Investigating Mobile Graphic-based Reminders to Support Compliance of Tuberculosis Treatment

By

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Supervised by:

Professors

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DECLARATION

I hereby declare that this Ph.D thesis is my own original work, and all sources have been acknowledged through referencing.

This work is being submitted for the degree of Doctor of Philosophy in Computer Science at the University of Cape Town, South Africa. This thesis has not been submitted, either in this or in any other university or institution for any other degree or examination.

Date: March 2017 **Signature:** Signed by candidate

Haji Ali Haji

ABSTRACT

The phenomenon of rapid increment of the mobile phones can be utilized through supporting patients, such as those who have tuberculosis, for treatment adherence. This utilization will enable these patients to directly communicate their needs and requirements or receive health information such as reminder messages from healthcare facilities. However, the current mobile interventions, such as text messaging and speech reminder systems have limited use for people with low literacy levels. To overcome these challenges, this study proposed that the mobile graphic-based reminders be used to support tuberculosis patients to improve compliance with treatment regimens, especially for semi-literate and illiterate patients. A review of the literature and initial investigation study were carried out. The findings from the review were useful in understanding both the current practice of tuberculosis treatment regimens and the patients' needs and requirements. These findings, in addition, were referred in the choices of the components of the mobile graphic-based reminders to be implemented. A visual aid for communication theory was applied to the design and development of graphic-based reminder prototypes. An application prototype was implemented for the Android platform. Experiments were conducted to investigate the effects of an application prototype in supporting tuberculosis treatment. To measure the effect, the recovery rate was measured based on the effect of: (1) the graphic-based reminder group versus the control group; and (2) the graphic-based reminder group versus the speech-based reminder group. Data was collected using application event logs, interviews, field notes and audio recordings. It was found that treatment adherence of patients in the graphic-based group was higher than in the speech-based or in the control groups. It was further noted that the number of reminder responses in the graphic-based group was higher than in the speech-based group. Additionally, it was observed that patients in the graphic-based group responded sooner after receiving reminder messages compared to those in the speech-based group. The qualitative feedback also indicated that most patients not only found graphic-based reminders more useful to supporting their treatment than speech-based reminders and traditional care but believed that the application met their needs. This study provides empirical evidence that graphic-based reminders, designed for and based on patients' needs and requirements, can support the treatment of tuberculosis for patients of all literacy levels.

PUBLICATIONS

The following publications have emanated from this study. The acceptance of these publications by the scholarly community has given direction, motivation and encouragement to the production of this thesis. In all cases, these published works have been updated and re-formatted into this thesis.

Peer reviewed conference papers

Haji, H. A., Suleman, H., & Rivett, U. (2014). Mobile Graphic-based Communication: Investigating Reminder Notifications to Support Tuberculosis Treatment in Africa. *In International Conference on Health Information Science (pp. 204-211).* Springer International Publishing.

Haji, H. A., Suleman, H., & Rivett, U. (2014). Developing Mobile Graphic Reminders for Reinforcing Compliance in Tuberculosis Treatment in Africa. *In Proceedings, the 1st International Conference on the Use of Mobile ICT in Africa. ISBN: 978-0-7972-1533-7, pp. 11-15.*

Haji, H. A., Suleman, H., & Rivett, U. (2015). Development of a Mobile Image-Based Reminder Application to Support Tuberculosis Treatment in Africa. *In Proceedings, 17th International Conference on Mobile Wireless Communication and Healthcare, Paris, France. Vol:9, No:08, pp. 522 – 529.*

Haji, H. A., Rivett, U., & Suleman, H. (2015). Evaluating the Effectiveness of mobile graphic-based reminders to support treatment of tuberculosis patients. *Beyond development. Time for a new ICT4D paradigm? In Proceedings, the 9th IDIA conference, Nungwi, Zanzibar. ISBN: 978-0-620-68395-1, pp. 189-201.*

Peer reviewed journal paper

Haji, H. A., Rivett, U., & Suleman, H. (2016). Improving compliance to tuberculosis treatment: Supporting patients through mobile graphic-based reminders. *J Public Health Dev Countries;* 2(3): 235-247.

DEDICATION

To my family:

To my mother and my father for their love, patience and support.

To my lovely wife for her understanding, patience and support.

To my Boys, Hatim and Hamid for their patience and love.

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LIST OF ABBREVIATIONS

AIDS	Acquired Immune Deficiency Syndrome
API	Application Programming Interface
ART	Antiretroviral Therapy
ARV	Antiretroviral
BG	Blood Glucose
CARDS	Computerized Automated Reminder Diabetes System
CIS	Commonwealth of Independent States
DOTS	Direct Observed Therapy Short-course
E	Ethambutol
ECG	Electrocardiogram
ENACQKT	Enhancing Nurses, Access for Care Quality and Knowledge through Technology
GBR	Graphic-based Reminder
GPRS	General Packet Radio Service
GPS	Global Positioning Systems
GSM	Global System for Mobile Communications
HAART	Highly Active Antiretroviral Therapy
Hb	Haemoglobin
HCD	Human-Centred Design
HCI	Human Computer Interaction
HIV	Human Immunodeficiency Virus
I	Isoniazid
ICT4D	Information and Communication Technology for Development
IDRC	International Development Research Centre

ISO	International Standard Organization
IVR	Interactive Voice Response
MDR	Multi Drug Resistant
MMS	Multimedia Message Service
PC	Pill Count
PDA	Personal Digital Assistant
PHC	Primary Health Care
PHNPP	Primary Healthcare Nursing Promotion Program
R	Rifampicin
RCT	Randomized Control Trial
RTMM	Real Time Medication Monitoring
SDGs	Sustainable Development Goals
SHC	Secondary Health Care
SMS	Short Message Service
SPSS	Statistical Package for the Social Sciences
SR	Self-Reported
TB	Tuberculosis
THC	Tertiary Health Care
TTC	Text to Change
UCD	User Centred Design
UI	User Interface
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
VAS	Visual Analogue Scale
WHO	World Health Organization
Z	pyraZinamide

"In fact there isn't really anything more personal than a mobile phone"

by Osibo Imhoitsike.

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Technological advancement can improve people's lives in various ways. One of the many basic aspects of human life that can be greatly affected, and in many cases improved, through technological advancement is the accessibility of the right to good health. This basic right to good health was identified in the UN's Sustainable Development Goals (SDGs), one of which is the goal to improve healthcare for all (UN, 2016).

The SDGs indicates that improving people's health is essential in reducing the poverty gap, especially in the poorest regions of the world. However, addressing this particular goal has proven to be challenging for many countries, especially developing regions.[1] Compared to developed countries, most developing countries

[1] According to the United Nations (UN, 2008), developing countries are those remainder countries excluding the United States, Canada, Australia, Japan, New Zealand, and Europe.

are faced with a shortage of resources, even in countries where there might be a high penetration of technology (ITU, 2014). Most of the currently existing and readily available technologies in the developing world are basic. In East Africa for example, there has been recent technological advancement in mobile money transfers, which allows people who have never accessed bank services before to safely transfer funds (Hellstrom & Troften, 2010, p.49-51).

Information and Communication Technology for Development, or ICT4D, is a widespread term used to refer to the multi-disciplinary research conducted on the application of technology to raise the level of development in the poorest countries of the world (Heeks, 2008; Ponelis & Holmner, 2015). ICT4D research has been evolving, especially in the field of mobile health, in an effort to improve healthcare services for the communities most in need. In the past few decades, posters, calendars, and personal visits have been used as methods to remind patients with chronic or infectious diseases to comply with their treatment. ICTs have also focused particularly on the use of mobile technologies to address healthcare issues (mobile health).

Mobile health, also known as mHealth or m-health, refers to the use of mobile devices such as mobile phones, tablet computers, and Personal Digital Assistants (PDAs) to support the practice of medicine and public health (Games, Yang & Kahn, 2010; Betjeman, Soghoian & Foran, 2013). It is a rapidly growing practice, especially with the increasingly frequent use of cellular phones for healthcare services.

Many studies have focused on the potential of m-health systems to improve patient management and treatment, including studies conducted by Reidel et al. (2008), Kunawararak et al. (2011), Vervloet et al. (2012), Nglazi et al. (2013), Iribarren et al. (2013), and Rana et al. (2015). These studies have addressed the use of mobile reminder systems to support treatment of Human Immunodeficiency Virus/Acquired Immune Deficiency Syndrome (HIV/AIDS), tuberculosis (TB) and diabetes. However, it is important to note that many of these studies were conducted in areas where resources and literacy levels are relatively high, and they did not consider the challenge of illiteracy (Kunawararak et al., 2011; Iribarren et al., 2013).

Therefore, this study aimed at interesting how m-health might be adapted in effectively addressing the healthcare needs of people in developing countries where low-resource and mixed literacy exists. More specifically, the study focuses on the use of a mobile Graphic-based Reminder (GBR) system to support improve adherence to TB treatment in the context of resource-limited settings and in mixed literacy populations.

1.2 Problem Definition and Motivation

TB is a global health concern, particularly in developing countries. Non-adherence to TB treatment is one of the major challenges in improving TB cure rates. TB treatment requires patients to take medication for a minimum period of six months (WHO, 2015). However, patients often do not follow the recommended treatment regimen. This normally leads to an extended recovery period and the development of resistance to the medication, eventually aggravation of the disease.

A patient who does not take his/her TB medication as prescribed is at a greater risk of treatment failure, relapse and the development of drug-resistant TB (WHO, 2012). The World Health Organization (WHO) highlights that the most common reason why patients miss medication is forgetfulness (WHO, 2012). Mobile technology has been identified as a potential method of supporting TB patients by helping to reduce patients' forgetfulness by encouraging patients to adhere to the treatment regimen through a reminder system (Kunawararak et al., 2011; Iribarren et al., 2013).

Mobile phones have become powerful personal tools. People in developing countries use mobile phones for communication and in order to gain access to and transfer information. Several studies have been conducted to find out the ways mobile technology can be used to access and transfer information in regards to education (Rashid & Elder, 2009; Porter et al., 2016), health (Blaya, Fraser & Holt, 2010; Chib, Velthoven & Car, 2015), business (Laukkanen & Lauronen, 2005; Boretos, 2007), and water and sanitation (Brown, Marsden & Rivett, 2012; Champanis & Rivett, 2012). Mobile phones have essential features that make their adoption for applications in developing regions promising. These features include low infrastructure investment, low energy consumption, simplicity of use, affordability of devices and services, and low vulnerability (Heeks, 2008).

The rate of use of mobile phones in developing countries has increased rapidly in the past decade (ITU 2014, 2015). Mobile phones can be used as a tool to improve human service delivery and are accessible to a large population with relative ease and low cost (Blaya, Fraser & Holt, 2010; Chib, 2013). In 2014, seven billion mobile phones were available throughout the world. Africa alone had more than 650 million subscribers. The penetration of mobile phones in Africa reached close to 20%, up from 2% in 2010 (ITU, 2014). Furthermore, Africa, Asia and the Pacific are the regions with the strongest mobile subscriber growth and the lowest penetration rate (ITU 2014, 2015). Figure 1.1 shows global mobile phone subscriptions per 100 inhabitants. In Africa, 69 out of 100 inhabitants are known to have mobile phones.

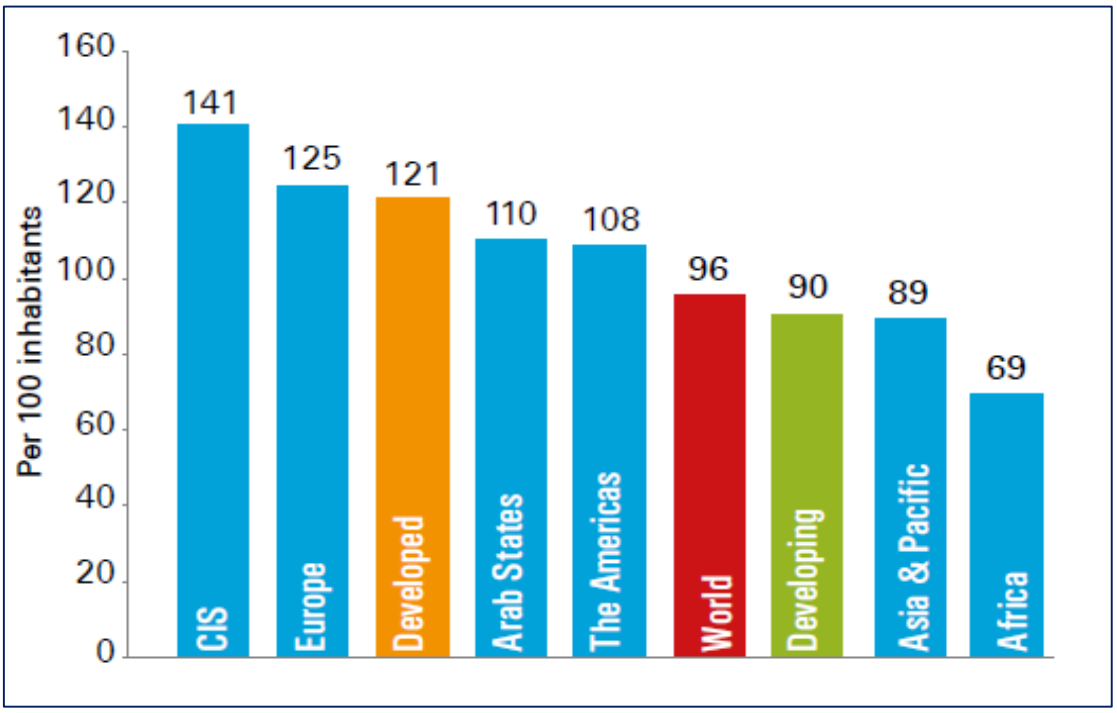

Figure 1.1: Mobile phone subscriptions per 100 inhabitants (Source: ITU Statistics, 2014)

Presently, various strategies have been proposed for the implementation of mobile reminder systems to support and improve treatment adherence for patients with TB (Kunawararak et al., 2011; Iribarren et al, 2013). Iribarren et al. (2013) conducted a study on TB patient's compliance with treatment programs. In this study, the patients were given daily Short Message Service (SMS) text messages to remind them of their treatment regimen. Kunawararak et al. (2011) described a mobile

reminder system in which TB patients were given daily phone calls to remind them to take their medication. The results of these studies showed that mobile reminders effectively improved patients' adherence to TB treatment. However, these systems did not take patients with low-literacy or illiteracy into consideration. Text messaging and phone calls are of limited use for certain patients (Caldwell, 2013; DeSouza et al., 2014). The only patients who would be able to benefit from SMS and phone call reminder systems are those who have the ability to read and understand a particular language.

To date, in Africa there are no studies cited on the implementation of GBR applications to promote treatment compliance through reminder systems. However, the use of images (graphics or pictures) for medical diagnosis has so far shown potential benefits (Savini, Vogt & Wenger, 2008; Tran et al., 2011). Tran et al. (2011) presented a picture-based system to support patient diagnostics. In this study, patients with skin infections were photographed using a mobile phone camera and the images were transmitted to medical experts for further diagnosis and treatment decisions. This study found that the use of images in diagnosis provided quicker treatment and allowed the physician to view and clearly understand the patient's problem, rather than via text or speech.

Picture-based applications have also been used to transfer radiological images in emergency neurosurgical consultations (Waran et al., 2012), transfer electrocardiogram (ECG) images for diagnosis, interpretation and treatment consultation (Bilgi et al., 2012), and share medical images between patients and doctors or between patients and families who are living far apart to share images of their medical conditions (Hyodo, 2005). Pictures have been also used to facilitate the communication of medication instructions to patients. Dowse and Ehlers (2001) investigated the influence of medication labels using pictograms to support patients' understanding of medication instructions. The study results indicated that the presence of pictogram instructions positively contributed to the patients' understanding of the medication instructions and patients' adherence to the treatment program (Dowse & Ehlers, 2001).

Other studies have shown that people understand and remember what they see much more readily than what they hear or read (Marsh & White, 2003; Houts, et al.,

2006). Albert Mehrabian's (1981) study on human psychology and communication found that humans retain 55% of information received via visual form, 38% of speech and only 7% of text. This finding indicates that people perceive and retain information more readily through visual communication than in texts or words (Mehrabian, 1981).

In this study, a mobile GBR system is proposed to support TB patients in their treatment regimen through a reminder system. The system makes use of graphics (as opposed to text or speech) to remind patients to follow their treatment regimen. Compared to other mobile interventions, a visual application is arguably more applicable, easy to use, and generally more comprehendible than other formats (Lipkus & Hollands, 1999; Gupta, 2008).

