sentence assistance (DP = 2). The primary reason assistance was needed was their lack of familiarity with the app. By default, the apps automatically go to the next question when a participant makes a selection for a single-choice question. However, they have to click the "next" button for a multiple-choice question or a question that requires text entry.

Task 2) Modify a medication alert: The success rate for completing task 2 improved from 89.06% using the original app to 98.61% using the redesigned app.

a) Original apps – About 41.67% (n=10) of participants completed this task without mistakes. The mistakes that confronted the other participants were identified in the following activities:

- Seven participants were reminded to click on the existing record to modify the alert. Participant 23 was able to self-correct this mistake without any assistance (DP=1). Participants 4, 16, 20 & 22 were able to correct this mistake with one-sentence assistance (DP score = 2). Participants 5 & 23 required more assistance from the researcher (DP=3).
- Participants 3 & 5 forgot to save the time after modifying the alert time, but these participants were able to correct the mistake with one-sentence assistance (DP=2).
- Eleven participants forgot to save an alias and notes for completing the task to schedule a new medication. Participants 5, 13 & 15 were able to self-correct the mistakes without any help (DP=1). All of the others (participants 2, 3, 4, 10, 11,

14, 18 & 23) were able to correct the mistake with assistance in one sentence (DP=2).

- Participant 19 was reminded in one sentence to close the keypad to see the schedule list (DP=2).

b) Redesigned apps – About 92% (n=22) of participants were able to complete this task without any mistakes. Participants 4 & 22 tried to add a new schedule rather than change the time of the existing alert. The researcher reminded them that this task was to modify an existing alert (DP score = 2).

Task 3) Respond to a medication alert: Only one click was required to complete this task both in the original and the redesigned apps. Though all participants were able to complete it without any mistakes (success rate=100%), participants indicated that they liked to view a photo of the pill and the directional notes for how to take the medication in an alert in the redesigned app.

Task 4) Schedule a skin check: The success rate for completing task 4 using the redesigned app was 100%. This number is an increase over the 96.53% success rate of participants when using the original app. Nineteen subjects (about 79.17%) were able to complete task 4 without any errors in the original apps. Participants 1 & 3 were reminded to save the alert in one sentence (DP=2). Participant 2 clicked on the existing schedule instead of creating a new one, but she realized the mistake and self-corrected it without assistance (DP=1). Participant 4 & 15 forgot how to add a new schedule for a skin check; however, he was able to self-correct after one-sentence assistance (DP=2).

Task 5) Modify a skin check-up alert: The success rate for completing task 5 improved from 96.43% using the original app to 97.50% using the redesigned app.

a) Original apps – Eighteen participants (about 75%) were able to complete task 5 in the original app without mistakes. The common mistakes include the following:

- Participants 1, 8 &15 were reminded to save after modifying the alert time with assistance in one sentence (DP=2).
- Participants 3 & 14 clicked on the wrong area to modify the existing alert; however participant 3 self-corrected the mistake without any assistance (DP = 1). Participant 13 was able to correct the mistake with one-sentence assistance (DP=2).
- Participant 4 was reminded to modify an existing alert in the SkinCare app with two sentences of assistance (DP = 3).

b) Redesigned apps: About 88% (n=21) participants were able to complete this task in the redesigned app without any assistance. The three others tried to edit an alert by clicking on the time of the alert rather than the edit icon. Participant 11 was able to self-correct without any assistance (DP score = 1). Participants 4 & 20 received assistance in one sentence to resolve the issue (DP score = 2).

<u>Task 6) Report a new skin problem</u>: The success rate for completing this task improved from 97.29% with the original app to 98.72% with the redesigned app.

a) Original apps – Fifteen participants (about 62.5%) were able to complete task 6 in the original app without mistakes. Common mistakes include:

- Five participants forgot to click on the plus sign to add a new record. Participants 10, 12 & 19 were able to self-notice and self-correct the mistake without any assistance (DP=1). Participants 4 & 22 were able solve the mistake with one-sentence assistance (DP=2).

- Four participants saved the skincare record without responding to a survey. Participants 17 & 22 self-noticed and corrected without any help. Participants 4 & 21 received four sentences in reminder from the researcher (DP=3).
- Participant 4 forgot to save after answering the survey but was able to self-correct without any assistance (DP=0).
- Participants 5 & 17 forgot to use the help button to specify the location of the problem skin. Participant 17 self-noticed and used the help button to expand the selection to describe location (DP=1). Participant 5 was reminded in one sentence (DP=2).

b) Redesigned apps – About 88% participants (n=21) were able to complete task 6 without any mistake in the redesigned app.

- Participant 4 was reminded to add a new record in the SkinCare app in two sentences (DP=3).
- Three participants forgot to click the "next" button to continue when they finished answering multiple-choice questions. Participant 11 self-corrected without any assistance (DP=1). Participants 17 & 22 received assistance from the researcher related to the "next" button (DP score = 2).

<u>Task 7) Update an existing skin problem:</u> The success rate for task 7 was about 94.3% for the original app and 98.64% for the redesigned app.

a) Original apps: Twelve participants (52.17%) were able to complete this task without any mistakes. Common mistakes include the following:

- Four participants forgot this task was to update the condition of an existing problem. Participant 23 self-noticed and self-corrected without any assistance (DP=1). Participants 20, 21 & 22 were reminded in one sentence (DP=1).
- Eleven participants forgot to click on the plus sign to update the condition of the existing problem. Participant 8 self-corrected this mistake without any assistance (DP=1). Participants 2, 5, 9 10 & 23 were able to correct this mistake after one-sentence assistance (DP=2). Participants 1, 4, 15, 21 & 22 needed assistance in two sentences (DP=3).
- Participant 21 forgot to finish the survey after updating the picture of the problem skin (DP=3).

b) Redesigned apps: Twenty-one participants (about 87.50%) had no problem completing this task using the redesigned apps. Problems were identified in the following activities:
- Three participants forgot to click on the plus sign to update the condition of existing problem. However, participant 9 self-corrected without any assistance (DP=1). Participants 4 & 10 required a two-sentence reminder from the researcher (DP=3).

<u>Task 8) Configuring personalized settings</u>: The ability to configure personalized settings was only available in the redesigned apps. Since no mistakes were identified while participants completed this task, the success rate was 100%.

Overall, participants were able to self-correct 21 (22.58%) out of the 88 mistakes identified while they were using the original apps (DP=1). Fifty-two mistakes (55.91%) were corrected after assistance in one sentence (DP=2). The remaining 20 mistakes (about 21.51%)

received two sentences of assistance (DP=3). On the other hand, about 20% (n=3) of the 16 mistakes identified while participants were using the redesigned apps were self-corrected without any assistance (DP=1). Participants were able to correct about 73% (n=11) after one-sentence assistance from the researcher (DP=2). Participants were able to correct the one remaining mistake (about 7%) after two-sentence assistance (DP=3) using the redesigned apps.

8.3.5 Users' Satisfaction

8.3.5.1 TUQ

A TUQ was collected to assess participants' satisfaction with the original and the redesigned apps after completing the abovementioned tasks. Figure 41 shows the comparison of TUQ scores from each participant for the original and the redesigned apps. Overall on average, participants' satisfaction scores improved from 5.86 out of 7 points (SD=0.97, about 83%) for the original designed apps to 6.46 (SD=0.53) for the redesigned apps, a 10.24% improvement rate. Improvements are highest in the sections for "ease of use & learning" (17.32%), "interface quality" (12.30%), "interaction" (11.05%), and "reliability" (15%). The average TUQ scores over other sections, including "usefulness," "satisfaction and future use," also increased more than 7%. According to a paired-sample t-test, the difference in satisfaction levels for the six usability factors between the original and redesigned apps was significant at $p<0.001$ level; $t(5)=-9.08$, $p=0.000$.

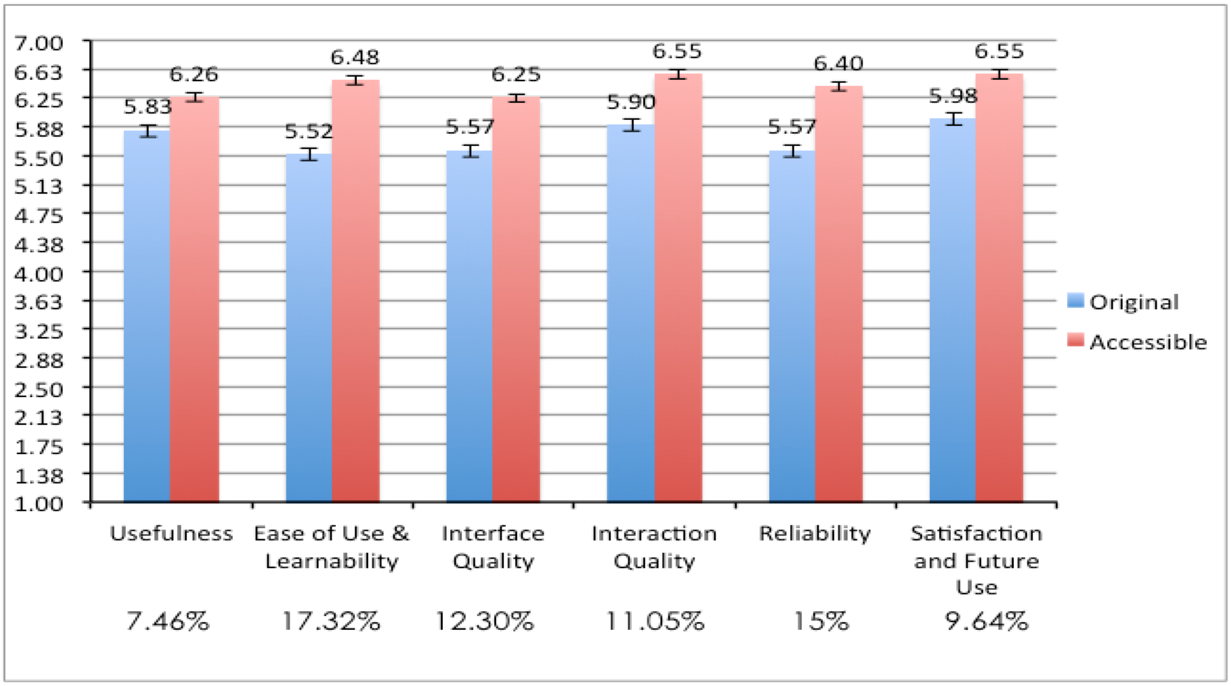


Figure 41. Comparison of TUQ factors and scores

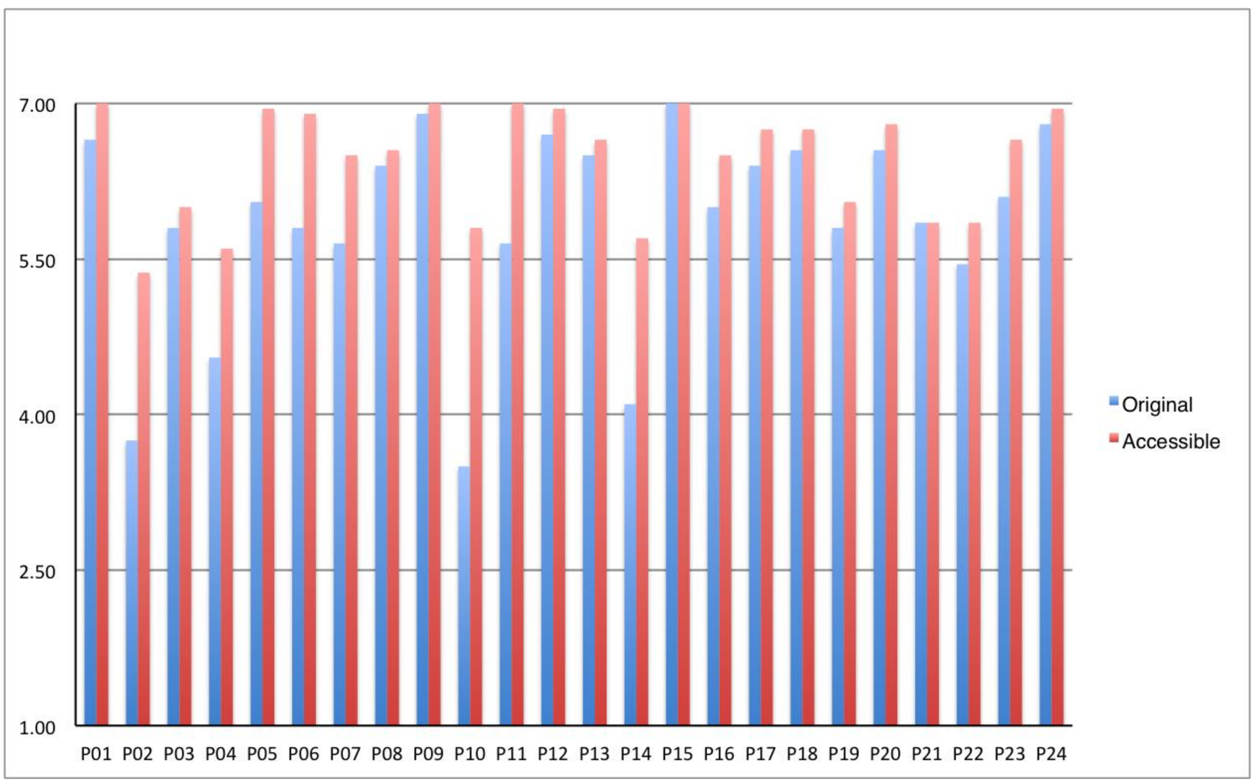


Figure 42. TUQ scores from participants

Figure 42 illustrates the overall average of TUQ scores for each of the 24 participants using the original and redesigned apps. Except for the participants 15 & 21 who had the same TUQ average score for both apps, all of the others gave higher scores for the redesigned apps. The difference of TUQ scores was highly significant between the original and redesigned apps at the $p<0.001$ level, $t(23)=-4.87$, $p=0.000$.

8.3.5.2 Ease-of-use

As mentioned above, Personal Preferences and Ease-of-use Questionnaire was also collected to gather participants' general ideas about how easy it is to complete tasks and get an idea of their preferences with respect to the accessibility features implemented in the redesigned apps. On this questionnaire we asked participants to indicate the difficulty levels of each task from very easy to very difficult. Table 27 & 28 show the participants' feedback with respect to the ease-of-use of completing tasks in the original and the redesigned apps.

Table 27. Ease-of-use of Original Apps

Tasks	Very Easy # (%)	Easy # (%)	Average # (%)	Difficult # (%)	Very Difficult # (%)
Schedule a new medication	1 (4.35%)	9 (39.13%)	11 (47.83%)	2 (8.70%)	0 (0.00%)
Modify a medication alert	2 (8.70%)	12 (52.17%)	9 (39.13%)	0 (0.00%)	0 (0.00%)
Respond to a medication alert	11 (47.83%)	12 (52.17%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
Schedule a skin check	4 (17.39%)	10 (47.83%)	8 (34.78%)	1 (4.35%)	0 (0.00%)
Modify skin check alert	7 (30.43%)	11 (47.83%)	4 (17.39%)	1 (4.35%)	0 (0.00%)
Report new skin problem	1 (4.35%)	8 (34.78%)	11 (47.83%)	3 (13.04%)	0 (0.00%)
Update the existing skin problem	0 (0.00%)	10 (43.48%)	11 (47.83%)	2 (8.70%)	0 (0.00%)

Table 28. Ease-of-use of Redesigned Apps

Tasks	Very Easy #(%)	Easy #(%)	Average #(%)	Difficult #(%)	Very Difficult #(%)
Schedule a new medication	7 (30.43%)	12 (52.17%)	4 (17.39%)	0 (0.00%)	0 (0.00%)
Modify a medication alert	6 (26.09%)	12 (52.17%)	5 (21.74%)	0 (0.00%)	0 (0.00%)
Respond to a medication alert	11 (47.83%)	12 (52.17%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
Schedule a skin check	7 (30.43%)	12 (52.17%)	4 (17.39%)	0 (0.00%)	0 (0.00%)
Modify skin check alert	9 (39.13%)	10 (43.48%)	4 (17.39%)	0 (0.00%)	0 (0.00%)
Report new skin problem	3 (13.04%)	13 (56.52%)	7 (30.43%)	0 (0.00%)	0 (0.00%)
Update the existing skin problem	5 (21.74%)	11 (47.83%)	7 (30.43%)	0 (0.00%)	0 (0.00%)
Configuring settings	12 (52.17%)	11 (47.83%)	0 (0.00%)	0 (0.00%)	0 (0.00%)

According to these tables, all of the participants thought the abovementioned tasks on the redesigned apps were average difficulty or less, compared with other smartphone apps they used before. Some of the tasks on the original apps were rated as difficult to complete. All mistakes in the redesigned apps were related to participants' lack of familiarity with the services. All of them believed, they could improve their familiarity with a longer use than just the 10-minute demo that was provided at the beginning of each test.

8.3.5.3 Preferences

As shown in Table 29, 11 participants tested the original apps first, then the redesigned apps. Twelve participants tested the redesigned apps, and then the original apps. When we asked participants' preferences with regards to using the original or redesigned apps, 19 participants (about 83%) indicated that they preferred to use the redesigned apps. Two participants (about 0.09%) thought they might like to use the redesigned apps.

Table 29. Test Procedures

PARTIC	First Tested	Preferred to use	Reasons
P01	Redesigned	Redesigned	Because I can adjust the size and display
P02	Redesigned	Redesigned	Navigation is easier in redesigned apps. The target is bigger.
P03	Redesigned	Redesigned (maybe)	Less typing involved; less steps
P04	Original	Redesigned (maybe)	Spaces were larger, follow the direction is much easier, I don't have to type.
P05	Redesigned	Redesigned	Like voice a lot, simpler to use.
P06	Original	Redesigned	Less type, larger target; like the newer version because of the navigation
P07	Original	Redesigned	Like the flow, the use of color, get user's attention for directional notes, like the voice.
P08	Redesigned	Redesigned	Less steps is easier
P09	Redesigned	Redesigned	Everything is larger in accessible app, which is easier.
P10	Original	Redesigned	Nice interface, easy to follow
P11	Original	Redesigned	Easier to use with less typing and larger icons.
P12	Original	Redesigned	Flow in accessible is clear. Following the directions were easier
P13	Redesigned	Redesigned	Easier process, larger target
P14	Original	Redesigned (maybe)	Don't have to type many info, target is bigger. I can take picture with larger icon, but a little hard with volume button to take pictures.
P15	Original	Redesigned	Like the interface, easier to use
P16	Redesigned	Redesigned	Like the interface, to make it more personalized, I am using stylus, but larger is better, sometimes the screen is not sensitive enough
P17	Original	Redesigned	Flow is easier to understand, less typing is good.
P18	Original	Redesigned	I like the larger target; I like the way of guide (text and voice) to promote to continue
P19	Redesigned	Redesigned	Easier to navigate, it prompts you through each screen, less clicking, visual feedback is good, message can promote users to do correctly
P20	Original	Redesigned	Much easier, less typing, buttons bigger, easier for navigation. Larger size is better. Shortcuts simplify the navigation. Easier for typing.
P21	Redesigned	Original	Original looks clean. But I like the flow in the redesigned apps.
P22	Redesigned	Redesigned	The process in the original is more complicated.
P23	Redesigned	Redesigned	Simpler to use
P24	Original	Redesigned	I like the ability to change contract (Theme), and button size.

Participant 21 preferred using the original apps (Table 29). This participant chose the picture of bamboo as background in the redesigned apps. He felt this might have made the redesigned apps look busy, which is why he did not prefer the redesigned apps over the original apps. However, he liked the flow in the redesigned apps, and he thought this flow was easier to understand when compared with using the original apps

Table 30 shows the 10 new accessibility features implemented in the redesigned apps. We asked each participant to give a score from 1 – 10 to indicate if the certain feature was important to them in terms of accessibility, with 1=most important to them and 10=not important to them.