The GBR system is based on the Android smartphone platform. The motivation to use the Android platform was that, according to IDC (2016), in 2016, Android had 86.8% of the mobile operating system market share, making it one of the most commonly used mobile operating systems. The price of Android phones is rapidly declining, and becoming very close to that of feature phones, which are largely available in Africa. At the time of this study, the price of low-end Android phones was ZAR 449 ($37), which is equivalent to various basic feature phones. Android has made strong headway in Africa, and makes up 30% of the total mobile phone population (Africa Brains, 2015). Figures 1.2 and 1.3 show the market share of operating systems globally in 2015 (Adappt, 2015). Android has become the number one operating system for newly purchased smartphones, accounting for about half of new sales by 2015.

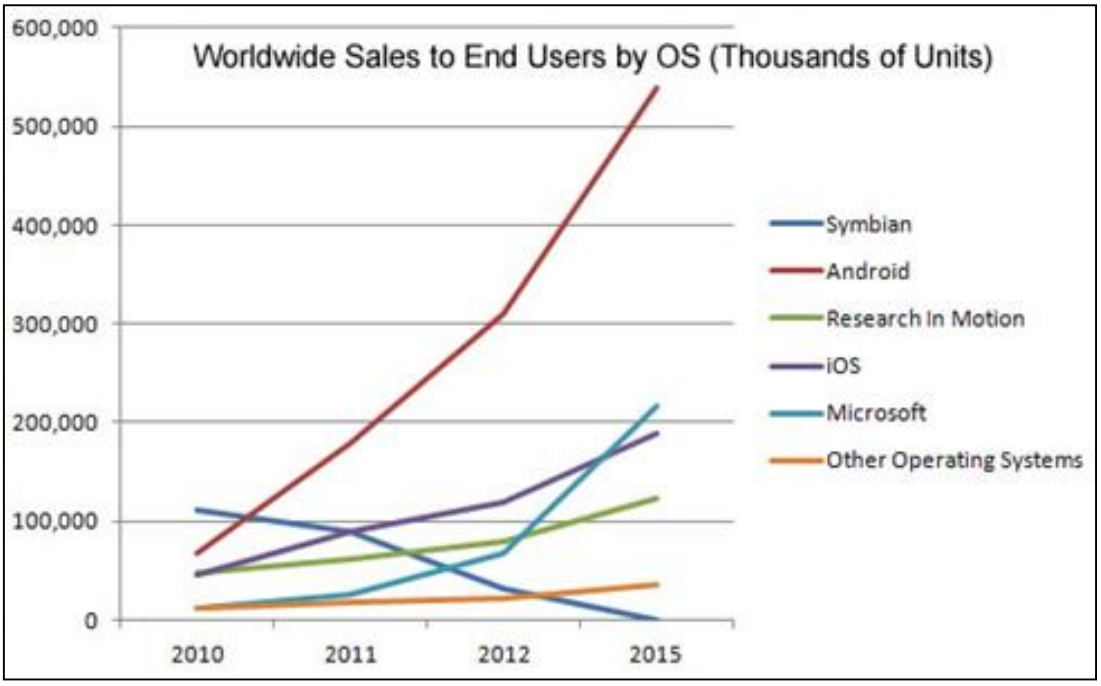

Figure 1.2: Worldwide sales to end users by operating system (Source: Adappt, 2015)

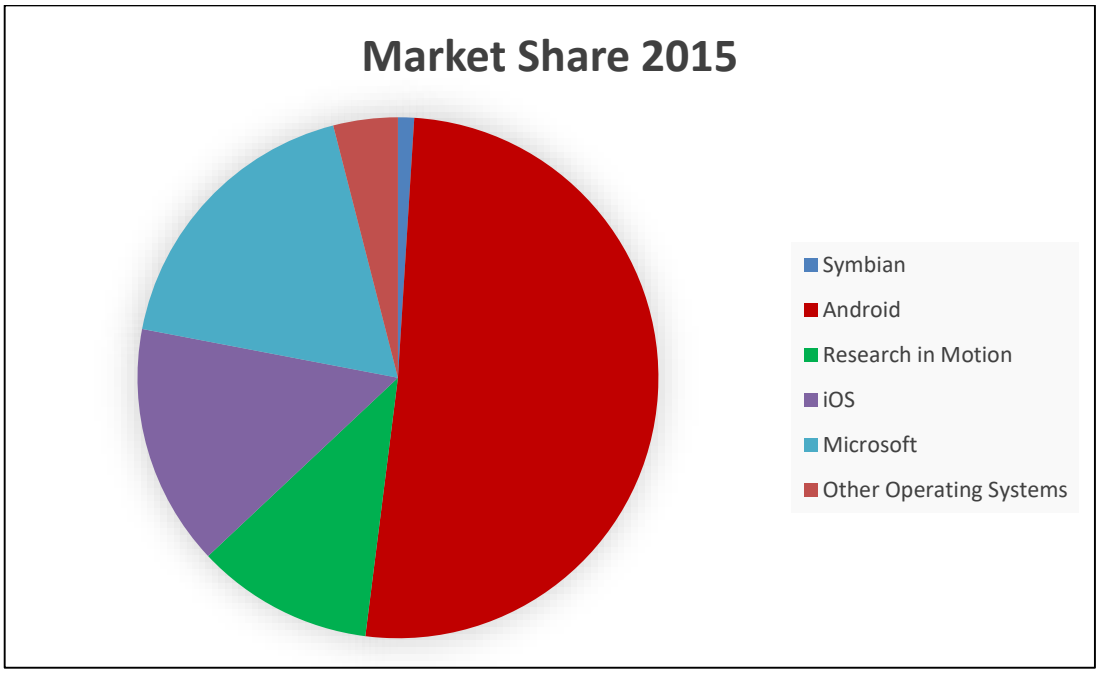

Figure 1.3: Market share of mobile operating system in 2015 (Source: Adappt, 2015)

1.3 What is a Reminder?

A reminder in the context of this study is defined as an action used to contact a patient shortly before he/she is due to take his/her medication or attend a clinic appointment in order to ensure adherence (Liu et al., 2010). There are various reminder strategies that have been used to support TB patients' treatment adherence. These include personal contact between the patient and health staff, calendar reminders, postal notices, alarm clocks, mobile alarm reminders, e-mails, mobile phone SMS text messages, and telephone calls (Liu et al., 2010; Tran et al., 2013).

1.4 Why Mobile Reminder?

The first reminder approaches used to support TB treatment rely on direct patient observation (such as when a patient is observed swallowing tablets by either a health professional or trained family member). This method is referred to as DOTS treatment (Direct Observed Therapy, Short-course). This type of therapy can prove cumbersome and impacts on the patients' right of confidentiality if a family member has to be asked to administer the therapy. Self-administration[2] systems (such as a mobile reminder system) have the potential to increase treatment success and can also make treatment more cost-effective (Thiam et al., 2007).

Postal, calendar, alarm and e-mail systems have also been tested as potential reminder strategies for adherence. These approaches have low rates of treatment success and are mostly used in small-scale TB control programs (Walley et al., 2001). Studies further indicate that e-mail systems are mostly used in high resource settings (Betjeman, Soghoian & Foran, 2013). Due to the rapid increase of mobile technology in the world, the use of mobile phones has been found to be an effective way to support TB treatment (Iribarren et al., 2013; Liu et al., 2014).

1.5 Research Question

The aim of this research was to investigate a GBR application, which could support TB patients in improving treatment adherence within the context of resource-limited and mixed literacy settings. In order to achieve this objective, the primary research question in this study was:

[2] Self-administration is defined as the process in which patient is swallowing prescribed tablets without a supervision from health staff or trained family member (Volmink & Garner, 2007)

RQM. Can mobile graphic-based reminders be used to support treatment compliance for tuberculosis patients in resource-limited and mixed literacy settings?

In addressing this research question (RQM), a GBR application was designed based on practical needs and within a theoretical framework, implemented, and tested. The following were the supporting sub-questions to complement the main research question.

RQ1. *What are the factors that contribute to the design and usability of graphic-based reminder systems?*

This research question investigates the factors associated with the design and usability of a GBR system.

RQ2. *How effective are mobile graphic-based reminders in supporting treatment adherence for TB patients?*

This research question addresses practical issues that are related to the effectiveness of a GBR system in supporting patients' adherence to TB treatment.

1.6 The Foundation of Study

Visual Aids for Communication is the theoretical foundation of this study (Ngoh & Shepherd, 1997). Visual communication is the transmission of information and ideas using visual objects such as graphics, symbols and photographs (Mehrabian, 1981). The "Visual Aids for Communication" theory proposes that people find it easier to understand the contents of a message through visual objects (Ngoh & Shepherd, 1997). In contrast to oral and written communications, visual communication enables the human mind to quickly retrieve information and makes a message easier to remember (Ngoh & Shepherd, 1997; Gupta, 2008). The basis of this theory is human psychology and communication (Mehrabian, 1981). The theory indicates that people perceive and retain information more readily through visual communication.

Practising new behaviours through visual observation is an important component of the theory. The practising of new behaviours results in TB treatment adherence to be more successful. The TB patient's treatment adherence is likely to increase when he/she receives medical reminders through visual objects. If the patient understands the content of reminder message, the compliance with treatment can be enhanced.

In addition, a number of studies have suggested that visual aids are a significant method of communication, particularly for low-literacy populations (Dowse & Ehlers, 2001; Medhi, Sagar & Toyama, 2006; Gupta, 2008).

This study therefore, focused on designing visual objects on mobile phones environment for supporting TB patients, particularly semi-literate and illiterate patients, to comply with their treatment. Chapter 4 provides a detailed description of this theory and how it is applied in this study.

1.7 Research Process

There were series of processes (as illustrated in Figure 1.4) followed in the investigation of this study. A mixed methods research approach was used to address the research questions. These include qualitative and quantitative approaches. The combination of these approaches provide a better understanding of the research problem (Azorin & Cameron, 2010). Data collection, analysis, and interpretation were conducted using a mixed methods approach. Chapter 4 presents details of the research process.

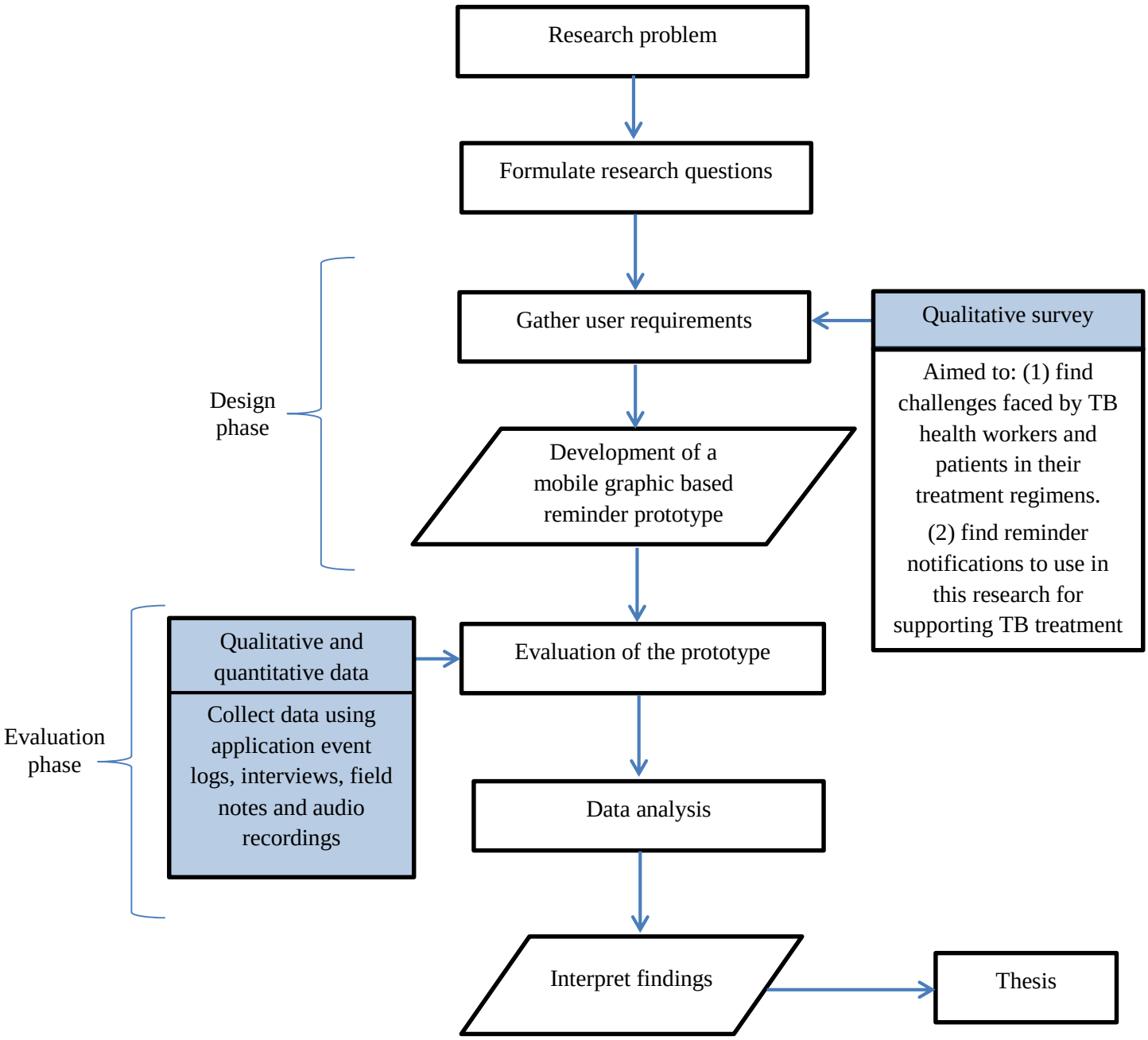

Figure 1.4: Flow chart showing a series of processes followed in the study

1.8 Research Contributions

This study has the following contributions to the field of m-health:

- Application of processes of the theory of Visual Aids for Communication in designing GBR reminders for TB treatment.
- An evaluation of the graphic reminders to assess the appropriateness for supporting TB patients to treatment adherence.
- A proof-of-concept for a GBR prototype in resource-limited and mixed literacy settings.

- Empirical evidence to assess the difference between GBR and speech reminder systems.

It is expected that the above contributions will generate interest among researchers and healthcare practitioners in developing an effective mobile GBR system to support patients with varying levels of literacy.

1.9 Research Limitations

The following were the potential limitations of the research:

- The research sample population was relatively small and fell within the treatment capacity of a few TB clinics in Zanzibar. Treatment may vary between different medical sites.
- The experimental deployment time was dependant on the timeline of TB treatment. This is a relatively short time and may therefore not represent cases that are on a longer treatment plan.
- The application prototype was developed on an Android smartphone. The findings may not be applicable to other handsets or operating systems.

1.10 Outline of the Thesis

Chapter 1 outlines the problem statements and motivation for the research, the research structure and the research questions. It also presents an overview of the approach taken for the research.

Chapter 2 presents the background information, including the conceptual foundation of the research.

Chapter 3 discusses the literature review. This chapter, and Chapter 2, provide the foundation for the research study.

Chapter 4 presents the theoretical framework and research methodology, including a description of the evaluation processes of the experiments.

Chapter 5 discusses the process and methodology of developing a prototype of the GBR system.

Chapter 6 presents the findings of the study, including: findings of a pilot (initial investigation) study, aimed at understanding the current practice of TB treatment

regimens and understanding patients' needs and requirements; and findings regarding the measurement of effectiveness of the GBR reminders versus speech-based reminders and traditional care.

Chapter 7 presents the discussion of the findings.

Chapter 8 presents the conclusions of the research.

CHAPTER TWO

BACKGROUND

2.1 Introduction

This chapter provides the background to the research in this study. The chapter begins by defining and describing the definitions of ICT4D and its significance in regards to the improvement of healthcare systems. This is followed by a discussion of an overview of TB and its treatment challenges. The chapter also discusses the healthcare system, including a definition thereof, as well as an overview and the categories that comprise the healthcare system. The chapter then discusses healthcare implementation challenges in Africa and other developing countries. The chapter ends with a description of the case study areas chosen for this research.

2.2 Information and Communication Technology for Development (ICT4D)

ICT4D, as its name indicates, consists of two major areas: (a) ICT (Information and Communication Technology) and (b) D (Development). The combination of both

terms is interpreted as the use of information and communication technologies to improve the lives of people, particularly those living in the poorer areas of the world (Unwin, 2009; Ponelis & Holmner, 2015).