Table 30. Preferences with respect to accessibility features

#	10-Likert scale: • 1 = most important • 10 = not important	Score 1 – 3 (#)	Scores 4 – 7 (#)	Scores 8 – 10 (#)	Avg. scores	Ranking based on the avg. scores
1	Customized application list	16	6	2	2.83	2
2	Customized text display (size)	12	8	4	3.96	9
3	Customized theme	11	4	9	5.25	10
4	Customized button Size	17	5	2	3.13	3
5	Custom keyboard	16	5	3	3.33	4
6	Picture of pill or medication bottle for medication alert	15	4	5	3.79	8
7	Matched color for app name	15	6	3	3.75	7
8	Short cut for navigation	16	6	2	3.50	6
9	Text guide	16	7	1	2.67	1
10	Voice guide	16	5	3	3.33	4

The average scores were calculated to rank the accessibility features most important to least important (Table 30):

1) Feature #9 – providing short text guidance in one or two sentences about what to do on the current screen – ranked as the most important (1^{st}) to this group of participants. Participants could get help when they were not sure what to do.
2) Feature #4 – providing ability to record individual's figure tip size using smartphone and adapt button/icon size accordingly throughout mHealth apps – was ranked as the 2^{nd} most important feature to accessibility. As our target population for this study was persons with dexterity impairments, this ability to set personalized button/icon size could improve their accuracy to make selections.
3) The 3^{rd} most important feature is #1, the ability to customize the application list. Not all patients need all five apps available in the iMHere system. The ability to hide apps from or select apps for the home screen made participants feel the system was more personalized.
4) Though more than 50% participants (n=16) gave scores 1- 3 for feature #10 – voice guide -- this feature ranked no. 4 on average. Participants gave lower scores (8 – 10) because they thought using the voice guide in situation such as an office or movie theater was annoying.
5) Custom keyboards ranked as the 5^{th} important feature for our participants. They were only used when entering dosage information and the time for an alert. Customization in this case means that some words, such as the dosage information for a medication, were preconfigured for our participants to answer certain questions. When using the customized keypad to enter "2 tablets," for instance, only two touches were needed, "2"

and "tablet." This customized keypad was designed to reduce the number of required touches on the smartphone screen. P would like to expand this type of keyboard for regular typing.

6) Feature #8 – shortcut for navigation – was ranked as the 6th most important features for participants. Some participants noticed a difference with the shortcuts, such as the app would directly go to the scheduling page no alert was available in the SkinCare app.
7) Feature # 7 – matched color for app name – ranked as the 7th most important for participants. For instance, the title for the SkinCare app in homepage was highlighted in red. Thus, all screens under the SkinCare app had a red bar. Many participants thought this might benefit users with slightly cognitive impairments or elderly users in that it could serve to remind them of which app they were using.
8) Feature #2 – customized text display – was ranked no. 8. Participants were able to set up a reading size comfortable for them in the redesigned apps. The size, color, bold and italic versions of titles, text, attention text, and warning text were predefined in the mHealth apps relative to the setting of the display text. Participants felt this feature might benefit users' with vision issues more.
9) More than 50% participants liked to take a picture of the pill or medication bottle for medication alerts and to verify the medication with the image when they received an alert. But others thought it might not be necessary to improve accessibility. Thus this feature ranked as the 9th important to our participants.
10) Many participants indicated that while they like to have different background in their apps, they thought feature #3 – customized theme – was more about the feeling of personal use, but not significantly important to access the apps. Therefore, this feature

was ranked as the least important to users' with dexterity impairments using redesigned apps, as no. 10.

Except for feature #3, customizing the theme to change the background and the text color on the smartphone screen, more than 50% participants (n=11) thought all of the other 9 features were important to improve the accessibility of mHealth services on a smartphone (scores from 1 to 3). Participants' individual medical and psychological needs with respect to self-care might have had an impact on their preferences with respect to accessing and using mHealth apps.

Table 31. Preferences for each group

Features	Average Scores			Ranking based on the avg. scores		
	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
Customized App List	3.714	2.167	3.200	7	1	4
Customized Text Display (size)	4.000	3.750	4.400	8	7	8
Customized Theme	7.286	4.500	4.200	10	10	7
Customized Button Size	3.571	3.000	2.800	4	4	1
Customized Keyboard	3.000	3.750	3.000	2	7	2
Picture of pill or medication bottle in Med alert	4.714	3.583	3.000	9	6	2
Matched color for app name	3.429	3.917	3.800	3	9	6
Short cut for navigation	3.571	3.083	4.400	4	5	8
Text Guidance	2.000	2.500	3.200	1	2	4
Voice Guidance	3.571	2.500	5.000	4	2	10

Table 31 summarizes individual's preferences grouping by different dexterity level (groups 1: mild, group 2: moderate & group 3: severe). Regardless of their dexterity level, all participants preferred using text guidance to learn what to do, ranking it no. 1 to no. 4. Participants with mild to moderate dexterity impairments preferred to use voice guidance, ranking it no. 4 and no. 2. However, users with severe dexterity impairments ranked the feature of providing voice guidance as less important, ranking it no. 10. Because of their physical limitations with respect to holding a smartphone and accessing the volume control button, participants with severe dexterity impairments had problems turning off the voice using the volume control button. The abilities to change the target/button size and to use the customized keypad were more essential for participants with severe dexterity issues, ranking it no. 1.

8.4 DISCUSSION

Scores from the TUQ for this study showed that the redesigned apps were viewed more positively than the original apps for our participants ($p<0.001$). Specifically, about 96% of participants preferred to use the redesigned apps. The only exception was a participant who did not like the redesigned apps because of the selected background image. However, he liked the ability to configure a personalized user interface and the process flow in the redesigned apps. After streamlining the task procedures in the redesigned apps, the average time to complete tasks dropped by 40%. Moreover, the number of mistakes made by users for task completion decreased by 88% using the redesigned apps.

Considering the time to complete tasks, the number of mistakes made by users when completing the tasks, and participants' feedback, the accessibility and usability of the redesigned apps were successfully improved over those of the original iMHere apps. This validates that accessibility can be improved at the two primary layers of the user interface (UI): physical presentation and navigation. Personalization, which offers a user the ability to modify the appearance of content, was shown to be an effective solution to addressing potential issues and barriers to accessibility.

The features aimed to improve the quality of services through personalization were identified as important for participants with dexterity impairments in the following ways:

- The use of text and voice guidance can extend the training and enhance the power for self-learning.
- The ability to change the target button size help to improve a user's experience and accuracy of touch, especially those with severe conditions.
- The customized keyboard helps to simplify the activities for entering text. This feature is also essential for users with severe dexterity impairments.
- The ability of users to choose which apps they wish to use can make the service more personalized.
- Shortcuts in navigation make the procedures in the redesigned apps easier to understand and to follow.

As shown by the above list, the features related to reducing the number of touches and increasing the accuracy of touch action are more essential to users with a higher degree of dexterity impairments. Other features might be more beneficial to users with other types of impairments. For example, enabling personalized settings for a user to hide unneeded apps and to use a preferred theme could benefit users in general. The ability to change the minimal text size would benefit users with visual impairments. In addition, users with larger fingers might benefit from the ability to set the button/icon size according to their finger size. Other accessibility features that were mentioned above, such as the use of text & voice guidance and guided services, are more important to improve the users' experience in terms of reduced cognitive workload and effective navigation. More work is certainly planned to evaluate individuals who have more complex cognitive, sensory, or motor impairments that make use of a smartphone difficult.

9.0 CONCLUSION

The smartphone is an ideal tool for implementing wellness programs for PwDs (Holman, 2004) but does pose accessibility challenges. For patients with dexterity impairments, potential accessibility issues include no keyboard (touch screen only), small screen space for touch, and multiple steps to accomplish a task. This dissertation describes a new model utilizing the design of the user interface to develop accessible mHealth apps. The concentration of the design is on personalization – making the app contents flexible and accessible to individuals with disabilities.

9.1 ACCESSIBLE DEVELOPMENTAL MODEL

The approach to designing an accessible interface involves working with two primary user interface (UI) components: physical presentation and navigation (Figure 43). Physical presentation refers to widgets and visual impacts and includes the following components:

- <u>Presentation of widgets:</u> focuses on the size and the contrast of text and the use of buttons. The size of the widgets (icons) and text and the contrast can be adjusted to the individual.
- <u>Visual impacts:</u> focuses on the use of charts, images and visual cues.

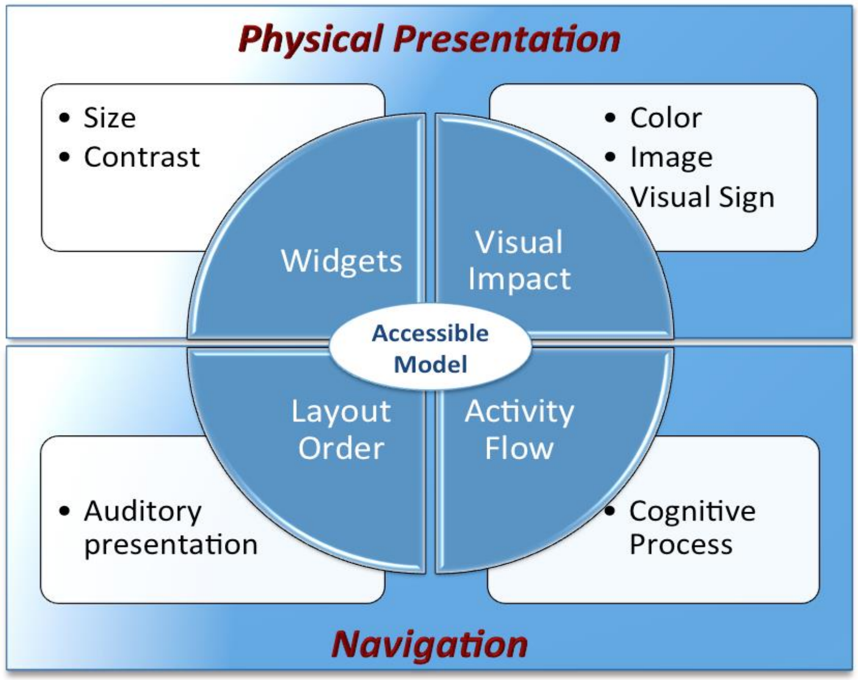


Figure 43. Four Elements of User Interface (UI)

Navigation refers to activity flow and layout order in terms of effectiveness. Simple navigation is important for all users, but especially important for patients with dexterity impairments as well as those with cognitive disabilities. The proposed design approaches the accessibility in terms of navigation from the following aspects:

- Activity flow: focuses on the cognitive process, on providing straight-line experiences for a user to complete a task. Good activity flow means the user is able to effectively and efficiently locate the needed information in the smartphone apps.
- Layout order: focuses on the presentation of individual screens. Placing related information in close proximity makes it easier for a user to understand the presented information. In addition, consistent layouts of the apps also provide a smooth learning curve for users.