Heeks (2008) defined ICT as technologies that facilitate the creation, management, storage and dissemination of information through telecommunications by electronic means. It is a broad term that comprises any communication devices or applications, such as television, radio, cell phones, computers and networks, hardware and software, satellites, and any applications and services associated with these technologies (Kleine & Unwin, 2009). This study focuses on cell phones and Internet technologies.

The term development is complex and has many different definitions. There are various dimensions of development, encompassing SDGs, individual's livelihoods and a nation's capability for socioeconomic development. According to Unwin (2009), development is concerned with economic growth and finding ways in which the economic systems of poor countries can be improved.

Thus, ICT4D can be defined as the use of ICTs in the fields of international development, socioeconomic development and human rights (Heeks, 2008; Ponelis & Holmner, 2015). Unwin (2009) points out that ICT4D is driven by the provision of appropriate technological solutions for the challenges faced by poor communities, rather than by an interest purely in the technologies themselves. Sterling and Rangaswamy (2010) noted that ICT4D research is mostly motivated by socioeconomic equity and loaded with interpersonal dynamics between the researchers and the community. Its objectives include income growth, education, health, water and sanitation and government service delivery (Gasco-Hernandez, 2006; Prakash, 2007). In the context of this study, ICT4D refers to the use of mobile phone technology to help patients with TB adhere to their treatment through reminder methods and the study expects to positively support patients in the routine of taking medication and attending clinic appointments.

2.3 Definition and Overview of TB

TB is an infectious disease caused by *Mycobacterium tuberculosis*. Pulmonary TB most often affects the lungs, while extra pulmonary TB can also affect other parts of

the body (Kaufmann & Britton, 2008). The disease is spread from one person to another through the air when someone who has contacted the TB lung infection coughs, sneezes, or spits. TB continues to be a major health problem in the world, particularly in developing countries. In 2012, there were almost nine million new cases of TB in the world, and more than one million people die every year because of this disease (WHO, 2013).

According to WHO, all countries are affected by TB, but about 85% of all cases occur in Africa and Asia (StopTB, 2011; WHO, 2013). Sub-Saharan Africa[3] has the largest number of TB cases. It is estimated that there are over 260 cases per 100 000 people (WHO, 2013). Out of the 22 countries that are referred to as 'TB high burden' countries, nine of them are in Africa. These countries are South Africa, Nigeria, Tanzania, Kenya, Uganda, Mozambique, the Democratic Republic of Congo, Zimbabwe and Ethiopia. High burden countries accounted for 80% of all estimated cases of TB worldwide (WHO, 2015). Figure 2.1 shows global TB incidence rates per 100 000 people in 2013 and Figure 2.2 shows percentages of TB patients with known HIV status from 2004-2014 (WHO, 2014; WHO, 2015).

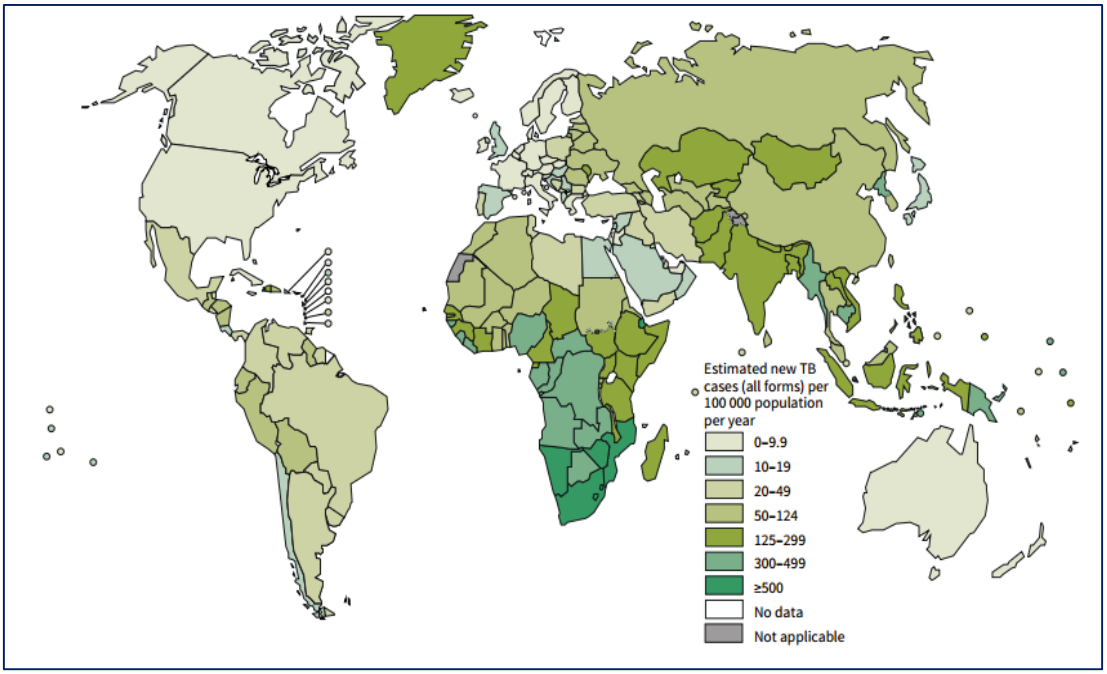

Figure 2.1: Estimated global TB incidence rates, 2013 (Source: WHO, 2014)

[3] Sub-Saharan Africa is the geographical area of the African continent that lies south of the Sahara Desert.

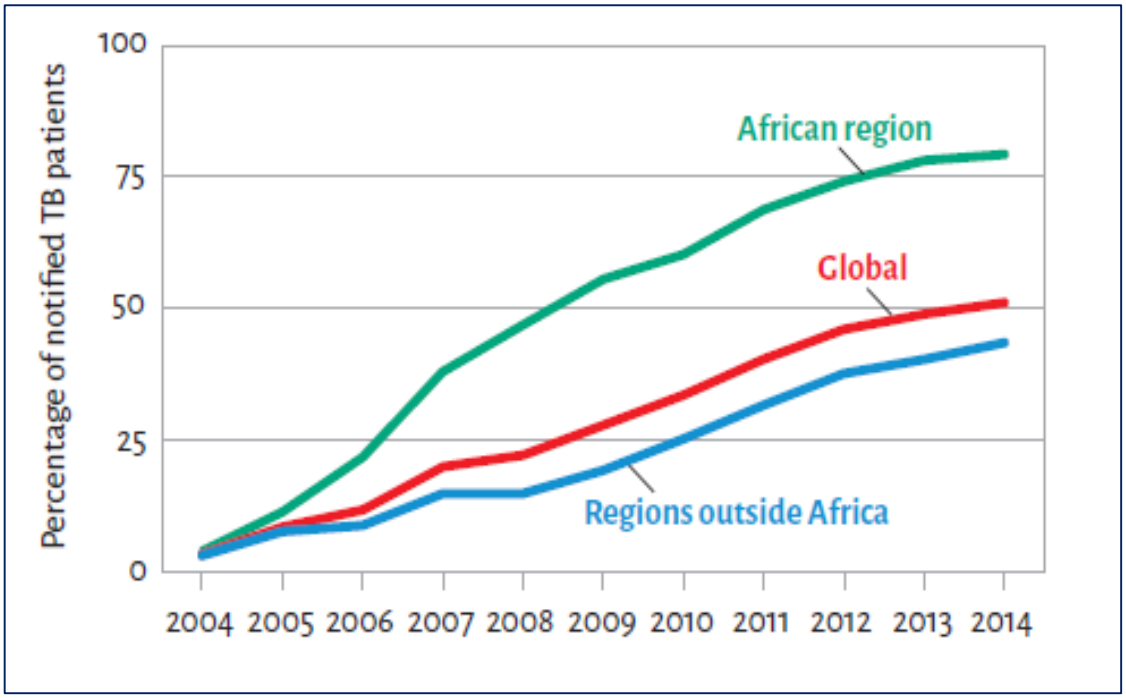

Figure 2.2: Percentage of TB patients with known HIV (Source: WHO, 2015)

2.4 Categories of TB Treatment

TB treatments are divided into three categories - Category I, II and III - as shown in Table 2.1. A new TB positive patient is assigned into Category I of treatment. The treatment entails taking medication once daily in pill form. The standard treatment regimen for an adult TB patient is usually from three to four tablets taken daily for the duration of six months (TZNational TB, 2011; StopTB, 2011). During the first two months, which are referred to as the intensive phase, a patient is given a combination of isoniazid (H), rifampicin (R), ethambutol (E), and pyrazinamide (Z) (StopTB, 2011; WHO, 2015). The aim of these drugs is to rapidly kill the actively growing bacilli. After two months of treatment, the combination of medication is usually reduced to two drugs - H and R. These are taken for the rest of the period of four months, which is known as the continuation phase. If the patient's sputum smear is still positive after six months, the treatment is deemed unsuccessful and the patient is then assigned to Category II treatment (WHO, 2015).

The Category II treatment entails injections for a period of three months as an intensive phase. After three months of treatment, the patient has to take tablets for a period of six months in what is known as the continuation phase. If the treatment is

unsuccessful after nine months, the patient is assigned to Category III for Multi Drug Resistant (MDR)-TB treatment (WHO, 2015).

MDR-TB treatment is administered in extremely serious cases. It takes up to two years for a patient to be cured from MDR-TB using second-line medication. The treatment starts with injections for the first six months. After that period the patient is required to take antibiotics daily until the end of the treatment period (WHO, 2015). The MDR-TB strain is treatable, but it requires extensive care. It is more expensive than medication-susceptible TB and is also more risky. Poorly supervised or incomplete MDR-TB treatment may cause the patient to incur serious health problems and also heightens the risk of infecting others (WHO, 2014; WHO, 2015).

Table 2.1: Types of TB cases (Source: WHO, 2013; WHO, 2014; WHO, 2015)

S/n	Type of case	Definition	Treatment phase
1	New case	A patient who has never had TB treatment before or has been on treatment for less than four weeks	Category I
2	Failure	A patient who, while on treatment, has a 'positive' sputum smear at the fifth month or later during the course of treatment	Category II
3	Relapse	A patient who was confirmed cured or treatment was completed but who reports back to the clinic and is found to have a 'positive' sputum smear	Category II
4	Return after default	A patient who returns to treatment, bacteriologically positive, after interrupting treatment for two months or more after taking treatment for more than four weeks	Category II
5	Chronic cases	A patient who has a 'positive' sputum smear after the second phase of treatment or a patient who coughs blood	Category III

The main goals of TB treatment are to cure the patient and restore their quality of life and productivity, to reduce the transmission of TB to others, to prevent relapse of TB, and to prevent the development and transmission of MDR-TB (StopTB, 2011; WHO, 2015).

According to the WHO, four rates are used to determine whether the treatment was successful or not. These are cure rates, completion rates, success rates and failure rates (Kochi, 2001; WHO, 2013). The cure rate includes patients whose sputum smear is found to be negative after completing the TB treatment in the last month of treatment. This includes, the patients would have a medication adherence greater than 90% (Awofeso, 2008; WHO, 2012). The completion rate includes patients who have completed TB treatment, but are not cured and therefore can be assigned to Category II. The success rate includes patients whose sputum smear is negative after the first or second month of treatment. The success rate can also refer to patients who were cured and completed the process of treatment (Kochi, 2001). The failure rate includes patients whose smear remains positive at the end of the treatment timeline (Kochi, 2001; Kunawararak et al., 2011).

2.5 Processes, Challenges and Opportunities in the Treatment of TB

Patient adherence to TB treatment is one of the most important determining factors in the control of the disease (WHO, 2014). Adherence can be measured by a patient showing improvement as a result of treatment, and includes appointment keeping, pill-taking success and cure rate. Good adherence is defined as a patient following the prescribed treatment and the ideal result is that the patient will be cured at the expected time. When a patient does not follow the treatment regimens as recommended by the healthcare provider, this is considered to be poor adherence. Poor adherence may result in a patient suffering extensive illness and disability (Sabate, 2003; WHO, 2014).

The DOTS is the most widely used approach to treat TB (WHO, 2012; WHO, 2013; WHO 2014; WHO, 2015). In this approach, the patient is observed when taking his/her medication. DOTS requires time, human labour and economic resources, all of which are in short supply in developing countries (WHO, 2012). DOTS necessitates face-to-face contact between the patient and a health worker. In the DOTS systems, a patient is usually required to go to the clinic daily and to take pills under the supervision of a healthcare provider. Due to the far distance between patients' homes and the DOTS centres, many patients are unable to make this daily trip and consequently miss medication. Kiros et al. (2014) and others highlight that

this is one of the main reasons for non-adherence (Adane et al., 2013; Kiros et al., 2014).

The DOTS system is challenging for most patients because it requires daily supervision (Adane et al., 2013). Studies show that patient self-administration therapy has shown improvement in treatment outcomes amongst TB patients in comparison to DOTS systems (observation) (Walley et al., 2001; Volmink & Garner, 2007). Nevertheless, it appears that patients often struggle to remember the time of medication. This means that in many cases it takes longer than necessary for TB patients to be cured. The medication may no longer be effective and the possibility of further aggravation of the disease increases. For this reason, adherence to TB treatment programs is a critical issue in the health sector, both from the viewpoint of health economics and the quality of life of TB patients. Technology-assisted DOTS is a useful method that can be employed to address this problem by reaching more patients at a lower cost through automated mobile reminders.

In recent years, mobile phone reminders have had variable success at empowering DOTS systems (Kaplan, 2006; Hoffman, 2010). SMS text messaging and speech messages have been suggested as reminder interventions to improve adherence to treatment, particularly for ART (antiretroviral therapy) adherence (which is administered to HIV positive patients). There are still various challenges that hinder the adoption of mobile reminder systems, especially in remote rural areas in developing countries. One of these challenges is illiteracy and language barriers (Haberer et al., 2010; Medhi-Thies, 2014). According to UNESCO (United Nations Educational, Scientific and Cultural Organization), there are more than 757 million illiterate adults in the world and the majority of them are in developing countries. The region of South and West Asia leads with more than half of the world's illiterate population (51%), followed by sub-Saharan Africa, where more than 25% of all illiterate adults in the world are found (UNESCO, 2015).

Chen et al. (2008) addressed poor mobile network connection as another challenge facing the implementation of mobile text message and phone call reminder systems. Compared to phone call reminder systems, text messages are preferred in areas where network connectivity is not stable (Kaplan, 2006; Chen et al., 2008).

The next section describes illiteracy and what constitutes illiteracy according to this research.

2.6 Illiteracy

Literacy has different meanings (McMillan, 1996) and its definition changes over time. In the traditional definition, literacy is considered to be the ability of a person to read and write, or the ability to use language to listen, write, read and speak. Literacy in modern contexts is further defined as the ability to read and write at an adequate level for communication, or at a level at which one can understand and communicate ideas in a literate society. This is also related to the concepts of 'ability' and 'competency.' Ability is associated with the use, access and creation of information through a digital medium such as computers (Atchoarena & Gasperini, 2003; UNESCO, 2006). Competency in modern contexts is typically related to technological literacy. Technological literacy is an extent to which an individual understands, and is capable of using technology (Prime, 1998).

Atchoarena and Gasperini (2003) define literacy as the quality or condition of being literate. It refers specifically to the ability to read and write. The Movement for Canadian Literacy (MCL) has developed guidelines for understanding literacy in broad terms (Murray et al., 2009). The MCL refers to literacy broadly using the terms 'literacy and essential skills,' which are categorised into nine skills including; reading text, writing, oral communication, numeracy, document use, thinking skills, continuous learning, working with others and digital use such as computers and mobile phones. Many of these are derived from an ability to read (Atchoarena & Gasperini, 2003; Huebler & Lu, 2012).

Literacy is also associated with a multiplicity of 'skills' that give a person the ability to understand and engage in activities that require literacy for effective functionality. Visual literacy is an example of multiplicity of skills. Visual literacy is a term that can be looked at from many fields and has many diverse definitions. Debes described visual literacy as an ability to comprehend, distinguish and interpret visual objects in the environment, integrate and use them to creatively communicate with others (Debes, 1969). To be visually literate can be viewed as having skills which enable someone to understand and use visuals for communication with others (Smith et al., 2004 p.479).

For the purpose of this study, the traditional definition of literacy has been adopted, which defines literacy as the ability of a person to write text and read and the ability to use language to listen, read, write, understand and speak. Semi-literacy is defined as the ability of a person to write his/her own name or recognize common words. And visual literacy is defined as the knowledge derived from visuals or pictures.

2.7 Definition and Overview of the Healthcare System

The WHO identifies healthcare as a human right with which everyone is endowed. Healthcare (also written as health care) refers to the process of diagnosis, treatment, and prevention of diseases, injury, illness, and other physical and mental impairments in human beings (WHO, 1981). It is an important component of any nation's development strategy, as the existence of good health in a country results in higher economic growth (Anand & Ravallion, 1993; Gough, 2016).

Healthcare systems are either organizations or institutions made up of people and resources who work together to deliver healthcare services in order to meet the health needs of the target population (WHO, 1981; HSS, 2005). There are several forms of healthcare systems that are adopted by different countries globally. These are categorised into three basic levels: primary, secondary and tertiary. Figure 2.3 shows the relationship between the three levels of the healthcare system.

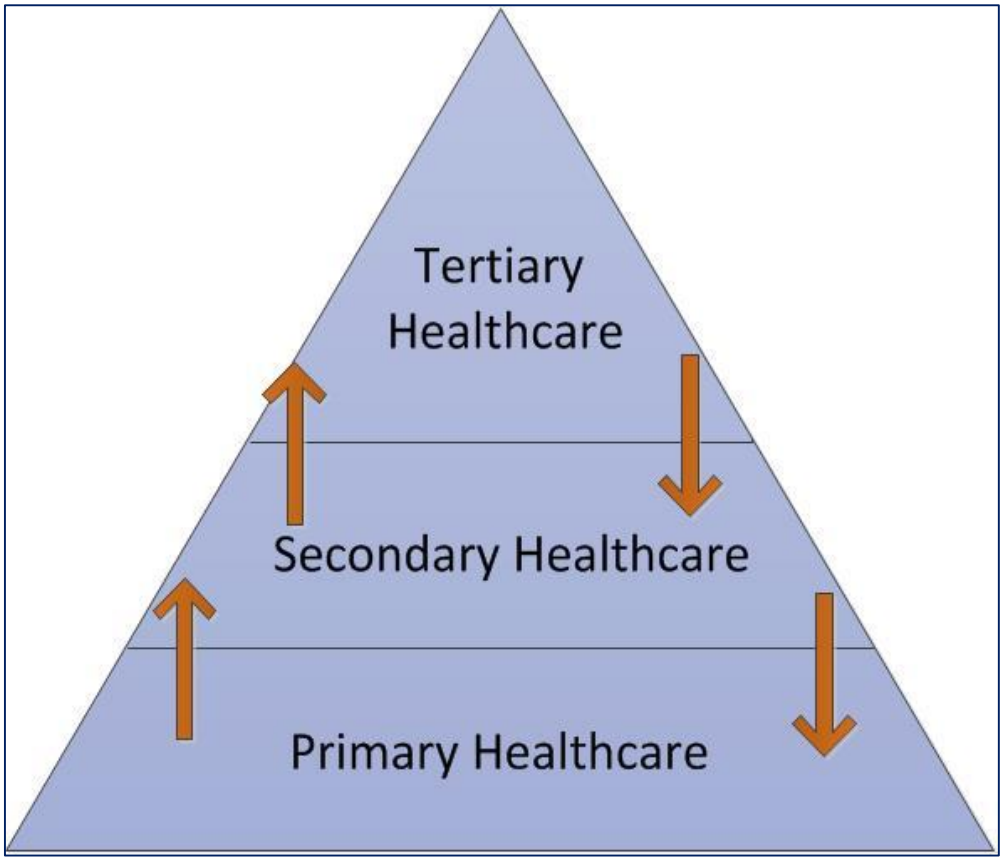

Figure 2.3: Categories of healthcare system

2.7.1 Primary Health Care

The first category of the healthcare system is primary health care (PHC). PHC is a healthcare service that involves individuals and families in the community in preventive and wellness care. It includes care for mothers and children in family planning, prevention of local diseases, treatment of common diseases, health education, and the provision of food and nutrition. Nurses or health care providers are usually involved in PHC. The primary goal of PHC is better health for all. This goal may be achieved by decreasing the risk of illness within a community and in individuals (WHO, 1981).

PHC is an important stage to be taken into consideration for the prevention of the transmission of diseases or illnesses.

2.7.2 Secondary Health Care

The second level of the healthcare system is Secondary Health Care (SHC). In this stage, a patient from PHC is referred to a specialist for further diagnosis and treatment. The goal of SHC is to detect illness in its early stages and advance

treatment in order to prevent further disease (Stange, 2010; WHO, 2012). The target users of this study are patients with active TB. Therefore, the aim of the study is to support their compliance with their treatment regimen in order to prevent further diseases or illnesses.

2.7.3 Tertiary Health Care

Tertiary Health Care (THC) is the third level of the healthcare system, in which patients from PHC and SHC get specialized consultative health care in order to restore them back to an optimal level of health (Stange, 2010; WHO, 2012). The main goal of THC is to decrease the risk of disability related to the disease. This is among the objectives of TB treatment. If TB medication is not taken as recommended by the healthcare professionals, there is a risk that the disease will become chronic and, as a result, a patient may become disabled or die.

2.8 Electronic Health (e-health)

At the end of the 19th and beginning of the 20th centuries, analogue telephony was used to deliver medical applications (Glinkowski, 2006). This technology enabled both the patient and doctor to call one another. A doctor or hospital could also transmit medical data such as electrocardiograms over telephone lines. This system was called ‘telemedicine.’ At that time, technology was in its early stages. The various challenges faced in telemedicine included the limitation of bandwidth, low rate of data transfer through phone lines (copper wires), and interference with other media, such as noise (ITU, 2008). In the middle of the 20th century, technology shifted into data digitization, digital networks and computerization.

E-health or electronic health is the method of transferring healthcare and health resources by electronic means (Glinkowski, 2006; Gaddi, Capello & Manca, 2013). The term ‘electronic’ includes the Internet and mobile and related technologies. However, other definitions have associated e-health exclusively with the Internet (Harrison & Lee, 2006). The term e-health covers all aspects of health and not only healthcare. There are two major scopes of e-health, namely public health and healthcare. In terms of public health, e-health refers to a government taking responsibility to prevent and respond to diseases (Blaya, Fraser & Holt, 2010). In healthcare, e-health addresses the treatment of diseases in individual patients (ITU,

2008). The major objectives of e-health systems are to assist prevention, diagnosis, treatment, health monitoring and lifestyle management.

There are different forms of e-health technologies that are currently being used to support the improvement of access to healthcare information for underserved people and to reduce healthcare delivery costs (Blaya, Fraser & Holt, 2010; Gaddi, Capello & Manca, 2013). These include:

- Electronic health records, which is a method of collecting patient or population health information electronically.
- Clinical decision support, which is a system designed to improve clinical decision-making in which the standards and protocols for doctors to use in diagnosing and treating patients are available electronically.
- Healthcare information system, which is the use of software solutions for supporting healthcare management.
- Telemedicine, which is a process of diagnosis and treatment at a distance through telephone or network communication.
- Mobile health, which is the use of mobile devices such as mobile phones for providing healthcare services and supporting patients' treatments.

This research focuses on mobile health, as discussed later in the literature review chapter (Chapter 3).

2.9 The Healthcare Challenges in Africa

The following sections describe the healthcare challenges facing people living in Africa. These challenges are based on observations, case studies and studies conducted.

2.9.1 Limited Education

A lack of schools and the low quality of many schools in Africa has resulted in many children failing to receive adequate education (Parikh & Lazowska, 2006). Similarly, the high rate of poverty has resulted in high dropout rates among school-age learners. Many children spend a significant portion of their time helping their families in agriculture, fishing and other activities to raise money for their household. Many people living in Africa, particularly in rural areas, are as a consequence of the poor schooling illiterate (Rouvinen, 2006). The UNESCO

Institute for Statistics reported that 40% of sub-Saharan African adults are illiterate. In some nations such as Ethiopia, Chad, Benin, Central African Republic, Ivory Coast, Liberia, Mauritania, Senegal, Burkina Faso, Niger, South Sudan, Guinea, Mali and Sierra Leone, almost 50% of adults are illiterate (UNESCO, 2015). The high level of illiteracy contributes significantly to the high burden of disease in poor countries (Kickbusch, 2001), especially because in many cases patients are unable to understand the oral and written information provided by healthcare professionals (such as the information provided on medication labels) (Ganasen et al., 2008).

2.9.2 Shortage of Healthcare Services

In addition to limited resources in the education sector, African countries are also faced with a lack of healthcare centres and a shortage of healthcare workers. Many existing healthcare centres are very far from residences. Poor infrastructure, such as road networks, further hinders many people's ability to reach clinics in time. Infrastructure plays an important role in the delivery of social and economic services. In many African countries, especially in rural areas, infrastructure such as hospitals and road networks are not well organized and in some regions do not exist at all (Smith, Lomba & Andersen, 2008; Jahan & Chowdhury, 2014). Consequently, many people do not have access to basic social services such as healthcare. Low income is another challenge that prevents many people living in rural areas from having access to adequate healthcare (Parikh & Lazowska, 2006).

2.9.3 Electricity

The availability of consistent electricity is an issue of concern in regard to the functionality and delivery of healthcare services. The power grids of many African countries are unpredictable (Parikh & Lazowska, 2006; Jahan & Chowdhury, 2014). Load-shedding[4] is common in many countries in both rural and urban areas in order to conserve energy. Although the African continent is well endowed with power sources, including renewable resources and fossil fuels, consistent and efficient electricity is still largely unavailable. This leads to the problem of regular blackouts. As a result, the unreliability of electric power, especially in rural areas, requires people to travel long distances to locations where electricity is available, such as towns or sub-towns for charging their mobile phones (Collings, 2011).

[4] Load-shedding is an action to reduce an electricity supply to avoid extra load on the generating plant.

2.10 Case Study Areas

According to Baker et al. (2006):

> "If you want to develop new technologies or innovate old technologies for different contexts, you are crazy if you don't go to those contexts. If you want to build something for Mexico, go to Mexico. If you want to think about what a piece of technology looks like in Nairobi or Cairo or rural South Australia, you have to go [to] those places because your own imaginings of them are often profoundly flawed."

This study is conducted in a resource-limited setting in Africa. Africa is the second most populous and second largest continent in the world. It has approximately 30.2 million km² of land, including adjacent islands. In 2014, there were over 1.1 billion people on the continent, making up about 15% of the world's human population (WorldData, 2015). According to the WHO, sub-Saharan Africa has a high percentage of new TB cases (WHO, 2013; WHO, 2014).

Tanzania has a population of 44.9 million people (NBS, 2012). The overall literacy rate in 2011 was 74% among people 15 years of age and older (UNICEF, 2013). In the year 2010, more than 63,000 TB cases were reported in Tanzania (NTLP program) (WHO, 2014). The rate of transmission of TB in Tanzania is 200-300 per 100,000 people. More than 73% of people have mobile phones in Tanzania (Poushter & Oates, 2015). In comparison, South Africa had an estimated population of 54 million people in 2014 (SAStatistics Report, 2015), and the adult literacy rate was 83% in 2013 (SAEducation Report, 2014). It was reported that in the year 2012 there were more than 300,000 notified cases of TB in South Africa (WHO, 2013). The rate of transmission of TB in South Africa alone is 700-800 per 100,000 people (SANAC, 2012; WHO, 2015). The percentage of South Africans who own mobile phones is currently 90% (Poushter & Oates, 2015). Tanzania and South Africa are among the 22 countries considered to be high burden TB countries. These countries were selected as case studies for this research. Two cities - one from each country - were studied, namely Zanzibar in Tanzania and Cape Town in South Africa.

Zanzibar is an autonomous part of the United Republic of Tanzania and has a population of 1.3 million (NBS, 2012). Zanzibar is an island located in the Indian Ocean 30kms off the coast of Tanzania, in East Africa.

Cape Town is the third most populous city in South Africa (after Johannesburg and Durban), with a population of 3.7 million.[5] It is the provincial capital of South Africa's Western Cape Province.

2.11 Chapter Summary

This chapter described the background of the research study. The chapter began with a discussion on TB, including a definition and overview of the disease. It also provided an overview of the treatment process of TB patients and presented challenges incurred in the treatment of the disease. Additionally, a definition of literacy was also presented. A discussion of the healthcare system, including a definition, an overview and the categories that comprise the healthcare system were also presented. This chapter also showed the overall challenges facing healthcare systems in Africa and other developing countries, among them - limited access to education, a shortage of healthcare workers, and infrastructure and electricity challenges. Finally, the chapter provided a description of ICT4D and its potential in supporting TB treatment and concluded with a discussion of the case study areas.

[5] http://en.wikipedia.org/wiki/CapeTown

CHAPTER THREE

LITERATURE REVIEW

3.1 Introduction

Many developing countries are concerned with supporting healthcare systems using mobile technology (Rashid & Elder, 2009; Nglazi et al., 2013; Chib, Velthoven & Car, 2015). This chapter reviews ways in which mobile technology has been used to support patients' compliance with treatment regimens and the healthcare system as a whole. The chapter begins with a discussion about mobile healthcare systems, key applications of mobile healthcare and their examples in developing countries. The chapter then discusses the forms of m-health communication. This is followed by descriptions of the potential, challenges and limitations of SMS, speech systems and Multimedia Message Services (MMS) in supporting healthcare systems. The chapter then presents discussions of related studies and concludes with the opportunities and gaps identified in the literature review.

3.2 Mobile Healthcare Systems

The growing area of m-health in low and middle income areas has contributed to an increase in the number of systems targeting patients, such as those with HIV/AIDS (Mbuagbaw et al., 2011; Okuboyejo, Omoregbe & Mbarika, 2012), malaria (Mabunda et al., 2009; Barrington et al., 2010), diabetes (Hanauer et al., 2009; Vervloet et al., 2012) and TB (Barclay, 2009; Kunawararak et al., 2011). A number of studies have been conducted in the use of mobile technology to support patients' treatment. Recently, mobile reminder systems have shown positive change in improving treatment adherence in comparison to traditional reminder systems, such as poster and calendar systems or care without any reminders (Pop-Eleches et al., 2011; Nglazi et al., 2013).

Furthermore, mobile phones have been integrated as health intervention tools in many healthcare aspects, including disease prevention, data collection (Zurovac, Talisuna & Snow, 2012), diagnosis and treatment (Naughton, Jamison & Sutton, 2013), and adherence management (Fenerty et al., 2012). Thus, in this study, mobile phones are proposed as a tool to support the treatment of TB.

3.3 Key Applications of m-Health

Applications of m-health within the field of global health can be categorized into six key areas, namely education and awareness; remote data collection; disease and epidemic outbreak tracking; communication and training for healthcare workers; diagnosis and treatment support; and remote monitoring and treatment adherence (Consulting, 2009, p.9). The following sections present these applications, including the descriptive characteristics of each type and examples.

3.3.1 Education and Awareness

Education and awareness is one area of m-health in which mobile phone services such as text messages are used to spread mass information from hospitals to people (Consulting, 2009, p.41). A text message is sent directly to the intended audience to offer information about disease management. Recently, various studies have been conducted globally with the aim of supporting the dissemination of education and awareness about specific diseases.

Bonny (2010) presented a system called Text to Change (TTC). The project was originally deployed in Uganda and it has since been adopted in several African countries, including Kenya, Tanzania, Namibia and Madagascar. The project employed an SMS-based quiz to test people who are living with HIV/AIDS and encouraged counselling and testing. The main objective of TTC was to support change by increasing the awareness of citizens regarding health issues.

In the same way, 'Learning About Living' is an interactive eLearning and mobile phone-based program that encourages young people to learn about health, AIDS, relationships, sex, and living skills (FLHE, 2009; Consulting, 2009, p.41). The project was deployed in Nigeria. It consisted of two parts: 'My question' and 'My answer.' With My question, a person could submit a question via SMS or phone call, and a trained health worker would attempt to answer the question. My answer, on the other hand, sends monthly questions to people about disease awareness. Trained health staff then select a winner based on the responses. The winners are awarded gifts as motivation and encouragement for other people to participate.

'HIV Confidant' is an initiative deployed in rural South Africa that encouraged people to test for HIV/AIDS (Welz & Herbs, 2008). The system ensured confidential, secure results. People who were tested were given a unique ID code and, once the results were declared, they received confidential results. This encouraged many people to participant in HIV testing. In the same way, this study focuses on encouraging patients with active TB to adhere to treatment, and it also contains information about education and awareness of TB.