The abovementioned UI elements in physical presentation are important for constructing the basic displays on smartphone screens. Navigation impacts the quality of access as a higher requirement. Because user preferences vary with respect to these elements, we designed the UI components to be adjustable to an individual's impairments through personalization. The following concepts are incorporated into the accessible design:

- <u>Customized styling:</u> provides the foundation for personalization. UI elements (includes widgets and visual impacts) are categorized into a specific group. The user's experience can be personalized by allowing the modification of visual attributes, including the size and the color of the element.
- <u>Adaptive navigation:</u> focuses on the activity flow of the apps to achieve a higher level of personalization. The apps can make use of the user's previous experiences with particular apps to eliminate unnecessary steps and create a shortcut in the activity flow.

With the capability for customizing UI settings, the redesigned apps enables the customization of the contents and displays based on individual's needs and preferences, making smartphones more accessible for those with additional needs based on physical limitations.

9.2 SUMMARY

I have approached the personalized and accessible design using the above-described developmental model. The end-users' access needs were considered at the beginning of the design and throughout the development procedures. Three major research questions explored in this dissertation are:

- What are the barriers for individuals with dexterity impairments to using mHealth services on a smartphone?

- How can we design and implement personalized and accessible mHealth apps?
- What are users' acceptance of and preferences with regards to the different designs (original designs vs. accessible designs)?

I have addressed these questions by conducting the following studies:

1. Exploration study – A group of end-users with dexterity impairments were included here to explore their needs with respect to accessing the original iMHere apps. As we expected, the accessibility features provided in iMHere were not sufficient to enable individuals with dexterity impairments access the program fully. In general, users expressed the desire to have simpler apps, meaning ones that make processes easier. Some findings from this study reveal ways to improve the accessibility in general, such as the use of thematic colors and instructive guidance, and simpler cognitive process. Other suggestions were related to user's preferences with respect to using mHealth apps, including the button size, text color, and background color/image.

2. Design and development study – Proposing a design and developmental model to approach accessibility through two primary elements of UI: physical presentation and navigation. A usability study showed that the effectiveness and efficiency of and user satisfaction with the redesigned apps were significantly improved after implementing accessibility strategies (see Chapter 8) into UI design. A list of strategies was identified as important to improving accessibility on the different stages of human information processing (Figure 44). Text in white identifies the features pinpointed in this research as important for persons with dexterity impairments. Text in black reveals the strategies identified from the prior studies (Chapter 4) and this research (Chapter 6 – 8) as important for general users.

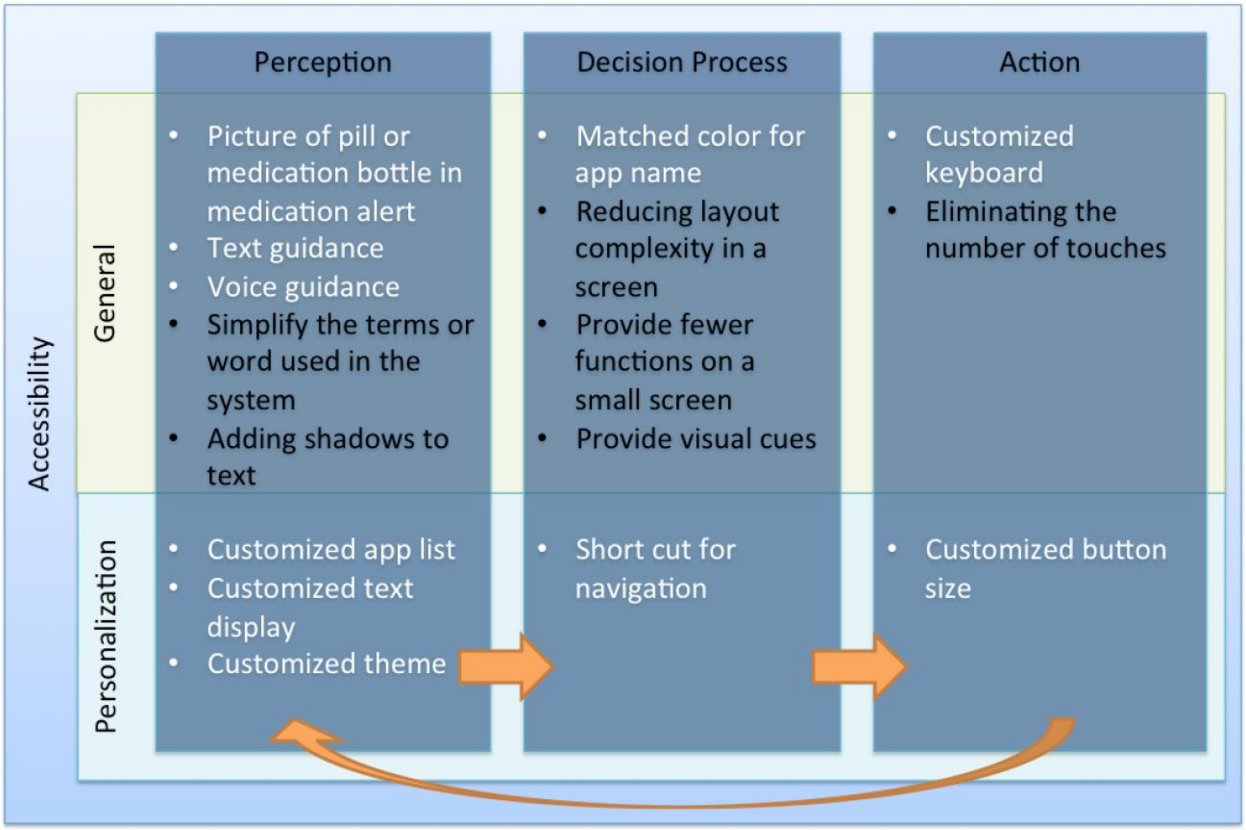


Figure 44. Accessibility Strategies

The majority of the strategies can enhance accessibility in general. Particularly, using contrasting colors between the text and background and adding shadows to text could enhance contrast and thereby improve readability. Text and/or voice guidance are useful for any smartphone user when they need assistance. Additionally, the redesign implemented in this study offered the ability to measure the finger size of a user using the smartphone, and use that measurement to create an optimum target button/ icon size. This feature is especially beneficial for users with higher degree of dexterity impairments.

3. Evaluation study – This study concentrated on evaluating the usability of the original and the redesigned apps. More participants with dexterity impairments were included. Results showed that the personalized and accessible strategies implemented in the redesigned apps benefited users with dexterity impairments. An accessibility mHealth model approached

from the direction of redesign of UI components and personalization has been presented. Some common accessibility challenges can be solved using personalized UI designs. By extending the concept of personalization to navigation and task flow, the efficiency of users' performance was significantly improved.

A wide range of dexterity problems was identified in these individuals. The accessibility features such as changing the size of targets/icons and simplifying and streamlining the procedures for task completion are important for this population, especially those with a higher degree of dexterity impairments. Other design features that focused more on improving user's experiences from other sensory (e.g., vision & hearing) and intelligence perspectives are also beneficial to these populations. However, each individual's condition and need to access mHealth apps is unique, meaning personalization plays an important role in enhancing the accessibility of such services and user satisfaction.

9.3 LIMITATIONS

One limitation of this study is the sample size. However, our sample size was likely sufficient to assess the accessibility challenges of a larger population for many of reasons. First, the usability of the iMHere system for persons with SB in general was conducted before this research (see Chapter 4). The accessibility development of the iMHere system for people with dexterity impairments was based on the most recent iteration of a design from the prior studies. Second, the same participants were included at the beginning of the design and development procedures (study 1 & 2). Their needs and preferences with respect to accessing the iMHere apps were considered in the redesign. Third, more participants were included the evaluation study (study 3) to assess user's acceptance and preferences. Particularly, using iterative design[7] based on a cyclic process of prototyping, testing, analyzing, and refining a system, we were able to probe deeper into the usability of the fundamental structure (Nielsen, 2000),

The second limitation is that participants with wide range of impairments were included. Persons with SB, SCI, CP or MD have a wide variety of reasons for having dexterity impairments (see Chapter 1). Though we excluded persons who have severe vision, hearing, speech or cognitive problems that entirely precluded the use of a smartphone, persons with mild to moderate conditions were still included in this research. By conducting tests on persons with multiple impairments, we were not able to determine which types of modifications could be more beneficial to people with specific sensory, learning, and/or memory limitations. Additionally, we were not able to infer which types of modifications are appropriate for people with different dexterity problems. For example, which modifications help people with visual-motor problems versus those with poor sensation in their hands or weak hand muscles?

Moreover, the following limitations are related to the study design:

- About 15 minutes of face-to-face training were provided at the beginning of each individual test. This training period might not be sufficient for a user to understand and to get familiar with apps. Ideally, users should be able to use the app upon being given an introduction or a demo. The face-to-face training served as an introduction. The activities in mHealth apps requiring certain self-management skills are more complicated than other commercial apps. This training period teaches users about self-management skills.