3.3.2 Remote Data Collection

Remote data collection involves the use of mobile phones to collect and transmit data from a source area to a hospital quickly, cheaply and efficiently. The data includes the location and level of disease (such as chronic disease), and helps medical institutions to identify epidemics and target medical resources to affected areas (Consulting, 2009, p.43; Mechael et al., 2010, p.23).

One example of a remote data collection project is 'PDA for Malaria monitoring' in Mozambique (Mabunda et al., 2009). The aim of the project is to collect malaria data from households and transmit them to a central database via a General Packet Radio Service (GPRS) network to facilitate informed decision-making. The PDA

was integrated with Global Positioning Systems (GPS), which shows the location of the health worker who entered the data. The GPS system ensures that the data is entered at the field area and not from field workers' homes.

Barrington et al. (2010) discussed SMS for life, a program that supports the recording of anti-malaria drug stock levels. Mobile phone SMS text messages are used as the method of communication. The system sends an SMS to a registered healthcare worker requesting stock counts. The health worker then replies via SMS regarding anti-malaria drug stock levels. This system was deployed in Tanzania.

A similar approach known as TRACnet was also deployed by Frasier, May and Wanchoo (2008). TRACnet is a data entry, storage, access and sharing system implemented in Rwanda. The project aimed at managing information about people living with HIV/AIDS. The system provided support for monitoring Antiretroviral (ARV) therapy drug stocks from remote hospitals. The reports were then submitted electronically in real time to the central hospital for further decision. The system also provided rapid access to blood test results in remote facilities.

In an attempt to support the collection of medical data using mobile phones, Curioso et al. (2005) also presented cell-PREVEN, a system that enables health workers to use mobile phones to collect and transmit medical data from the field to a central database. The study found that mobile phones helped to report medical data in real time and an expert decision was made promptly. It was also evident that the use of cell phones in remote rural communities to assist data collection is technically feasible.

Additionally, Open Data Kit (ODK) is a suite of tools that has been widely used for remote data collection and management, particularly for studies that require more and a larger variety of data (Macharia et al, 2013). Tierney et al. (2007) presented a study in which ODK had been used as a tool for collecting, managing, and reporting clinical data to improve electronic medical record system to support HVI/AIDS care. Dell et al. (2013) proposed an ODK scan, as a standardized data collection and reporting mobile application to track community health workers' consumption of health commodities in Mozambique. These studies indicated, that when using ODK tools, data was collected and managed simply. It also helped to quickly digitize, aggregate and disseminate the collected data.

3.3.3 Disease and Epidemic Outbreak Tracking

Another m-health application is disease and epidemic outbreak tracking. The projects in this area are focused on monitoring the spread of infectious diseases by establishing patterns of progression. Mobile phones and other ICT devices can be used to track disease movement. The main objective of disease and epidemic outbreak tracking is to prevent the spread of diseases and minimize the harm (Consulting, 2009, p.58; Mechael et al., 2010, p.36).

Handhelds for Health[6] was deployed in India with the aim of identifying the transferable disease trends within the country. Field health workers were empowered to use handheld mobile devices to collect and transmit disease data from remote communities to a central public hospital (Consulting, 2009, p.60). Another project was introduced by Lescano et al. (2003), called Alerta DISAMAR, and deployed in Peru. The system allowed health workers to access and report disease outbreaks from rural areas to central hospitals through either mobile phones (i.e. text message, voice call) or the Internet (i.e. e-mail). The results found that Alerta DISAMAR helped to report disease outbreaks once it happens, so it assisted in preventing the spread of disease.

3.3.4 Communication and Training for Healthcare Workers

One of the most common challenges in developing countries is a shortage of healthcare workers. Projects in this area aim to train new health workers and empower current ones in order to increase job satisfaction and meet human needs (Consulting, 2009, p.55; DeRenzi et al., 2011). 'Health Line' was launched in Pakistan with the aim of training semi-literate community health workers through mobile phones (Sherwani et al., 2004). Health workers were able to learn about a specific health topic or disease through the Health Line system.

Similarly, the International Development Research Centre (IDRC) and the University of Saskatchewan deployed a system called Enhancing Nurses, Access for Care Quality and Knowledge through Technology (ENACQKT) in the Caribbean that empowered health workers by providing training through PDAs (Petrucka, 2012). The aim of ENACQKT was to build health workers' capacity and provide the means to access healthcare applications through technology (Petrucka, 2012). A

[6] http://healthmarketinnovations.org/program/handhelds-health

similar program entitled the Primary Healthcare Nursing Promotion Program (PHNPP) aimed to increase the number of nurses in rural areas of Guatemala. The program succeeded in teaching different nursing courses through mobile phones. The PHNPP continues to train virtual nurses (Consulting, 2009, p.56).

3.3.5 Diagnosis and Treatment Support

Developing countries suffer from a shortage of doctors and healthcare centres, especially in remote rural areas. Diagnosis and treatment support projects are designed to provide direct diagnosis and treatment of patients using remote communication (Consulting, 2009, p.62). In these kinds of projects, a mobile device is used to collect a patient's diagnostic data. Diagnostic data can be filled out electronically by either the patient or a health worker and forwarded to a doctor through mobile technology for a treatment decision. The primary objective of these projects is to reduce a patient's travelling cost and waiting time.

TeleDoc, an initiative deployed in India, was designed to connect community health workers with doctors. The system allowed remote diagnosis and treatment, through which health workers from remote rural areas could collect patients' diagnosis information and submit them to doctors electronically in real time. Communication between doctor and health worker occurs through mobile technology (Consulting, 2009, p.66). Sutjiredjeki et al. (2007) discussed an approach called the Mobile Telemedicine System (MTS), which provides remote consultation and diagnosis. A patient and a doctor using any ICT device, such as a mobile phone, landline phone, or the Internet, were able to share real time health information. The patient was able to ask any health related questions and receive appropriate answers from the doctor.

Furthermore, Zimic (2009) showed a mobile phone is used to support the diagnosis of TB. In this study, heath care workers using mobile phones captured patient images taken by an inverted microscope. The photography was then transferred to a medical expert for further diagnostic processes.

3.3.6 Remote Monitoring and Treatment Adherence

Remote monitoring and treatment adherence is another m-health project area. This is one of the areas most likely to grow in regard to the use of mobile phones in the healthcare system (Consulting, 2009, p.50; Mechael et al., 2010, p.15). Patients,

particularly with infectious diseases, can receive messages while at home. The purpose of the messages is to remind them to follow their treatment regimen.

SIMpill is a project deployed in South Africa, with the aim of reminding patients to take their pills (Madyo, 2010). SIMpill works by equipping a pill bottle with a SIM card and transmitter. When a patient opens the pill bottle, a text message is sent directly to a healthcare worker. If the pill bottle is not opened at the expected time, the patient receives an SMS that reminds him/her to take his/her pills (Barclay, 2009; Bosch, 2009; Madyo, 2010). SIMmed is a rival of SIMpill. SIMmed claims to be less expensive than SIMpill (Madyo, 2010). A patient in the SIMmed system is asked to press the speed dial button on his/her mobile phone after taking medication. The phone connects to the server to record the patient's confirmation. If a patient fails to dial the number, a reminder is sent to him/her via SMS or he/she is contacted by a health worker who reminds him/her to take the pills (Barclay, 2009). This present research considers this type of m-health application (remote monitoring and treatment adherence) for supporting TB patients to adhere to their treatment.

3.4 Forms of M-Health Communication

In m-health systems, the communication between sender and recipient can be either one directional (one-way communication) or two directional (two-way communication) (Hardy et al., 2011; Wald, Butt & Bestwick, 2015). One-way communication is a communication system in which the flow of information is from one side to the other. In mobile reminder contexts, usually a healthcare worker or application sends reminder messages to a patient to remind, educate or encourage the patient regarding disease care or treatment adherence. One-way text messages have been used as a communication tools in many areas such as: providing information about HIV (Lester et al., 2010); encouraging patients to take their ARV medication (Curioso et al., 2005); encouraging patients to follow their treatment regimens (Mbuagbaw et al., 2011); and supporting patients to remember their clinic appointment times (Da Costa et al., 2010).

A two-way communication flow of information is from both sides, involving both the sender and the recipient. The interaction could be in real time (as in the case of a phone call) or asynchronous (such as via SMS text message). In this form of communication, a health worker or application sends a message to a patient

reminding him/her about medication adherence. The patient has the opportunity to text in, give feedback (reply) to the sender, or indicate his/her health information.

'MedAlert' is an example of two-way communication system. This system aimed at promoting compliance to HIV treatment (Okuboyejo, Omoregbe & Mbarika, 2012). Patients received text messages to remind on their treatment adherence. They were also asked to respond to indicate whether the medication was taken or not. Computerized Automated Reminder Diabetes System (CARDS) is another example of two-way communication system. This system designed to encourage patients to do Blood Glucose (BG) monitoring. The patients were also required to submit their BG value for further progressions (Hanauer et al., 2009). Other two-way communication systems are presented by Sidney et al. (2012) and Dowshen (2012). The patients were asked to respond to the system soon after they had taken the pills. These studies aimed to support patients' adherence to ARV medication.

Hardy et al. (2011) explain that two-way communication has more benefit compared with one-way communication, because it provides information that the recipient has to confirm receipt of. Compared with one-way (reminder only), the two-way text messaging (reminder plus patient reply) had shown effectiveness in improving patients' medication adherence (Wald, Butt & Bestwick, 2015).

Furthermore, the two-way system is more interactive than one-way communication (Hardy et al., 2011; Rana et al., 2015). Studies found that patients were more likely to adhere to treatment when the two-way communication system was used, compared with one-way communication systems (Wald, Butt & Bestwick, 2015; Sutjiredjeki et al., 2007).

In this study, two-way communication is proposed. The patient is asked to reply or confirm that he/she has received the message by completing an action. This is described in detail in Chapter 5.

The next section describes the types of mobile phone interventions used for accessing healthcare and provides examples of a one- and two-way mobile reminder approaches.

3.5 Mobile Phone Interventions for Healthcare Application

The main capabilities of mobile phones that are used for providing healthcare services are text messaging (Back & Makela, 2012; Caldwell, 2013) and phone calls (Puccio et al., 2006; Kunutsor et al., 2010). However, some studies argue that there are advantages to MMS, such as image and video, which can also be used to support the practice of medical care (Hoffman et al., 2010; Bilgi et al., 2012). The following sections provide descriptions and examples of each of these mobile interventions.

3.5.1 Short Message Service Intervention

SMS, also known as text messaging, is a component of mobile communication systems that allows for messages of up to 160 characters to be exchanged from one mobile device to another (Deglise, Suggs & Odermatt, 2012; Perosky et al., 2015). Today, SMS has become a widely used method of communication. SMS messages offer many benefits compared to other mobile communication services, including better reliability of services. SMS is available on all mobile phones, including cheap low-end phones (Deglise, Suggs & Odermatt, 2012; Zurovac, Talisuna & Snow, 2012).

SMS messages can be sent, stored, answered and retrieved. The store feature is also known as 'store and forward.' This feature helps to store messages if the recipient's mobile phone is not available and forwards them immediately when the phone becomes reachable (Caldwell, 2013). This technique is preferable in areas where mobile networks are unpredictable.

Further, SMS messages have the capability to reach large groups, even those who live in remote rural areas in developing countries. This makes it suitable to assist with healthcare services (Back & Makela, 2012). In low-resource environments, the SMS has largely been used to spread mass information about disease awareness (Mimunya, Kredo & Volmink, 2012, p.5) and support treatment adherence through reminder systems (Prasad & Anand, 2012; Iribarren et al., 2013). In relation to reminder systems, literature mostly demonstrated the potential of mobile phone SMS messages to support patients' medication adherence (Pop-Eleches et al., 2011; Nglazi et al., 2013) and clinic appointment attendance (Lund et al., 2012; Naughton, Jamison & Sutton, 2013). The following are examples of studies showing the potential of text messaging in supporting healthcare systems.

Prasad and Anand (2012) investigated the use of mobile SMS messages in reminding patients to keep their appointments. The study was conducted at the Centre for Dental Studies and Research in India. Participants received SMS reminders 24 hours before their appointment date and on the appointed day to remind them to attend clinic. It was found that the attendance rates of patients was significantly higher in the intervention group (79.2%) compared with the control group (35.5%) (Prasad & Anand, 2012).

A similar approach was undertaken by Mbuagbaw et al. (2011) in which they assessed the efficiency of mobile text messaging reminders compared with usual care. The study aimed at improving the treatment adherence of HIV patients in Cameroon. The communication was one-way, and participants in the mobile intervention program received a weekly SMS reminder encouraging them about drug adherence. The participants in the control group were given face-to-face consultations. In the six months of the trial, the study found that patients in the mobile group improved their rate of adherence to treatment to 80%, compared with 60% for those patients in the control group (Mbuagbaw et al., 2011).

The impact of mobile reminders over control care was also assessed by Lester et al. (2010). The study was conducted in Kenya with patients who are HIV positive. Participants of this study were categorised into two groups: the mobile group (which received a weekly SMS reminder) and the standard care group (which received no reminder). The aim of the study was to measure the impact of treatment. Furthermore, those participants in the mobile group were requested to respond within 48 hours after receiving a reminder. The study findings showed that patients with mobile reminders had significantly improved ART adherence compared with those in standard care.

The potential of mobile phone reminder messages is presented by Okuboyejo, Omoregbe & Mbarika (2012). In their research, a Mobile Med Alert application was developed, which was a phone-based reminder that aided HIV/AIDS patients in remembering medication times and dosage. The system was deployed in Nigeria. In this study, two-way communication was used, in which patients received daily-automated SMS reminders to enhance their compliance with drug regimens. The system also contained a feature that allowed patients to reply to SMS alerts to

indicate whether they had taken the pills or not (Okuboyejo, Omoregbe & Mbarika, 2012). It was found that the Mobile Med Alert significantly improved the patients' adherence. In the research conducted for this thesis, the patient is also asked to respond by pressing a feedback button after taking the pills.

Lund et al. (2012) examined the effectiveness of mobile phone reminders over control care in improving the attendance rate of pregnant women in Zanzibar. Those participants in the phone intervention received automated SMSs that reminded them about health education and appointments, to encourage attendance at the clinic. Participants were also given mobile phone vouchers that allowed them to make short calls; afterwards a primary health worker would call them back. Those participants who were in usual care received consultation when they visited the clinic. After a one-year trial, it was found that cell phone intervention increased skilled delivery attendance of pregnant women to up to 60%, compared with 47% of the control group (Lund et al., 2012).

These studies show that compared with the control groups (who received traditional care), the intervention groups have positively supported patients' compliance with their treatment. However, the text messages still faced the problems of language and literacy barriers (Caldwell, 2013; Medhi-Thies, 2014; DeSouza et al., 2014), particularly in the rural areas of developing countries where the highest number of illiterate people reside (Kickbusch, 2001; UNICEF, 2013). For instance, a study by Kaplan (2006) that aimed at reminding patients of their appointments using an SMS text message intervention reported illiteracy as a barrier. It was found that illiteracy was a major barrier for patients who do not understand the meaning of the messages because the language used to send the SMSs was not familiar to them. Thus, this present research focused on GBR applications as opposed to text messages.

3.5.2 Telephone Call (Speech) Intervention

Telephone calls or voice calls are a component of mobile phones where the sender and recipient communicate using voice/sound. In comparison to SMS, telephone call services are more expensive. The longer the voice call, the higher the cost. However, a phone call provides real time interaction between the sender and the receiver.

The phone call reminder system can be categorized into three groups: automated phone call, live (direct) phone call, and interactive voice response. All these types

can be used in supporting patients' compliance with treatment or encouraging patients to attend follow-up appointments (Fenerty et al., 2012).

a. Automated phone calls can be used as one-way mobile reminders in which a database sends automatic messages to recipients reminding them regarding disease care or treatment adherence.

Pai et al. (2013) presented an automated voice call system to promote adherence to iron supplements among pregnant women in a low-income area in India. The study assessed the impact of haemoglobin (Hb) levels in the blood of pregnant women. Participants received automated voice calls three times per week, encouraging them to take iron supplements. The findings were that the use of phone call reminders positively impacted the Hb levels of pregnant women. However, there were participants who were unreachable due to their phone numbers being out of service (Pai et al., 2013). Telephone call reminders usually require strong network signal and wide coverage (Chen et al., 2008) in order to reach many people, and these two requirements are among the major challenges facing developing countries (Aker & Mbiti, 2010). Additionally, Prasad and Anand (2012) and Perron et al. (2013) addressed language barriers as another challenge facing phone call reminder systems.