[7] Iterative design is a design methodology. Changes and refinements of a system are made based on the results of testing the most recent iteration of a design.

- A one-week field trial was completed before the lab tests in study 1 & 2. Although daily access to the apps was required during this practice period, a user's interactions with apps were hard to control. Some complicated tasks such as reporting a skin problem or adding a new medication might not have taken place during this practice period. However, this reflects the real use of apps in self-care routines. Users only perform a certain task when needed. Less practice or lower memory effort should be expected for users performing self-care in the long term. The apps should be accessible and usable at any time regardless the frequency of use.
- Study 3 was conducted in a lab environment and no field trial was included. Participants might need more time to practice and to get familiar with different apps. The purpose of study 3 was to evaluate users' acceptance and preferences. Their initial impressions of different designs are important. Additionally, the first tested apps were utilized as the baseline to judge the usability of the second designed apps in our crossover study design. It is easier and clearer to do side-by-side comparison. However, learning effects might have occurred when a user carried the experience from the first test to the second. We equally assigned participants into two groups to use the different designed apps in the first test in order to balance the influences of learning effects. Moreover, training for the second apps was also utilized as the washout period to eliminate learning effects.

Overall, the abovementioned studies addressed some of the potential solutions to the accessibility of mHealth apps and barrier mitigation. This research focused on studying those who have dexterity difficulty while using a smartphone but are still able to access a smartphone using a finger, a part of a hand, or a mounted stylus. There are other PwDs with different types of sensory, motor or cognitive impairments, and there are many other ways to improve the usability of services on smartphone for PwDs.

9.4 FUTURE DIRECTIONS

I will continue to explore other solutions to enhance the accessibility of and satisfaction with mHealth apps for PwDs. Future studies could be pursued in the following areas:

1. Expanding the personalized and accessible development model to those with various impairments: Although the main population of this research is persons with dexterity impairments, this research provides insights for other types of impairments. I expect some of the abovementioned changes might be applicable for users with other types of impairments. More work is certainly planned to evaluate the accessibility of mHealth for individuals with more complex cognitive, sensory, or motor impairments.
2. Developing adaptive configuration model for users with chronic conditions: Users with the same type of impairments or disease could have similar preferences or needs accessing mHealth apps. For instance, large buttons might be appropriate for patients with spina bifida, diabetes, and spinal cord injury, because they all have great potential for dexterity impairments. A pre-configured accessibility model could be utilized as the baseline configuration for further refinement.
3. Investigating the information presentation and receiving models: The number of mistakes made and the user's ability to recover from mistakes significantly improved when they received audio output in the redesigned apps. Though participants liked to have both text and audio output, a different presentation model should be suggested for users with

different impairments and for use in private or public areas. Audio output works with speech recognition; this information-receiving model could benefit users with dexterity or vision impairments, as well as users without disabilities.

4. Investigating machine-learning methods to measure and improve accessibility: Machine learning in the context of mHealth is a type of artificial intelligence that designs programs to learn user's actions and behaviors as they use smartphone apps. It focuses on the development of software programs that can teach themselves to change when exposed to new data. Shortcuts such as those described in Chapter 7 are one type of machine learning that we implemented in the redesigned apps. When we applied a list of shortcut rules to task procedures, we found user's performance was better than when they were using the original apps. This might indicate that machine learning algorithms and rules offer a new way to measure and improve accessibility.

9.5 SIGNIFICANCE

Various suggestions have been offered to improve accessibility of smartphones for PwDs. On such suggestion is that auditory feedback could be used to enhance the accessibility of mobile phones (Amar et al., 2003; Astrauskas et al., 2008; Kane et al., 2008; Li & Patrick Baudisch, 2008; Pirhonen et al., 2002). For example, sound feedback could be used to improve the usability of buttons (Brewster & Cryer, 1999). Another suggestion is that universally designed models could feature large font sizes to help visually impaired users more easily access e-mail messages and mobile Internet sites (Watanabe et al., 2008). Other studies have suggested using larger button size (Chen et al., 2013; Colle & Hiszem, 2004; Jin et al., 2007; Monterey Technologies

Inc., 1996).

A new development model presented in this dissertation demonstrated a way to approach accessibility from the perspective of user interface design and development. Incorporating the concept of personalization allows the redesigned apps to provide flexibility for users in the presentation of UI components, such as the color of display text and the reading size. Rather than using a fixed button size, the redesigned apps use the actual touch size to set buttons/icons. Moreover, the concept of personalization was also used in navigation to ensure more meaningful and efficient task completion.

Smartphones are a crucial way of receiving and sending information as well as interacting with other people. Business providers are primarily responsible for making their smartphone apps or services accessible. In 2010, approximately 56.7 million people living in the US had some kind of disability (United States Bureau of the Census, 2012). Additionally, the number of people at 65 and over was 40.3 million in the US as of 2010, and this population is growing at an increasingly faster rate (Howden & Meyer, 2010). With the size of PwDs and the trend of an aging population, the need for smartphone apps to be accessible is becoming more essential to gain market share.

Moreover, accessibility directly impacts a user's experiences. Creating and maintaining accessible smartphone apps is important to ensure the quality of such services. Our accessibility development model also aims to improve a user's experiences from all stages of human information processing. As a curb cut design, the identified features from this dissertation can benefit users with varying degrees of dexterity impairments as well as people without disabilities. In other words, the development model for implementing personalized and accessible apps also applies to diverse user groups, with or without impairments.

The accessibility standards and guidelines described in Chapter 2 are mainly aimed at improving accessibility of the web but not specifically that of smartphone apps. Since people's needs with respect to accessing information and interacting with smartphones are similar to those with respect to computers, G3ict (2012) suggested extending W3C's accessibility guidelines (WCAG 1.0 & 2.0) to the design and development of mobile phone services. However, web use on the computer and the services on smartphone devices are different. As a stand-alone device to function independently, smartphones are limited with respect to the use of third party assistive technologies such as an alternative keyboard or electronic pointing device. Additionally, a clear and simple intellectual process is more essential in app design because of the smaller size of the smartphone screen compared with that of a computer or tablet.

Because the smartphone is an essential way of receiving information and interacting with other people, smartphone apps need to be accessible in order to provide equal access and equal opportunity to PwDs. We hope that the results from this dissertation could help governments to address the issue of accessibility with regards to the limitation of the current regulations. Commercial entities can also make use of these results, hopefully considering not only the financial benefits of making their products and services accessible to a larger consumer base, but reflecting on their own social responsibilities based on government legislation as well.

APPENDIX A

MOOD QUESTIONNAIRE

1. Felt a persistent sad, anxious or empty mood?

   ☐Yes ☐No

2. Been sleeping too little or sleeping too much?

   ☐Yes ☐No

3. Had a loss of appetite and weight loss or increased appetite and weight gain?

   ☐Yes ☐No

4. Lost of interest or pleasure in activities you once enjoyed?

   ☐Yes ☐No

5. Felt restless or irritable?

   ☐Yes ☐No

6. Had physical symptoms as headaches and muscle soreness that do not respond to treatment?

   ☐Yes ☐No

7. Had a hard time concentrating, remembering, or making decisions?

☐Yes ☐No

8. Felt tired and had loss of energy?

☐Yes ☐No

9. Felt guilty, hopeless or worthless?

☐Yes ☐No

10. Had thoughts of death or suicide?

☐Yes ☐No

APPENDIX B

CONSENT TO ACT AS A PARTICIPANT IN A RESEARCH STUDY

TITLE: Usability & Accessibility Studies of Mobile Health

SOURCE OF SUPPORT: National Institute of Child Health & Human Development (NICHD)

Why is this study being done?

The overall goal of this research is to design and to implement personalized and accessible (individualized and easy to use) mobile health applications (mHealth applications or "apps") for the smart phone, which can be used to assist or manage daily routines for people with disabilities. Personalized and accessible mHealth apps will provide you with many features and advantages that might improve the effectiveness for you to use mHealth apps. The material for this study will be the iMHere rehabilitation system that consists of a web portal and mHealth apps. The following two iMHere apps will be used in this research:

- MyMeds app for medication management. The activities in MyMeds include searching and finding the correct medication, entering the reason to take this medication, setting up a medication schedule, and responding to medication reminder(s).

- Skincare app for managing wound and skin issues. The activities in Skincare include setting up a skin check schedule, responding to a skin check reminder, and taking a picture of the wound. Subjects will also be entering size, color, condition and thickness of the affected skin.

To achieve our research goal, the following two usability and accessibility studies will be conducted:

- Study 1 (Evaluation) is aimed to identify the barriers of iMHere apps to accessibility, and to explore the necessary features that may improve users' experiences.

- Study 2 (Validation) is aimed to conduct usability and accessibility studies on mHealth by comparing the original iMHere apps with the redesigned apps after feedback from Study 1. Approximately 40 people will participate in this study.

Who is being asked to take part in this study?

You are being invited to participate in this research study because:

- You are an adult 18 - 64 years old;
- You have a motor impairment (such as a difficulty in manipulating small buttons, icons or controls on the smartphone) that would interfere with accessing smartphone apps (apps are software programs for a smartphone that help you perform a specific task);
- You are interested and willing to use a smartphone to manage your daily routines that are related to medical care, such as receiving alerts for taking medicine.
- You have the potential for skin breakdown (e.g., pressure sores, pressure wounds or pressure ulcers) or have the insensate areas of skin which means that you may not feel pain, touch, or respond to heat or cold on the area of skin.
- You are currently on at least one prescription medication and/or over the counter medication.

What are the procedures of this study?

The procedures of this study will be conducted either at the Department of Health Information Management on Atwood Street or at a site of the subject's choosing, i.e., home. If you decide to take part in this research study, you will undergo the following for research purposes:

<u>Screening Procedures</u>

The following tests are designed to evaluate your ability to understand the test procedures, to perform and to complete the tests. Testing will take approximately 30 minutes and will be conducted either in the research office or in your preferred location. You will be asked to complete two screening tests to determine your eligibility to participate:

- *Purdue Pegboard Assessment* to evaluate the functional performance of your hands (dexterity).
- *Vision Test* to assess your ability to reproduce information from medication bottle to smartphone.