Chen et al. (2008) also addressed the efficiency of mobile phone reminders in comparison with groups that do not receive reminders. The trial was conducted at Sir Run Run Shaw Hospital in China, with the aim of detecting adult diseases at early development stages. They compared three interventions: SMS, automated phone call and usual care. The participants in the intervention groups received reminders encouraging them to attend the clinic. Those who were in the usual care group did not receive any reminders. The cost and attendance rates for mobile reminder groups were collected. The results showed that mobile reminder participants had a significantly improved attendance rate compared with those who were in the control group. It also found that the SMS intervention was cheaper than the telephone reminders (Chen et al., 2008). However, both SMS and phone call interventions require the operational cost of mobile network operators' service charges.

b. Direct phone calls are a two-way mobile phone reminder system in which a patient directly receives an interactive call from a healthcare worker. Both the health worker and patient interact on the call in real time. Real time communication might have more potential for a patient as he/she can discuss his/her health condition directly with the health worker. The intervention, however, requires high operational costs and this is a challenge, particularly in low and middle-income countries. At present, quite a number of studies have focused on direct call technology globally.

Puccio et al. (2006) presented a HAART (highly active antiretroviral therapy) mobile reminder system to support HIV patients and to increase adherence. A study was conducted in Los Angeles, USA. Participants received direct phone reminders to assist with their adherence to HIV medication. They were also given airtime vouchers to make calls to ask various questions regarding their health development. The study findings showed that most participants found that the mobile reminder was helpful in assisting patients in treatment adherence. It also found that using mobile phones to remind patients does not require a lot of the daily health workers' time.

A direct call reminder system for supporting patient's adherence to treatment regimes was also presented by Kunutsor et al. (2010). The study investigated the impact of mobile phone usage for improving clinic attendance in an ART cohort in Uganda. Patients were given direct calls to remind them to visit the clinic for refilling their medication. The findings were that even though a mobile reminder was found to encourage patients to visit a clinic frequently, the intervention was very costly (Kunutsor et al., 2010). The findings of these studies show that the use of direct phone calls in supporting patients' treatment adherence is very costly, which makes it infeasible for most developing countries.

c. Interactive voice response (IVR) is a technology that allows for an exchange of information to and from a database. It is a computer-linked telephone in which a system interacts with a human through pre-recorded speech, and it allows human response through speech recognition or touch-tone keypads. The distinction between IVR reminders and automated and direct call reminders is that IVR technology allows users to interact with the database and does not require human interaction as direct calls do. The IVR system is mostly used by banks and credit card companies

as a customer can receive up-to-date information without directly communicating with a person. In recent years, IVR has been studied for its use as a reminder intervention to support patients' adherence to treatment regimens (Reidel et al., 2008; Crawford et al., 2005).

A study by Reidel et al. (2008) discussed the feasibility and accessibility of mobile IVR for reminding chronic patients to take and refill medication. The study was conducted in Canada. Patients were asked for their phone numbers and had the option to choose the right time they preferred to receive a call. The IVR system then telephoned patients to remind them of daily medication and/or to refill drug prescriptions. Participants also had the option to make free calls to the system to update their information, and stop or withdraw from the system. The study finding was that the participants reported that the IVR system is an acceptable and effective method to support them in their treatment processes. However, there were major technical problems reported, including incorrect call times and difficulties with voice recognition (Reidel et al., 2008).

Sidney et al. (2012) examined the usefulness of mobile phone IVR reminders and pictorial SMSs to help support adherence to treatment among HIV patients in Bangalore. The pictorial SMS messages were black and white images created on feature phones to remind patients to take their medication. Participants received IVR reminders once a week and they were asked to respond by pressing keypad buttons: '1' for 'Yes' if a patient has taken the pills or '2' for 'no.' Furthermore, participants received pictorial SMSs once a week, three days after the IVR. Compared with pictorial SMSs, the IVR reminder was preferred by many participants. The majority of participants reported that they did not receive SMS messages and some reported that they did not know how to use the SMS feature on their cell phones. A similar approach was also reported by Rodrigues et al. (2012) in which participants reported that IVR mobile reminders were more helpful in reminding them to take their medication compared to SMS. However, mobile SMS is more cost-effective compared to IVR intervention.

3.5.3 Multimedia Message Service Intervention

MMS (Multimedia message service) extends the core SMS ability to include sending messages that include multimedia content (such as images and videos) to

and from mobile phones. Compared with SMS, MMS has more potential for usage in healthcare (Back & Makela, 2012; Waran et al., 2012). However, at the moment there is limited literature on this application. MMSs (image, video) have potential to convey a diagnostic problem clearly. Literature shows that people understand pictures more clearly than text or speech (Mehrabian, 1981; Medhi-Thies, 2014). The existing studies in this area suggest that MMS images can be used to either support diagnosis (Ohtsuka et al., 2007; Farber et al., 2011), assist treatment follow up (Martinez-Ramos et al., 2009; Walker et al., 2011), or support diagnostic measurement data i.e. ECG (Mitra, Mitra & Chaudhuri, 2008; Tahat 2009). Despite the potential of image technology, so far, no study has been cited that suggests the use of mobile graphics to support compliance to treatment through a reminder system.

Tran et al. (2011) demonstrated the use of multimedia images for supporting skin disease diagnosis and consultation. A pilot study was conducted in Cairo, Egypt. The patient's skin problems were captured by a mobile phone camera and wirelessly transmitted to expert dermatologists for further medical advice. The study found that the transmission of images through mobile phones is technically feasible and diagnostically possible, particularly in regions where access to computers with Internet is unreliable. Further, it was found that a 'teleconsultation' system provided faster medical advice than face-to-face consultation (Tran et al., 2011).

Another approach was presented by Bellina and Missoni (2009), in which pathological microscope images were transmitted to an expert through multimedia messages for diagnosis. Due to high camera resolution, it was possible to transmit images of more than 0.8 megapixels resolution, which provided a clear interpretation. Walker et al. (2011) discussed the feasibility of the use of images as the follow-up to laceration patients. In this study, patients were asked to capture and submit their laceration photography every six months after surgery. In the same way, Martinez-Ramos et al. (2009) presented work where patients who ambulated surgery were asked to capture their surgery images and submit them to a physician for further treatment. The findings found that experts were more easily able to follow-up on the patients' treatment development.

Bilgi et al. (2012) used MMSs to assist cardiologists to clearly interpret the ECG images taken by a mobile phone. Patients who were admitted to the emergency department in Baskent University Hospital, Turkey, with cardiac complaints such as chest pain, syncope, palpitations, etc., were photographed using a mobile phone camera. The images were sent through MMS. The interpretation of the ECG on the screen of the mobile phone significantly reduced the interpretation errors of the ECG compared with those interpreted without phones. A similar approach was also employed by Ohtsuka et al. (2007) and Mitra, Mitra and Chaudhuri (2008), in which ECG images were used to assist diagnostics.

Many mobile phones today have high pixel cameras that are capable of recording videos. The MMS system allows users to send video from one device to another. This means that short video clips could also be applicable for diagnosis or in supporting a patient's follow up of their treatment processes (Hoffman et al., 2010).

For example, Hoffman et al. (2010) presented a system that supports the DOTS system to TB treatment. The patients in this trial were asked to take a daily short video showing them swallowing the medication. The video was submitted to health workers through an MMS system. The video DOTS was viable and helped healthcare professionals to track the patient's treatment. There were various challenges facing the MMS video DOTS system. The primary challenge was cost, as it was found that the use of MMS video clips is very costly (Hoffman et al., 2010). Other challenges were low or unavailable Internet access, lack of supporters at home who can assist patients with video recording and lack of video enabled phones within the community (Hoffman et al., 2010). Other challenges presented by MMS video systems include poor quality of the pictures (resolution) and frame rate. Furthermore, the study did not evaluate the medication adherence improvement.

Back and Makela (2012) point out that MMS systems have become a more standard communication tool in healthcare systems compared to text messages and speech systems. Tran et al. (2011) added that image applications are now a more influential way of communication than other mobile interventions such as text and speech. People are conveying more information visually than through reading or hearing (Lipkus & Hollands, 1999; Marsh & White, 2003; Gupta, 2008). Due to the limited resources in developing countries, image applications can be used as a way to

support TB patients' treatment adherence. Therefore, in this present study, a GBR application is proposed as a tool to support the treatment adherence of patients with TB through reminder systems.

The next section reviews related works in supporting TB medication adherence.

3.6 Mobile Phone Reminders for Supporting TB Medication Adherence

This section reviews studies on supporting the compliance of TB patients with their treatment adherence. The studies highlighted are related to the research conducted in this thesis because they all target promoting TB treatment. The key difference is that the studies mentioned below propose SMS text message and speech interventions while the current study proposes GBR technology.

In a closely related study in the context of mobile reminders for TB treatment, Tanke and Leirer (1994) investigated the impact of telephone reminders in supporting the compliance of patients with TB with their treatment regimen. The TeleMinder system was used to record and deliver messages to patients. TeleMinder was an interactive speech system, running under the MS-DOS operating system (Tanke & Leirer, 1994; Tanke & Morrow, 2013). The system consisted of a database and software that allowed users to create and record speech messages. Every recorded message in the work of Tanke and Leirer contained the name of the patient and indication of the day and time of appointment or dosage. Four languages were used: English, Spanish, Tagalog and Vietnamese. Each patient was asked to choose his/her primary language or a preferred language in which to receive the reminders. If the primary language of the patient was not one of the specified languages, the message reminder was sent in English. The study reported that it was challenging to create speech messages in four different languages.

Supporting TB patients in taking their medication is also presented by Kunawararak et al. (2011). In this study, the participants were categorised into two models; Model 1 included patients who were treated through a DOTS strategy and Model 2 was the same as Model 1 but patients were given mobile reminders. The MDR-TB and non MDR-TB patients were randomly grouped into either Model 1 or 2. The patients in Model 2 were given a daily phone call reminder to take their pills. The research is

similar to the current one in the sense that patients also received daily medication reminders. The Model 2 patients were also reminded to follow up their clinic appointments the same way as in this study, where patients were given various appointment reminders, including reminders to attend the clinic to collect their medication for upcoming days, submit sputum specimens for testing, and other consultation reminders.

Furthermore, the Kunawararak et al. (2011) study assessed patients' treatment outcomes. The treatment outcome was measured in terms of success rate and failure rate. This was conducted after six and 18 months of trial for both non MDR-TB and MDR-TB respectively. It was found that, after six months of the pilot study, the patients' treatment success rates had improved substantially for those patients who were in Model 2 compared with those in Model 1.

Huesler (2005) evaluated the use of SMS reminders in the treatment of TB. The study conducted in South Africa. The patients were categorized into two groups: treated with traditional care and those who received phone reminders (Huesler, 2005). Those patients who were in the mobile reminder group received SMSs daily. The study, found that the completion rate of TB treatment in the SMS intervention was higher than in traditional care.

Huesler also assessed patients' satisfaction with mobile technology (Huesler, 2005). Participants made comments such as "I am very pleased with the service and I think it is a good idea," "This system helped me remember to take my medicines", and "This system makes me connected to the clinic than usual." The study found that patients were pleased with the technology. This current study also assessed the patients' satisfaction using face-to-face interviews. Other systems of supporting TB patients' compliance with treatment are SIMpill and SIMmed as presented by Madyo (2010) and Barclay (2009). The similarity of these studies and Huesler's (2005) study is that both were conducted in South Africa with the aim of improving adherence to TB treatment. However, in the SIMpill and SIMmed studies, patients only received an SMS reminder when they failed to take the drug at the expected time, as described in detail in Section 3.3.6.

The assessment of the feasibility and efficacy of text messaging interventions to promote TB treatment compliance was presented by Iribarren et al. (2013). During

the trial, participants were categorized into two groups as in the studies of Huesler (2005) and Kunawararak et al. (2011): usual care and mobile reminder. Mobile phone feasibility and acceptability were assessed as the primary outcome and the initial efficacy was assessed as a secondary outcome. After two months of the trial, Iribarren et al. (2013) explored the initial efficacy of treatment by comparing the changes in sputum smear samples over time, from positive to negative. As in the work of Kunawararak et al. (2011), the Iribarren et al. (2013) study also measured the treatment outcome rates, including treatment successes and failures. The study finding was that the mobile reminder systems improved patients' treatment success rates more than in traditional care. Moreover, in the Iribarren et al. study, mobile reminders contained educational messages to help educate patients and communities about the disease. In this current study, educational messages have also played a key role in educating the patients, their families, and friends on good behaviour in order to prevent transmission of the disease.

Another closely related work is by Mohammed et al. (2012), who describe how an interactive SMS text message reminder system was designed to support improved treatment adherence for TB patients. The study was done in Pakistan and described the patients' perception, acceptance and engagement with mobile reminders. The study provided details on how an interactive SMS text message reminder system for TB patients was developed. The system was developed using the SMSLib library with Java (Mohammed et al., 2012). SMSLib is an SMS messaging library that provides a universal texting application programming interface (API), which is used for sending and receiving messages via Global System for Mobile Communications (GSM) modems. Daily SMS reminders were sent to registered patients to remind them to take medication. Patients were asked to reply by text message every time they took their pills. The date and time of the patients' responses were recorded. The advantage of tracking a patient's medication responses is that it then assisted health workers with following up on the patient's treatment development. This study provided useful information regarding the conceptualisation of the system's design. The Mohammed et al. (2012) study further measured the system's acceptability and user engagement. The study findings found that there was a high degree of acceptability of the mobile reminder systems among TB patients.

The studies also assessed the effectiveness of mobile reminder systems over the DOTS strategy in supporting TB treatment. Bediang et al. (2014) investigated the effect of SMS text message reminders on the cure rate for TB patients who had a smear specimen that was positive (+ve). The study was carried out in Yaoundé, Cameroon and randomized two groups: a control group and intervention group. The intervention group participants were given DOTS, with SMS intervention, whereas the control group participants were given DOTS, with no SMS intervention. The study took 12 months. The first four months were used to recruit participants and the next eight months were dedicated to participant follow-up. The participants in both groups received a welcome message at the beginning of the study to verify their participation, and another message at the end of study to thank them for their participation. Participants in the intervention group continued to receive a daily SMS reminder to remind them to take their medication. Furthermore, motivational reminders were sent every two weeks to encourage them to continue to take their medication.

An interesting aspect of the Bediang et al. (2014) study is that patients' treatment adherence was estimated by patient self-evaluation using the visual analogue scale (VAS). VAS is a measurement instrument used to measure the treatment adherence of patients and the results associated as follow-up methods (Bediang et al., 2014). The VAS measures the amount (or level) of pain that a patient feels and ranges it across a scale from none to an extreme level of pain. The Bediang et al. study guided the research conducted in this thesis towards assessing patients' treatment adherence using the VAS approach, as described in detail in Chapter 4 (Section 4.5).

An assessment of technology was also presented by Albino et al. (2014). That study examined the attitudes and perceptions towards using text message reminders in increasing treatment adherence among TB patients in Callao, Peru. The study found positive perceptions of the use of SMSs among TB patients and indicated that mobile reminder technology may be an effective strategy in increasing treatment adherence for low and middle income patients. Patients suggested that they would like to continue receiving healthcare related messages.

The participants, however, raised concerns about health literacy and the confidentiality of SMS messages related to TB. The majority of them feared stigma.

Some patients expressed fear that someone might read the TB SMSs on their phones and they would feel bad, because then people would know that they have TB and potentially segregate them. Issues of stigma were also reported in Rana et al. (2015) and Ndwe et al.'s (2012) studies. In Rana et al. participants suggested that they would prefer to receive simple coded text messages without any words related to the disease. In Ndwe et al. confidential matters that are associated with stigmatized issues led participants to prefer one technology over the other - DTMF (dual tone multi frequency) modality over ASR (automatic speech recognition) modality - in supporting them to access information using the contemporary tools such as multipurpose computes and the Internet. Therefore, in this present study, the graphic messages do not contain any TB-related signs, thus avoiding stigmatisation.

In conclusion, the analysis has identified that text-based and speech-based reminder systems have limited use for some people due to literacy and language barriers. For many people in the rural areas of developing countries such as sub-Saharan Africa, literacy is a significant limitation.

The literature review also identified that cost is one of the main challenges hindering mobile reminder systems in developing countries. The cost charged by mobile network providers for the use of communication services between the sender and the receiver might result in untimely sending and receiving of SMS text messages, phone calls or MMS services.