<u>Study Procedures</u>

If you are eligible for the study, you will be introduced to either or both Study 1 (Evaluation) and Study 2 (Validation). You will be asked to provide your opinion of the smartphone apps; whether or not you like them and whether or not you think they might help you in daily routines. The following procedures will be conducted in this research:

<u>Study 1: Evaluation</u>

Procedures for Study 1 will take 3 weeks:

Week 1 – One time visit for a 60-minute meeting:

- You will be asked to fill out the *Background Questionnaire* if it hasn't been done previously. This questionnaire is designed to collect your experiences with mobile phones and your knowledge with mobile health. This will take approximately 15 minutes to complete.

- Then, you will receive face-to-face training and orientation in your preferred location (approximately 45 minutes). Two (2) apps will be introduced, which include the medication management and the skincare apps. The activities in the medication app include scheduling and responding to medication reminder(s). The activities in the skincare app include scheduling a daily alert for a skin checkup and recording skin problems. You should have your medication list ready at the time for this orientation and training. During the orientation, you will be trained to perform tasks for each of the apps (setting up a schedule for your medication(s), responding to reminders, taking a picture of a mock skin problem) until you are confident in your ability to use the apps. A mock skin problem will be used in this training due to privacy concerns. At the end of this training, data that is saved on smartphones will be erased to avoid any confusion in the field trial (that is a one week test for using our smartphone apps on your own in your own environment). Then you will be asked to enter current medication and skincare reminders for your field trial. Researchers will check and make sure the entered information is correct.

Week 2 – Approximately one-week field trial, 30 minutes daily access is required:

- A field trial will be conducted after the training and orientation. The daily activities include responding to the medication alerts, responding to the skincare alerts, taking a picture of the problem skin, and filling out a form for describing the problem, such as the size and the color of the affected skin.
- You will continue to receive typical medical care during this field trial. However, you will be referred back to your doctor for any new medical issue that arises.
  - The investigator (with a clinical specialty in physical medicine and rehabilitation) will review all skin problems through the iMHere web portal. You will be referred back to your doctor, if you report a new skin problem or have any change in a previously identified skin problem.
  - You are allowed to enter the new medication and scheduling information if you receive a new medication during this field trial. The researcher named in this research will verify this information with you over the phone.

Week 3 – One time visit for a 60-minute meeting:

- You will be introduced to a test in a “lab environment” at your preferred location. This environment, such as home, should allow you to conduct the tasks without distractions from the surroundings. A trial bottle (non-prescription medication) will be used if you forget to bring your real medication, and a mock skin problem will be used in this lab test. A total of five (5) tasks related to medication and skincare management will be randomly given to you in the first 30 minutes. This includes:

1) Schedule Medication
2) Modify Medication Schedule
3) Response to Medication Alert
4) Schedule Skin check
5) Response to Skincare Alert

- An in-depth interview and discussion will follow the lab test and will take approximately 30 minutes to complete. Assessment procedures include:

a) *Telehealth Usability Questionnaire* (TUQ) will be given at the beginning of in-depth interview and discussion in the lab test. TUQ is a comprehensive questionnaire that covers all usability factors that focus on usefulness, ease of use, effectiveness, reliability, and satisfaction. You will be asked to rate your experience and/or feedback from 1(disagree) to 7 (agree).

b) Researchers will ask a list of questions. These questions are formed to explore the important factors that might impact your preferences and satisfactions.

The time for you to complete each task, the number of possible errors that confront you, and the number of errors you are able to self-correct will be recorded for statistical analysis. Only the information entered in mHealth apps will be transferred or uploaded automatically without identifiers to our server for storage of the information in a database. This includes medication name, schedule information (including time and type of activity), images of affected skin and description of their location and condition, and the response time for alerts. This information will be manually deleted and removed from the database server after the test has been completed. Other information that is not related to mHealth apps, such as emails, pictures, and text messages, will not be sent to our server.

Study 2: Validation

The same procedures described in Study 1 will be used in Study 2. All the procedures for Study 2 will be finished in 9 weeks: The procedures from Study 1 will be repeated for 3 weeks; then there will be a 3-week break with no procedures, followed by another 3 weeks of Study 1 procedures. In Study 2, you will be asked to test two different apps: The apps from iMHere (those that were implemented based on clinician's suggestions) and the accessible apps (those that were implemented after Study 1, based on users' needs to access). The training for the next set of apps will be scheduled after the 3-week washout period. However, if you already participated in Study 1, you will not have to go through a second round of using original iMHere apps. In this case, at least a 3-week washout period is required between your participation in Study 1 and 2, and then you will finish Study 2 in 6 weeks.

Video & Audio Procedures

For Study 1 and Study 2, the lab test and in-depth interview will be video recorded for reference purposes. We will not videotape your face or body, so you will not be identifiable. Video recordings will be focused to capture the activities on the smartphone only. If there are limitations due to the location, such as difficulties setting up a camcorder in the area, we will capture the smartphone screen and use the audio record instead.

What are my responsibilities with the smartphone device?

Smartphone devices and/or apps will be provided to you for this study. If you prefer, you are allowed to use the smartphone device for your personal use, including making domestic phone calls, Internet access, and sending and receiving text messages in the United States. The costs of using the device for personal use will be paid by the study. A smartphone will be given to you at the beginning of the training and orientation. This device needs to be returned after the lab test and interview.

The smartphone device is University property. Once you receive the smartphone, it is your responsibility to maintain it and return the device to the researcher after completing the tests. In case of damage, you are responsible to return the smartphone to the researcher for repair. But, you are not responsible for repair or replacement costs. If you fail to return the smartphone device, you will be fully responsible and pay a $300 penalty. In case of loss, you are responsible for a $300 penalty. We will hold your payment until you return the smartphone device or the penalty has been paid.

If you want to use your personal android smartphone, the research apps will be provided for free during the testing period. After the test, these research apps will be uninstalled and removed from your personal device. Any data use or airtime charges will be your responsibility if you use your own smartphone for this research.

What are the possible risks and discomforts of this study?
The potential risk is the frustration you might experience when you attempt to solve problems. If you like, we will discuss your feelings and concerns after you complete the tasks. Another potential risk is associated with the loss of the smartphone or access of information by others. In this case, no identifiable information, such as name or birthday, is saved in the smartphone apps, however we suggest a password be programmed to prevent unauthorized access. You also may become fatigued during the interviews and surveys.

mHealth apps will not have access to your personal information from your smartphone, such as email, text messages, and pictures. The phone number will be used to transfer information only from the smartphone to the database. It will only be accessible by investigators named in this research. This personal phone number will be stored separately from the coded subject name and other mHealth information.

Data that will be saved on the smartphone phone device for testing include medication name, scheduling information (including time and type of activity), response time for alerts, images of affected skin, and the location and condition of affected skin. After each session of the test, all personal data will be erased from the device. To reduce the likelihood of a breach of confidentiality, all researchers have been thoroughly trained to maintain your privacy.

Research information will be stored using a code/study number instead of your name to protect your personal information. Hard copies of video sessions will be stored in a locked file cabinet using a study number instead of your name.

As previously indicated, the electronic data that was entered and stored on the smartphone will also be sent into the database server. If needed, the investigator will access this information through a clinical monitoring portal on the Web to monitor your behaviors in responding to alerts during the field trial. This information will not be copied or transferred to other locations, and it will be manually deleted and removed from the database server after the test has been completed. This medical related information will be not revealed in any description of written reports and publications.

Will I benefit from taking part in this study?
You will receive no direct benefit from participating in this study. However, your feedback and suggestions will help us to gain knowledge in improving the quality of smartphone apps with respect to accessibility.

Who will pay if I am injured as a result of taking part in this research study?
If you believe that the research procedures have resulted in an injury to you, immediately contact the Principal Investigator who is listed on the first page of this form. Emergency medical treatment for injuries solely and directly related to your participation in this research study will be provided to you by the hospitals of UPMC. Your insurance provider may be billed for the costs of this emergency treatment, but none of those costs will be charged directly to you. If your research-related injury requires medical care beyond this emergency treatment, you will be responsible for the costs of this follow-up care. At this time, there is no plan for any additional financial compensation.

Are there any costs to me if I participate in this study?
There are no costs to you or your insurance provider for participating in this study if you use our smartphone device. But, if you use your own smartphone device, the data usage for mHealth apps will be included in your data plan. Because the data usage for you to participate in this study is minimal, your current data plan will be enough.

How much will I be paid if I complete this study?
You will be asked to participate in one or more usability and accessibility tests. Each test includes face-to-face training (about 60 minutes), the field trial (approximately one week, and 30 minutes access per day), and a lab test with an in-depth interview (about 60 minutes).

You are required to complete all activities in each test to receive payment. In general, two tests will be administered: 1) the test for iMHere apps, either in Study 1 or Study 2, 2) the test for redesigned apps in Study 2.The maximum amount you can receive for completing all study procedures is $60. If, for whatever reason, you complete a part but not all of the study, the terms of this payment will be as follows:

- $30 for completing the usability & accessibility test on iMHere apps
- $30 for completing the usability & accessibility test on redesigned apps.

You will not be compensated if you stop in the middle of a test. If the visits are scheduled at the Department of Health Information Management (at Forbes Tower), parking validation will be provided for the UPMC lot at Meyran Avenue and Forbes Avenue. Otherwise, it will be your responsibility to turn-in the parking receipt for reimbursement.

Will anyone know that I am taking part in this study?
All records pertaining to your involvement are kept strictly confidential (private) and any data that includes your identity will be stored in locked files and will be kept for a minimum of 7 years following final reporting or publication of the project. Your identity will not be revealed in any description of publications of this research.

It is possible that authorized representatives from the University of Pittsburgh Research Conduct and Compliance Office (including the University of Pittsburgh IRB) and the study sponsor (NICHD) may review your data for the purpose of monitoring the conduct of this study.

In very unusual cases, your research records may be released in response to an order from a court of law. Also, if the investigators learn that you or someone with whom you are involved is in serious danger of potential harm, they will need to inform the appropriate agencies as required by Pennsylvania law.