The following is a summary of opportunities and gaps highlighted in the related studies that guided this present study in developing a reminder technology that will support patients with TB in treatment adherence:

- Mobile reminder systems are useful to support TB patients in treatment adherence.
- SMS text message and speech systems have limitations for some people due to literacy and language barriers.
- It is important to propose a reminder technology that overcomes the challenges of literacy and language barriers.
- This reminder technology should also work in resource constrained environments, such as in remote areas where mobile networks are limited (engagement with a mobile network provider).

- Mobile reminder technology should be cost effective.
- Mobile reminder technologies should not contain any TB-related signs or symbols.

In addition, other studies that show conceptual similarities and differences to the current study are presented in Appendix A. However, these studies were conducted to support the treatment adherence of different diseases such as HIV/AIDS, HIV and Diabetes. The studies guided the current study in a variety of ways.

3.7 Chapter Summary

The objective of this chapter was to look at the importance of mobile technology in supporting healthcare systems. It also looked at the concepts, opportunities, challenges and gaps of current mobile interventions used in supporting healthcare systems. The existing literature was discussed with the aim of supporting patients and improving healthcare services' use of mobile technology. The discussion has revealed that the mobile phone is an important tool in supporting and improving treatment adherence among patients. The literature cited showed that mobile phones can be used in different ways to support healthcare systems, including: the dissemination of health information, promotion of health education, training of healthcare workers, disease control, diagnosis and treatment support.

The literature review in Section 3.3 analysed the key applications of m-health. The review shows that there are six main areas of m-health applications. The current study considers one of these applications - remote monitoring and treatment adherence – for supporting TB patients to adhere to their treatment regimens.

Section 3.4 presented the two forms of m-health communication which are mostly used in reminder systems. These are one-way communication in which flow of information is from one side to the other and two-way communication where flow of information is from both sides of the sender and the recipient (i.e. doctor and patient).

In Section 3.5 it was revealed that SMS text message and speech systems are the two main capabilities of mobile phones that are most widely used in supporting healthcare services. In the context of reminder systems, these mobile interventions are used to remind patients to take their medication and attend their clinic

appointments. The main focus of this study is to support TB patients' adherence to their treatment through reminder systems using a GBR system.

The literature review in Section 3.6 analysed research related to TB. The review shows that these studies show some similarities and differences with the current study and these are used to guide the study. The literature review also identified gaps that might be addressed in this study, as described in Section 3.6.

The next chapter presents a description of the theoretical framework and research methodology employed in this study.

CHAPTER FOUR

THEORETICAL FRAMEWORK AND RESEARCH METHODOLOGY

4.1 Introduction

This chapter presents the theoretical framework and research methodology of this study. The main research question in this study is: *"Can mobile graphic-based reminders be used to support treatment compliance for tuberculosis patients in resource-limited and mixed literacy settings?"* To answer the main research question, two specific research questions were posed in Chapter 1. This chapter describes the research design and approach that will be used to answer the research questions and practical details for how the strategies are to be implemented in practice. The research design of this study is based on a mixed methods approach.

Data was collected through semi-structured interviews, questionnaires, focus groups discussions, observations, and application responses. The qualitative data was analysed systematically[7], and quantitative data resulting from application responses that were collected through event logs analysed using Statistical Package for the Social Sciences (SPSS) in order to draw numerical findings.

This chapter begins by discussing the theoretical framework guides this study. The chapter then discussing the research design and approach, methodology and methods applied in the study. It then describes the implementation of the framework that supports the developments of GBR applications. This is followed by a description of the system evaluation approaches, ethical clearances, data collection and analysis methods.

4.2 Theoretical Framework

This study adopts Visual Aids for Communication Theory (Ngoh & Shepherd, 1997), as a guiding lens to investigate the GBR application for supporting TB patients to treatment adherence. The theory was earlier traced from observational learning theory developed by Bandura (1977) as a process of learning that occurs through watching and replicating the behaviours of a model. It is a form of social learning which takes various forms, based on various processes. Through observational learning, personal behaviours can spread across a culture[8] through a process called diffusion chain (Bandura, 1977; Bandura, 2001). This basically occurs when a person first learns a behaviour by observing another person and that person serves as a model through whom other persons learn the behaviour. Observation learning basically focused on the acquisition of behaviours through learning. Ngoh and Shepherd (1997) embraced the concept of observational learning into visual aids for communication.

The Visual Aids for Communication Theory focuses on conveyance of ideas and information in forms that can be read or looked at (Ngoh & Shepherd, 1997; Gupta, 2008). It is a theory used to support people's understanding of the meaning of content using visual objects, such as graphics, symbols and photographs and this

[7] Systematically analysis subjected to three stages analysis: data reduction, data display, and conclusion drawn (Pope, Ziebland & Mays, 2000)

[8] Culture is an interpretation or meaning of important events that results from the common experiences of members of collectives that is transmitted across generations (House et al. 2004, 2013)

theory is proposed especially for those who are unable to read text, such as illiterate or semi-literate people (Ngoh & Shepherd (1997).

4.2.1 Visual Aids

Visual aids are items of illustrative matter that are used to make something easier to understand. Visual aids can, but not always contain words, and/or numbers; however, the displayed words are never the emphasis of the medium (Jacquiline, 2012). Visuals help people remember important information better than if they only hear or read it (Mehrabian, 1981). The purpose of visual aids is to attract attention, motivate interest and move user/viewer to a specific action anticipated by the content of message. Visual aids are considered to have a higher persuasive communication because of the emotional appeal inherent in visual presentations (Jacquiline, 2012). Recognizable symbols used in visual presentation will become long-lasting memories with the power to change attitudes. This mostly happens when viewers have a chance to actively think about the content of the visual object and relate it to their own situation (Lester, 2000).

The use of visual aids in communication perspective has been ranged from a modern approach to a postmodern approach (Kostelnick, 1995).

The modern approach assumes that visual objects can be simplified and homogenized beyond cultural differences (Kostelnick, 1995, p. 184). A widely recognized example is the International System Of Typographic Picture Education (Isotype) developed by Otto and Neurath in the 1930s; Isotype was intended to serve as a means of global communication, particularly communication of social facts (Sandner, 2008). The modern approach is concerned with the use of highly simplified, abstract, and generic human forms that carry no suggestion of gender or race (Horton, 2005).

The postmodern approach is based on the premise that visual communication is largely a social construct that is learned through experience and varies across cultural groups (Kostelnick, 1995, p. 183). The postmodern approach therefore states that visual communication must match the cultural and social context in which it is deployed (Kostelnick, 2011, p. 43). Colour is an example of social construct, because colour inclines to be imbued with cultural dimensions within certain countries or cultures (Aykin & Milewski, 2005). Several scholars have theorized

about the ways in which the cultural dimensions may manifest themselves in visual aids for communications (Brumberger, 2014).

Callahan (2005) argued that the cultural dimensions depends on: the design differences influence usability for various people; individuals from a particular culture; or either of user factors, such as user behaviour and preference. The user behaviour factor is mostly associated with colour and user preference is associated with viewing patterns (Brumberger, 2014). Viewing patterns depends on the physical and cognitive behaviours that are largely habitual and automatic. The user preferences are eventually based on whether more conscious or deliberate interactions with visual material which are shaped by those viewing patterns.

Like the modern approach, the postmodern has both advantages and limitations. It essentially calls for visual communication to be designed, or redesigned, for each culture in which it will be used. Theoretically, this should lead to more attractive and helpful visual objects for the intended users. However, simply it is not feasible to translate visual objects for each cultural context (Brumberger, 2014). Particularly given the array of design choices and the indirect hints of each, translating visual objects effectively may prove even more complex than translating verbal language (Brumberger, 2014).

Somewhere in between the two extremes of the variety is a balancing point. In some situations, treating visual communication as universal may be sufficient. In others, a high degree of cultural specificity may be required. Most often, some combination of globalization and localization is likely to be necessary (Ngoh & Shepherd, 1997; Horton, 2005).

These premises treat the visual aids for communication as the one of the most important ways that people communicate and share information widely (Brumberger, 2014). The two critical assumptions underline this approach are first, that the ability to read visual objects, sometimes known as visual literacy (as defined in Section 2.5), is universal; and second, that the graphics, images, photographs, and other elements that comprise visual communication go beyond cultural differences (Horton, 2005; Brumberger, 2014).

Contemporary culture has become immensely dominated by visual aids for communication. Not only locally or nationally but also because visual language structure has a much more global character then a verbal language will ever have (Smith et al., 2004 p.23; Brumberger, 2014). For instance, the profane symbols used to indicate the male and female toilets; as long as visuals are used most people end up in their gender specific toilet. On the contrary if there is the use of capitals to indicate toilets like L(adies) and G(entlemen), there is likely to be a problem because of the differences in language and culture. For instance, for the Germans this would be D(ames) and H(erren) and in France it is capital M for both male and female - M(adames) and M(essieurs). Therefore, this study considers visual aids as a universal approach rather than cultural approach in order to support TB patients to comprehend the intended message.

The study, further, employs the semiotic and cognitive theories of visual communication to explain the implications inscribed in visual aids for communication for supporting TB patients to treatment adherence.

4.2.2 Semiotic Theory of Visual Communication

Semiotic Theory of Visual Communication is used in order to better explain, not only visual interpretation, but also explain communication in general. Semiotics is the study or science of signs (Smith et al., 2004 p.227). It studies what signs mean and how they relate to one another. The study of signs is important in visual communication because signs infuse every message.

A sign can be defined as an object or concept used to convey information or instructions (Smith et al., 2004 p. 228). Peirce identifies three types of signs that provides a richer context for understanding visuals and how they convey meaning. These are icons, indexes and symbols (Peirce, 1991, p.141). Iconic signs are signs that carry some quality of the thing they stand for. They are the easiest signs to interpret because they closely resemble the thing they represent. Indexical signs are signs that are physically connected with the object. They have a logical, common-sense connection to the thing or idea they represent. Their interpretation takes a little longer than iconic signs since people learn them through everyday experiences. Symbolic signs are signs that stand for something through a process of consensus.

Not like indexical signs, symbolic signs have no logical connection and so have to be taught (Jacquiline, 2012).

These signs are greatly influenced by viewer considerations. Symbolic signs may be complex but once the meanings are learned, they are less subject to distinctive interpretation. Symbols usually bring stronger emotional response from viewers than the iconic and indexical signs because the symbols have deep roots in the culture of a particular group (Lester, 2000). Smith et al. described visual objects as a collection of signs. They argue that signs within a visual object are presented in different ways depending on the style of the visual object designer (Smith et al., 2004 p. 228).

4.2.3 Cognitive Theory of Visual Communication

To understand the effectiveness of visual objects, it is necessary to know how viewers view and interpret visuals. Cognitive Theory is an important theory since it presumes that a viewer arrives at a conclusion of a visual object through mental operations (Lester, 2000; Smith et al., 2004 p.193). The theory appreciates that the human mind is complex and there is a meaningful connection between what people see and how they use those visual objects. If a visual object looks like one that a viewer has seen before then the viewer will rely on memory to accurately perceive the visual object. When there are too many signs in a visual object, it is usually competing for the viewer's attention, as a result the visual object may not be understood by the viewer. This is because the human mind does not concentrate on too many things (Lester, 2000). Understanding these mental processes will help in the development of visual objects of this present study that will be interpreted in the way that the patient needs.

4.2.4 Conceptualise the Visual Aids for Communication Theory

This section describes how the Visual Aids for Communication Theory was conceptualised to fit the present study. There are four components/processes of visual aids for communication as identified by Ngoh and Shepherd (1997). These processes mediate between the presentation of the model and the appearance of the modelled behaviour. Research indicates that these processes are to be taken into consideration in the development of a technology within the Visual Aids for Communication Theory (Ngoh & Shepherd, 1997; Bandura, 2001). Figure 4.1

shows the four processes of the Visual Aids for Communication Theory and the description of each process is provided next.

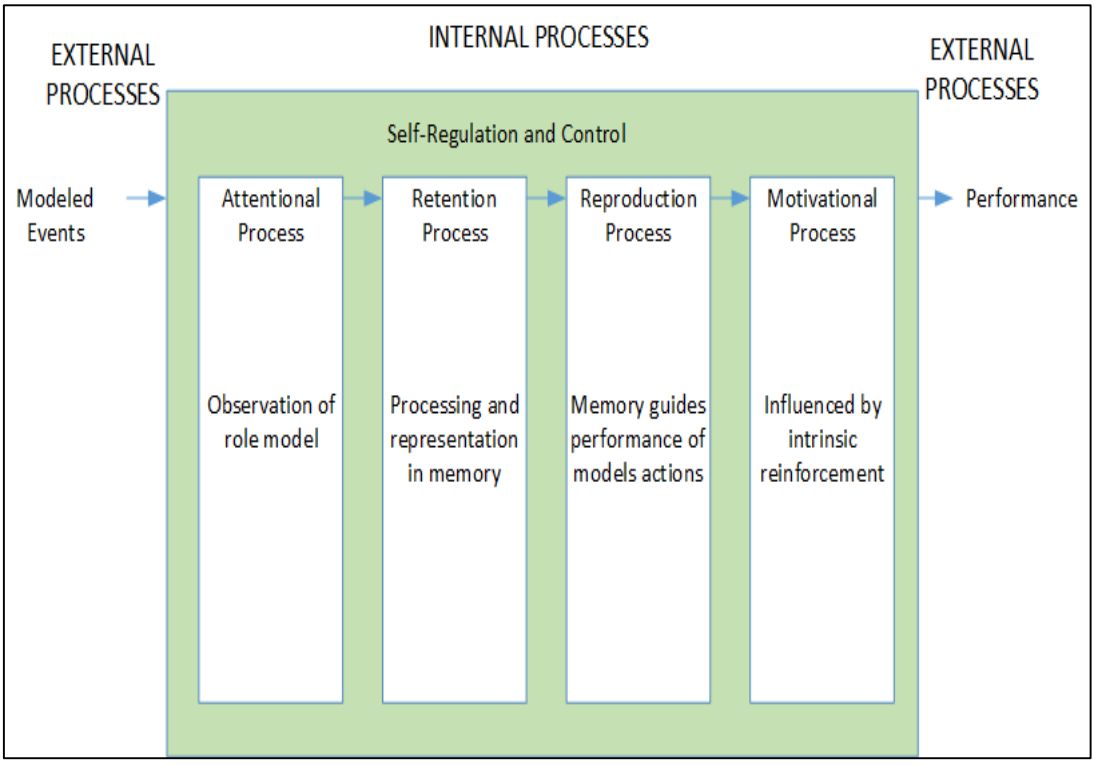

Figure 4.1: The processes of a visual aids for communication framework as adapted from Bandura (1977) and Ngoh and Shepherd (1997)

Attentional Process: Attention is a cognitive process which regulates exploration and perception, where the observer/user must notice the model or technology's behaviour and pay attention to it. The amount of attention the user pays to the technology is influenced by several factors, including: characteristics of the technology, such as how much the user likes or identifies with the technology; characteristics of the user, such as the user's expectations or level of emotional encouragement (Ngoh & Shepherd, 1997; Bandura, 2001). This process is therefore very important in whether a behaviour has an influence in others imitating it.

Retention Process: Retention is the process which consists of transforming the information of a technology in order to be represented to memory (Bandura, 2003). This process depends on the user's ability to structure the information so that it is easily remembered. Retention process requires the user to retain and remember all significant aspects of the model's behaviour unless the user is imitating the model's behaviour as that behaviour is taking place. If the user cannot remember the

behaviour possessed by the technology, then he/she is unlikely to reproduce it (Ngoh & Shepherd, 1997). In order to retain what has been attended to, it is necessary to encode and represent symbolically what has been seen.

Reproduction Process: Reproducing the observed behaviour is the process of conversion of technology representations into actions. It is a process whereby the user possesses the necessary responses. In this process, the user must be capable of imitating the behaviour (Ngoh & Shepherd, 1997; Bandura, 2001). This means that the user must be physically or mentally capable of carrying out the task, and they must perceive themselves as being able to do it.

Motivational Process: Given appropriate motivational conditions, the user performs the learned behaviour. Motivation is the process which focuses on whether the user is motivated to perform a certain type of behaviour. This motivation can come from external reinforcement, such as the user's environment or it can come to intrinsic reinforcement, based on the observation that models are rewarded. The presence of reinforcement, either to the technology or directly to the user, becomes most important (Ngoh & Shepherd, 1997; Bandura, 2001). The reinforcement is thus experienced intrinsically during the observation, after which the user can anticipate that his/her performance of the same behaviour will lead to the same consequences.