The sponsor of this study, The National Institute of Child Health & Human Development, may have access to stored information for the purpose of reviewing and monitoring the study.

Is my participation in this study voluntary?
Yes! Your participation in this study is completely voluntary. Whether or not you provide your consent for your participation in this research study will have no effect on your current or future relationship with the University of Pittsburgh. You may refuse to take part in it, or you may withdraw at any time, even after signing this form. Any data collected from you prior to the time you formally withdraw your permission will continue to be used.

If I agree to take part in this research study, can I be removed from the study without my consent?
Inappropriate use of the smartphone device and service package (e.g. voice, text/picture messaging, and internet access) provided to you may result in removal from the study. This includes, but is not limited to the following:

1) Intentionally or recklessly abusing or misusing the smartphone and service to cause damage or system interruptions.
2) Lending the smartphone device to any other person for use. Use of the device and service is limited only to the person who is enrolled in this study.
3) Using electronic media to harass or threaten other persons, or to display, design, copy, store, draw, print or publish obscene language or graphics.
4) Intercepting or attempting to intercept or otherwise monitor any communications not explicitly intended for him or her without authorization.
5) Making, distributing and/or using unauthorized duplicates of copyrighted materials including software applications, proprietary data, and information technology resources. This includes sharing of entertainment files (e.g. music, movies, video games) files in violation of copyright laws.

If you are removed from this study, the smartphone device provided from this study needs to be returned to researchers. If you use your personal smartphone for this study, the mHealth apps from this study will be uninstalled and removed from your personal device.

How can I get more information about this study?
If you have any further questions about this research study, you may contact Valerie Watzlaf (valgeo@pitt.edu, 412-383-6647). If you have any questions about your rights as a research subject, please contact the Human Subjects Protection Advocate at the University of Pittsburgh IRB Office, 1.866.212.2668

One or more of the investigators conducting this research has a financial interest in or a patent for the **development of the personalized and accessible iMHere apps for people with disabilities that are being evaluated under this study.** This means that it is possible that the results of this study could lead to personal profit for the individual investigator(s) and/or the

University of Pittsburgh. This project has been carefully reviewed to ensure that your well-being holds more importance than any study results. Any questions you might have about this will be answered fully by the Principal Investigator, **Dr. Valerie Watzlaf** (valgeo@pitt.edu, 412-383-6647), who has no financial conflict of interest with this research, or by the Human Subject Protection Advocate of the University of Pittsburgh (866-212-2668).

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VOLUNTARY CONSENT

• I have read the consent form for this study and any questions I had, including explanation of all terminology, have been answered to my satisfaction. A copy of this consent form will be provided to me.
• I understand that I am encouraged to ask questions about any aspect of this research study during the course of this study, and that those questions will be answered by the researchers listed on the first page of this form.
• I understand that my participation in this study is voluntary and that I am free to refuse to participate or to withdraw my consent and discontinue my participation in this study at any time without affecting my future relationship with this institution.
• I understand that I may contact the Human Subjects Protection Advocate of the IRB Office at 1.866.212.2668, University of Pittsburgh to discuss problems, concerns, and questions; obtain information; offer input; or discuss situations that have occurred during my participation.
• By signing this form, I agree to participate in this research study. A copy of this consent form will be given to me.

____
Printed Name of Participant

______________________________ ________________
Participant's Signature Date

CERTIFICATION OF INFORMED CONSENT

I certify that I have explained the nature and purpose of this research study to the above-named individual(s), and I have discussed the potential benefits and possible risks of study participation. Any questions the individual(s) has about this study have been answered, and we will always be available to address future questions as they arise. I further certify that no research component of this protocol was begun until after this consent form was signed.

________________________________ ______________________
Printed Name of Person Obtaining Consent Role in Research Study

______________________________ ______________________
Signature of Person Obtaining Consent Date

APPENDIX C

PARTICIPANT RECRUITMENT FLYER

Do You Experience Difficulties Using Smartphones?

The University of Pittsburgh is looking for men and women between 18 – 64 years of age to participate in a research study about mobile health applications. Mobile health is the use of software programs for a smartphone that help you perform specific tasks to support health care services.

If you have trouble moving or using your fingers, have skin breakdown (e.g., pressure sores, pressure wounds, or pressure ulcers) or have the insensate areas of skin (means that you may not feel pain, touch, or respond to heat or cold on the area of skin), and are taking at least one prescription drug and/or an over-the-counter drug, you may be eligible to participate in a research study to explore usability and accessibility of mobile health. Prior experience with a smartphone is preferred, but not necessary for participation. A smartphone will be provided as part of this study.

A rehabilitation system with mobile health apps developed at the University of Pittsburgh will be used in this study. Each session of testing includes a face-to-face orientation, a field trial, and testing of the apps in the laboratory as well as an in-depth interview.

You will be asked to provide your opinion of the mobile health apps, whether or not you like them and whether or not you think they might help you in daily routines. Your options will be valuable to improve the usability and accessibility of mobile health apps on the smartphone.

This study will take place at the Department of Health Information Management, Forbes Tower 6051, Atwood Street. For more information, please contact Daihua Yu at (412) 383-5101 (dxy1@pitt.edu) or Dr. Valerie Watzlaf (412) 383-6647 (valgeo@pitt.edu).

Compensation is available for participation.

APPENDIX D

PURDUE PEGBOARD TEST PROCEDURE SCRIPT

**Modified from Purdue Pegboard Test User Instruction* (Lafayette Instrument)

This is a test to see how quickly and accurately you can work with your hands. Before you begin each part of the test, you will be told what to do and then you will have an opportunity to practice. Be sure you understand exactly what to do before the test.

Test 1: Right Hand (30 seconds)

1. Please pick up one in at a time with your right hand from the right-handed cup. Starting with the top hole, place each pin in the right-handed row. Now you may insert a few pins for practice. If during the testing time you drop a pin, do not stop to pick it up. Simply continue by picking another pin out of the cup.
2. (Time for practice and questions)
3. Stop, now take out the practice pins and put them back into the right-handed cup. When I say "begin," please start to place as many pins as you could in the right-handed row, starting with the top hole. I will say, "stop," when time is up. Are you ready? Begin.
4. (30 seconds for this test).
5. Stop. (Count and record score: each pin in the hole counts for 1 point in the score).

Test 2: Left Hand (30 Seconds)

1. Please pick up one in at a time with your left hand from the right-handed cup. Starting with the top hole, place each pin in the left-handed row. Now you may insert a few pins for practice. If during the testing time you drop a pin, do not stop to pick it up. Simply continue by picking another pin out of the cup.
2. (Time for practice and questions)
3. Stop, now take out the practice pins and put them back into the left-handed cup. When I say "begin," please start to place as many pins as you could in the left-handed row, starting with the top hole. I will say "stop" when time is up. Are you ready? Begin.
4. (30 seconds for this test).
5. Stop. (Count and record score: each pin in the hole counts for 1 point in the score).

Test 3: Both Hands (30 seconds)

1. For this part of the test, you will use both hands at the same time. Pick up a pin from the right-handed cup with your right hand, and at the same time pick up a pin from the left-handed cup with your left hand. Then place the pins down the rows. Begin with the top hole of both rows. (Demonstrate) Now you may insert a few pins for practice.
2. (Time for practice and questions)
3. Stop, now take out the practice pins and put them back. When I say "begin," please start to place as many pins as you could, starting with the top hole. I will say "stop" when time is up. Are you ready? Begin.
4. (30 seconds for this test).
5. Stop. (Count and record score: each pin in the hole counts for 1 point in the score).

6. Now move to the next test.

Test 4: Right + Left + Both: This score is obtained from combining the test scores on the previous three tests.

APPENDIX E

ORIGINAL NORM IN GENERAL FACTORY WORKERS

* Purdue Pegboard Assessment: N=282 (Lafayette Instrument)

Right Hand: S.D. = 1.79

Poor		Low Avg.		Average			High Avg.		Excellent	
12	13	14	15	16	17	18	19	20	21	22

11.76	13.57	15.36	17.15	18.94	20.73	22.52
(-)3 S.D.	(-)2 S.D.	(-)1 S.D.	Mean	1 S.D.	2 S.D.	3 S.D.

Left Hand: S.D. = 1.70

Poor		Low Avg.		Average			High Avg.		Excellent	
11	12	13	14	15	16	17	18	19	20	21

10.91	12.61	14.31	16.01	17.71	19.41	21.11
(-)3 S.D.	(-)2 S.D.	(-)1 S.D.	Mean	1 S.D.	2 S.D.	3 S.D.

Both Hands: S.D.= 1.55

Poor	Low Avg.	Average			High Avg.		Excellent
10	11	12	13	14	15	16	17

9.02	10.47	11.92	13.37	14.48	16.29	17.72
(-)3 S.D.	(-)2 S.D.	(-) 1 S.D.	Mean	1 S.D.	2 S.D.	3 S.D.

Right + Left + Both: S.D. = 4.04

Poor		Low Avg.	Average				High Avg.		Excellent
35	40	41-	44	45-	48	49-	52	53	58

34.46	38.68	42.72	46.76	50.8	54.84	58.88
(-)3 S.D.	(-)2 S.D.	(-) 1 S.D.	Mean	1 S.D.	2 S.D.	3 S.D.

Assembly: S.D. = 5.89

Poor		Low Avg.	Average				High Avg.		Excellent
22	30	31-	36	37	42	43	48	49	56

21.63	27.52	33.41	39.90	45.19	51.08	56.97
(-)3 S.D.	(-)2 S.D.	(-) 1 S.D.	Mean	1 S.D.	2 S.D.	3 S.D.

APPENDIX F

AN EXAMPLE OF STEP-BY-STEP OBSERVATION NOTE

Schedule A New Medication						
	Description	**Step Involved**	**Correct**	**Not Correct**	**Self-correct score***	**Notes**
Step 1	Click on **MyMeds**					
Step 2	Click on the Plus symbol **(+)** in the top right corner to add your medication					
Step 3	Type in the medication name (such as Tylenol Cold or from bottle)					
Step 4	Select the medication from the list					
Step 5	Select the medication name to expand the detailed lists.					
Step 6	Select the correct medication from the list.					
Step 7	Select **"Yes"** from the notification screen to confirm the new medication					
Step 8	Fill out the form slots for **Alias** if needed.					
Step 9	Fill out the form slots for **Notes** if needed.					
Now Need to add new schedule for this Med.						

Step 10	Add a new schedule by clicking the Plus **(+)** symbol at the bottom right of the screen under the form					
Step 11	Select **"Time"**					
Step 12	Change the time to 5 minutes from now.					
Step 13	Click **"Set"** to confirm the change of alert time.					
Step 14	Select **"Dosage"** to expand the optional list.					
Step 15	Select the appropriate dosage info.					
Step 16	Click "**OK"** to confirm the change.					
Step 17	Selected "**Ringtone"** if needed to expand the list of ringtone options.					
Step 18	Select the silent, or wanted ringtone from list.					
Step 19	Click "**OK**" to confirm the ringtone change.					
Step 20	Click "**Vibrate"** if needed.					
Step 21	Select "**Once A Week**", if this medicine is not scheduled for daily use. Otherwise, got **Step 26**.					
Step 22	When **"Repeat"** option has be enabled, click on it to expand the options.					
Step 23	Select the Day(s) that need to enable alarm. (Such as Monday and Sunday)					
Step 24	Click **"OK"** to confirm the change.					
Step 25	Save the medication by clicking on the save icon in the upper right corner					
Step 26	Save again					

APPENDIX G

MOBILE PHONE BACKGROUND QUESTIONNAIRE

Section 1: General Background

Please check the most appropriate answer.

1. What is your age?

    ____ 18 – 30

    ____ 31 – 40

    ____ 41 – 55

2. What is your highest education level?

    ___ High School

    ___ Undergraduate

    ___ Graduate

3. What is your gender?

    ___ Male

    ___ Female

4. Are you currently using a mobile phone (including regular mobile phone, PDA, or Smartphone)?

    ____ Yes (***Continue***)

    ____ No (***Please go to section 2***)

5. What kind of mobile phone do you have now?

    ____ Regular Mobile Phone

____ Smartphone with Touch Screen

____ Other, please specify: ____

6. What kind of keypad do you have on your mobile phone?

    ____ Physical

    ____ Touch Screen

7. Do you have a data package for your mobile phone?

    ____ Yes

    ____ No, please specify the reason: ____________________________________

8. How many years has it been since you had your first mobile phone?

    ____ 0-2

    ____ 3-5

    ____ 5 or more

9. How much time do you spend on your mobile phone in a typical day?

    ____< 30 minutes

    ____30 – 60 minutes

    ____ > 60 minutes

10. What are your major activities on your Smartphone?

    ____ Making phone calls

    ____ Sending text messages

    ____ Taking photos

    ____ Playing games

    ____ Browsing the Internet

    ____ Checking E-mail

    ____ Listening to music (as MP3s)

    ____ Managing daily activities

    ____Other, please specify: ____

11. How easily can you learn to use a mobile phone? (Please give a score from 1 to 7. 1: not easy at all; 7: very easy)

    ____

12. How much do you like your mobile phone device? (Please give a score from 1 to 7. 1: not like it at all; 7: very much)

    ____

(Please go to Section 3.)

Section 2: Reason to Quit Using Mobile Phone

1. Have you ever experienced using a mobile phone before?

   ____ Yes (Continue)

   ____ No (Please go to Section5)

2. What is the main reason that you stopped using a mobile phone?

   ___ Cost

   ___ Don’t need it, please specify: ____

   ___ Don’t like it, please specify: ____

Section 3: Idea of Mobile Health

1. What is mobile health? Please explain.

2. Do you think mobile health could benefit you? Why or why not?

3. Are you currently using any application to manage your health information?

4. Are you interested in using mobile health apps to manage your health information?

5. What are your concerns about using mobile health apps on a mobile device?

APPENDIX H

TELEHEALTH USABILITY QUESTIONNAIRE (TUQ) FOR MHEALTH

*Telehealth in this usability study refers to the iMHere mobile health system.

		N/A		1	2	3	4	5	6	7	
1.	Telehealth improves my access to healthcare services.	☐	DISAGREE	☐	☐	☐	☐	☐	☐	☐	AGREE
2.	Telehealth saves me time traveling to a hospital or specialist clinic.	☐	DISAGREE	☐	☐	☐	☐	☐	☐	☐	AGREE
3.	Telehealth provides for my healthcare needs.	☐	DISAGREE	☐	☐	☐	☐	☐	☐	☐	AGREE
4.	It was simple to use this system.	☐	DISAGREE	☐	☐	☐	☐	☐	☐	☐	AGREE
5.	It was easy to learn to use this system.	☐	DISAGREE	☐	☐	☐	☐	☐	☐	☐	AGREE
6.	I believe I could quickly become productive using this system.	☐	DISAGREE	☐	☐	☐	☐	☐	☐	☐	AGREE
7.	The way I interact with this system is pleasant.	☐	DISAGREE	☐	☐	☐	☐	☐	☐	☐	AGREE
8.	I like using this system.	☐	DISAGREE	☐	☐	☐	☐	☐	☐	☐	AGREE
9.	This system is simple and easy to understand.	☐	DISAGREE	☐	☐	☐	☐	☐	☐	☐	AGREE
10.	This system is able to do everything I would want it to be able to do.	☐	DISAGREE	☐	☐	☐	☐	☐	☐	☐	AGREE

11.	I can easily update my health status with the clinician using the telehealth system.	☐	DISAGREE ☐ ☐ ☐ ☐ ☐ ☐ ☐ AGREE
12.	I can-easily manage my condition(s) using the telehealth system.	☐	DISAGREE ☐ ☐ ☐ ☐ ☐ ☐ ☐ AGREE
13.	I felt I was able to express myself effectively.	☐	DISAGREE ☐ ☐ ☐ ☐ ☐ ☐ ☐ AGREE
14.	Using reminders from the telehealth system, it is easy to manage my self-care activities.	☐	DISAGREE ☐ ☐ ☐ ☐ ☐ ☐ ☐ AGREE
15.	~~I think the visits provided over the telehealth system are the same as in-person visits.~~	☐	DISAGREE ☐ ☐ ☐ ☐ ☐ ☐ ☐ AGREE
16.	Whenever I made a mistake using the system, I could recover easily and quickly.	☐	DISAGREE ☐ ☐ ☐ ☐ ☐ ☐ ☐ AGREE
17.	The system gave error messages that clearly told me how to fix problems.	☐	DISAGREE ☐ ☐ ☐ ☐ ☐ ☐ ☐ AGREE
18.	I feel comfortable communicating with the clinician using the telehealth system.	☐	DISAGREE ☐ ☐ ☐ ☐ ☐ ☐ ☐ AGREE
19.	Telehealth is an acceptable way to receive healthcare services.	☐	DISAGREE ☐ ☐ ☐ ☐ ☐ ☐ ☐ AGREE
20.	I would use telehealth services again.	☐	DISAGREE ☐ ☐ ☐ ☐ ☐ ☐ ☐ AGREE
21.	Overall, I am satisfied with this telehealth system.	☐	DISAGREE ☐ ☐ ☐ ☐ ☐ ☐ ☐ AGREE

Please provide your own personal comments about the telehealth system:

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

APPENDIX I

MOBILE UI EXPERIENCE AND SATISFACTION QUESTIONS

Section 1: Factor of Task

1. Do you think the description of Task is clear?

2. Do you think the task is relevant to your daily use?

Section 2: Factor of widgets

3. Do you think the size of text is easy to read?

4. Do you think the size of button is good to target?

5. Do you think the contract of each screen is appropriate for you to read?

6. Overall, do you think the service provide presentation for widgets (e.g. text & buttons)?

Section 3: Factor of Visual impact

7. Do you think the use of color helps you to locate information quickly?

8. Do you think the images used are meaningful?

9. Do you think the charts are helpful for you to understand the content?

10. Do you think the visual signs help you to become aware of your current health status?

11. Overall, do you think the service provides a good visual impact on the screen?

Section 4: Factor of Activity flow

12. Do you think the structure of service is easier to understand?

13. Do you think menus are logically structured on the screen?

14. Do you think menus or items are reasonably linked to each other?

15. Do you think menus/titles are meaningful to describe the activities?

16. Overall, do you think the activity flow is clear and easy to follow?

Section 5: Factor of Learning

17. Do you think the training time was effective?

18. Do you think that you could learn this service more quickly with longer use and training?

19. Overall, do you think it was easy to learn to use this service?

Section 6: Factor of Terminologies/Words

20. Do you think the terminologies/words provided for the service is easy to understand?

Section 7: Overall satisfaction

21. Are you satisfied with how easy it is to use this service?

22. Are you satisfied with navigation in this service?

23. Will you feel comfortable to use this service in the future?

24. Do you like the User Interface (presentation/display) provided in this service?

25. Will you encourage your friends to use this service?

APPENDIX J

PERSONAL PREFERENCES AND EASE-OF-USE QUESTIONNAIRE

1. Please indicate the ease-of-use for medication and skincare tasks.

Activities	N/A	Every Easy	Easy	Average	Difficult	Very Difficult
Schedule medication alert						
Modify medication alert						
Response to medication alert						
Schedule skincare alert						
Response to skincare alert						
Record new skin problem						
Update the condition for existing problem						
Overall, configure personalized setting (when the option is available)						

*********Following questions for the redesigned apps **********

2. Please give a score from 1 to 10:

- 1: the feature is most important to you.
- 10: the feature is less important to you.

No.	Contents	Rank
1	Customized application list	
2	Customized text display size	
3	Customized theme (background with text color)	
4	Customized Button Size (from finger tip size)	
5	Customized keyboard	
6	Ability to take a picture of pill or med bottle	
7	Matched color for application name to the separator of action bar	
8	Short cut for navigation	
9	Text guide	
10	Voice guide	

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