Additionally, the more the user respects or likes the technology, the more likely they are to replicate the technology's behaviour (Bandura, 2001). If the user is not motivated in this process, or has no desire to reproduce the behaviour, then imitation is unlikely to occur.

The relationship between these processes is known as reciprocal determinism (Bandura, 2001). A user's physical characteristics, cognitive abilities, personality, attitudes and beliefs influence his/her behaviour and environment. These influences are reciprocal; however, a user's behaviour can affect his/her feelings about himself/herself and his/her attitudes and beliefs about others (Bandura, 2003). The first two processes; attention and retention, account for acquisition or learning of a technology's behaviour. The other two processes; reproduction and motivation, control the performance of the technology (Bandura, 2001).

To summarise, this study used Visual Aids for Communication Theory as adopted by Ngoh and Shepherd, (1997) and many other researchers who used a visual aid works on supporting patients to communicate and a get clear understanding of the content of messages (Dowse & Ehlers, 2001; De Jong, Ros & Schrijvers, 2014). It is imperative to note that, despite the challenges faced by visual objects, such as cultural dimensions within certain countries or cultures (Aykin & Milewski, 2005), visual aids have the power to capture human minds and their relation in interpreting and understanding the visual content. This makes Visual Aids for Communication as the method of communication that can be used and understood by the majority of people who come from different geographical locations, cultures, languages and literacy levels (Gupta, 2008). The choice of this theory is firstly grounded in the theory's ability to (1) illuminate how visual communications support people, especially illiterate to clearly understand the content of a message through observation (seeing) (Gupta, 2008; Medhi-Thies, 2014) and (2) provide an appropriate foundation for the investigation of how user factors influence the interpretation of visual objects. Secondly, justification for Visual Aids for Communication Theory in this study is that it has been advocated for the study of visual communication systems in low-literacy environments. It is argued that "Visual Aids for Communication" theory, is attractive as a means of advancing our understanding of the development of m-health reminder systems because it allows the combination of the different views that must be considered in the development of GBR applications.

The discussion of the processes of Visual Aids for Communication Theory and how they are associated with the development of GBR applications of this study is presented in Section 4.4.

4.3 Research Design and Approach

In conducting the research, a mixed methods design was used. Mixed methods research involves collecting, analyzing, and interpreting qualitative and quantitative data in a single study or in a series of studies that investigate the same underlying phenomenon (Leech & Onwuegbuzie, 2007). Mixed methods research is based on the idea that the use of qualitative and quantitative approaches in combination provides a better understanding of a research problem than the use of either

approach alone (Azorin & Cameron 2010). The qualitative approach is used to discover the underlying desires and motives of human behaviour. This approach is mostly used in a small sample and provides quality data (Creswell, 2013; Bryman, 2015). The quantitative approach was used in order to analyse data from the application responses to produce numerical findings.

This study followed a combination of a multiphase design of the mixed methods research. A multiphase design combines both sequential and concurrent use of qualitative and quantitative data over a period of time (Carayon et al., 2015). First, qualitative data was collected during the design phase. This qualitative data informed the design of the GBR prototype. Thereafter, both qualitative and quantitative data was collected and analyzed in the evaluation phase. Figure 1.4 presented the overall research approach. There were five phases in this study. Table 4.1 presents the overview of phases of the study, as described next.

Table 4.1: Overview of phases of the study

Phase	Place and date	Phase's aim	Number of participants	Data collection instruments
Phase I	Zanzibar, under the supervision of the TB department at Mnazi Mmoja Hospital[9], between July and August 2013.	User requirements (Initial investigation): (1) To identify the challenges facing TB patients and health worker in their treatment, and the reasons for these. (2) Identifying reminder notifications.	29	Interview, site observation and documents.
Phase II	Cape Town and Zanzibar, between September and December 2013.	Design considerations: (1) The design of graphic reminder notifications.	34	Interview and observation.
Phase III	Zanzibar, between July and August 2014.	Prototype I formative evaluation: (1) Usability and development of prototype.	38	Interview, questionnaire and observation.
Phase IV	Zanzibar, between December 2014 and January 2015.	Prototype IIA evaluation: (1) Feasibility and acceptability.	29	Interview and event logs.
Phase V	Zanzibar, between July and August 2015.	Prototype IIB evaluation: (1) Feasibility and acceptability.	30	Interview and event logs.

Note: Phase II and III investigated the design and development of the prototype applications while Phase IV and V investigated the effectiveness of the prototype applications. A difference between prototype IIA and IIB was the procedure of sending reminder messages (see Sections 4.5.1).

[9] Mnazi Mmoja is a referral hospital, located in Stone Town, Zanzibar's capital city. Mnazi Mmoja is a tertiary TB clinic; other secondary and primary TB healthcare centres are found in each district of Zanzibar.

The aim of this study was to contribute towards supporting TB patients with compliance to treatment regimens through the use of graphic objects. Therefore, the first step was to understand the challenges facing TB patients and health workers during the treatment process and to understand reminder notifications to be used in this study for supporting TB treatment. These challenges and reminder notifications were elicited from TB patients and health workers using interviews and were used as part of the requirements in the design process. The suggested reminder notifications were then designed based on the four processes of the theory of Visual Aids for Communication. These designed graphic notifications were then evaluated to various people, including TB patients and health workers to investigate whether they met the users' requirements and needs.

To implement the graphic reminder notifications in a mobile environment, an Android GBR prototype was developed. Android was selected as the platform of the implementation because it is an open source, and it has an 86.8% market share among smartphone users (IDC, 2016). Apart from the mobile GBR prototype, a speech-based reminder prototype was designed to be used in the experiment.

These prototypes were used in two experiments with a total of 59 TB patients undertaking medical treatment, from TB clinics in Zanzibar, Tanzania (as indicated in Table 4.1). In these experiments, patients were given mobile phones containing reminder systems, and they were asked to replay by pressing a 'feedback button' once a reminder had been triggered and after having taken their medications. Data was collected using application event logs and interviews.

Evaluation was conducted while patients used the mobile reminders to support the compliance with their treatment regimens. Following this, the evaluation criteria derived from the research questions were used to analyse the data. For example, to identify which reminder system was more effective in supporting adherence to treatment, the response rate to each reminder was recorded and then the total numbers of responses to the GBRs and speech-based reminders of each patient were compared. Thereafter, analysis was conducted on which mobile reminder system found more useful for supporting patients' adherence to treatment regimen. This evaluation process led to the research findings.

The next two sections provide detailed descriptions of qualitative and quantitative approaches and how they fit into this study.

4.3.1 The Qualitative Approach

The major aim of a qualitative approach is to explore and provide an in-depth understanding of specific issues (Bryman, 2015). Qualitative research is a more flexible approach that allows greater freedom of interaction between the researcher and the participants (Harwell, 2011; Green & Thorogood, 2013). The approach mostly uses 'open-ended' questions that allow the researcher to ask questions in a different way to each participant. It also allows the participant to respond in his/her own words. The approach can also use 'closed-ended' questions such as standardised questions. In the qualitative approach, data is collected through **interviews**, **observations** and **documents** (Green & Thorogood, 2013; Matthews & Ross, 2014). This approach allows for an in-depth understanding of human behaviour and the reasons behind such behaviour.

Interviews can be unstructured, semi-structured or structured. The unstructured interview allows for open-ended questions. The questions are more flexible and the researchers can ask about issues relevant to the context of the interview. Structured interviews, on the other hand, have standardised questions. The researcher asks the same questions for each respondent. Semi-structured interviews contain both open-ended and standardised questions (Kumar, 2005). In this study, semi-structured and unstructured interviews were used to collect the study participants' data. The main reason for this was that it allowed the participants to talk in depth. This helped the researchers develop a real sense of a participants' understanding of a situation. It also allowed the researchers to adapt or change questions depending on the respondent's answers. The interviews were conducted face-to-face by the researchers.

Observation is a fundamental method of gathering data by observing an event, behaviour or physical characteristics in the study settings. Observation is conducted when the researcher wants to understand an on-going process or situation. There are two types of observation: direct and indirect. Direct observation involves observing processes and interactions with a technology, while indirect observation includes observing the results of interactions and processes with the technology (Kumar,

2005; Bryman, 2015). Both types of observation were used in this study. Direct observations were made of the users' interactions with the application, and indirect observations were made through the users' response rates to the application.

Documents are standardised artefacts. They are a piece of written, electronic or printed material that provides information or evidence of an official record. Documents may occur in different formats, such as reports, notes, certificates, statistics, judgements, contracts, letters or newspapers (Wolff, 2004). Documents can be used to find or draw conclusions about the activities, ideas and intentions of an organisation or something they represent. In this study, official public and research publications on TB were used to garner information about TB and the challenges faced by both TB patients and healthcare workers.

4.3.2 The Quantitative Approach

The quantitative approach is applicable to systematic empirical investigation, which is then expressed in terms of quantities (Punch, 2013; Bryman, 2015). The researcher is an outsider, rather than part of the research, during the quantitative approach. Quantitative research is more applicable in research with larger sample sizes to produce evidence about the size and type of a problem. **Surveys** and **experiments** are used as data collection methods.

Surveys are used to collect data by asking participants about their attitudes, experiences and knowledge. This can be done through structured interviews or standardised questionnaires (Kumar, 2005; Bryman, 2015). The questions can be open-ended, as in the qualitative approach, or closed-ended. With open-ended questions, respondents are asked to write down answers in their own words. With closed-ended questions, several options are prepared and respondents are asked to choose the best option for the answer. In this study, closed-ended questions, in the form of a standardized questionnaire, were used to investigate the usability of the prototype.

Experiments are used to collect data. Experiments are mostly conducted to test the strength of the relationship between two or more variables. In this study, an experiment was used to measure the effectiveness of the GBR system with primary users. Data was collected through application event logs. Newman (1998) describes

statistical approaches as suitable for analysing and presenting experimental event logs' numerical data as descriptive information.

4.3.3 Approaches to Answering the Research Questions

The main research question that needs investigation for this research is:

"Can mobile graphic-based reminders be used to support treatment compliance for tuberculosis patients in resource-limited and mixed literacy settings?"

To answer this research question, two specific research questions were posed in Chapter 1:

The first research question (RQ1) is answered by investigating the design considerations and usability of the m-health GBR prototype. Users were given a prototype to test its functionalities. The aim was to refine the specifications of the system. Both quantitative and qualitative data were collected in order to analyse whether users understood the application. Qualitative data was also collected in order to understand the perception of users of the GBR system. Detail of the evaluation processes in addressing this research question is presented in Chapter 5.

The second research question (RQ2) is answered by investigating the effectiveness of the GBR system. Quantitative data generated from application event logs was collected in order to analyse the frequency of use of the GBR system. Data was collected to measure quantities such as treatment adherence rate, effect of reminders on the number of responses and efficiency of response time to reminders. In addition, qualitative data was collected to measure preferences and satisfaction with the GBR system. Detail of the evaluation procedures in addressing this research question is in Section 4.5 and results are presented in Chapter 6.

4.3.4 Approach for Software Design

The approach for software design employed in this study is influenced by the User-Centred Design (UCD) paradigm, also known as the Human-Centred Design (HCD) (Maguire, 2001). This approach was chosen because it involves end users during the system's development.

4.3.4.1 User-Centred Design

UCD is an approach that considers user requirements during the design of the system (Maguire, 2001). In UCD the users are involved in every stage of the technology design. The primary objective of UCD is to produce a higher quality system that is satisfactory to users. The following are three key principles from the International Standards Organization (ISO) 13407 standard on UCD (ISO, 1999; Maguire, 2001; Giacomin, 2014):

i. **Focus on involvement and a clear understanding of users and task requirements:** This is the first key to UCD, in which end users are involved and contribute their knowledge during system development. The involvement of end users can also increase the acceptance of software, as people come to feel that the software is designed based on end user consultation and is not being imposed on them.

ii. **Measurement of function between user and system:** The second principle of UCD is to determine which tasks are handled by users and which should be handled by software. This principle involves system testing and takes into account the users' capabilities and limitations.

iii. **Iteration of design solutions:** This is the third principle of UCD, in which there are iteration cycles in software design. The designer receives feedback from end users, followed by improvement. The system is reviewed by the users until they are satisfied with it.

UCD is a design methodology approach that emphasizes understanding end users' requirements and environment. The goal of this study is to design a mobile health care system for patients. Maguire (2001) argues that when technology is designed for patients, they must be involved and support the process between the designer, patients and health workers. Therefore, in this study, these stakeholders were involved in every stage of the technology's development. The advantage of involving them was to ensure that the primary users were satisfied before moving on to the next stage. Sterling and Rangaswamy (2010) added that involving end users in the technology development is to willingly and knowingly engage in potential outcomes of a technology.

Figure 4.2 shows the design processes of UCD. The approach consists of five activities: (1) planning the human centred process, (2) specifying the context of user, (3) specifying user and organisational requirements, (4) producing a design solution, and (5) evaluating the design based on user requirements (Bevan & Curson, 1999; Preece, Sharp & Rogers, 2015).

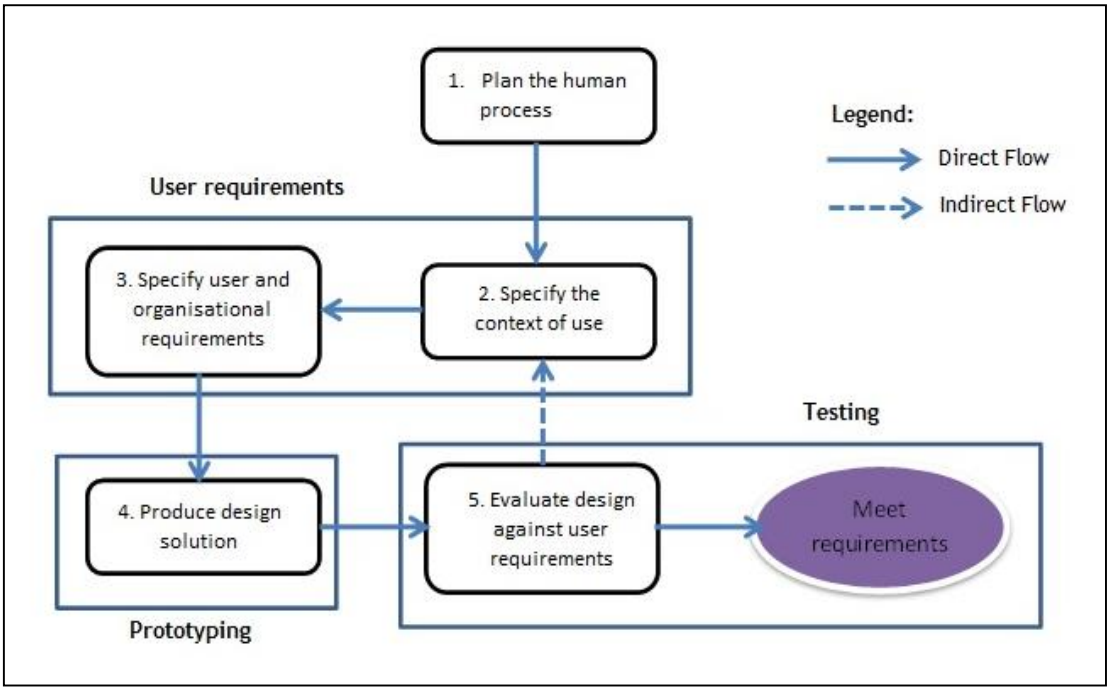

Figure 4.2: UCD methodology followed in this study as adapted from Bevan and Curson (1999)

To adopt this approach (UCD), we started by identifying the design needs. The researchers then informed a designer who planned which method to use in the development of the graphics. The researchers briefed the designer about the specification based on the users' needs and requirements. The communication between the designer and the researchers was very important.

The researchers knew where the application would be used and what environment the system would be implemented in. In the technology development stage, the team engaged users in co-design. The focus group method was used to evaluate the designed technology. It was testing to assess the degree to which users' requirements were met. In this study there were three types of users as identified by Eason (Eason, 1987; Abras et al., 2004): primary, secondary, and tertiary.

The primary users are those persons who actually use the technology. Secondary users are those who will occasionally use the technology or those who use it through an intermediary. Tertiary users, on the other hand, are persons who will be affected by the use of the technology. The primary and secondary users of the technology of this study are the patients, and tertiary users are healthcare workers. Abras et al. (2004) further described that the secondary users are the ones who are affected by the technology and therefore they need to be considered in the technology development stages. This was considered in every stage of the technology development of this study.

4.3.4.2 Design for Usability

The technology of this study intended to achieve the usability goals. Usability is the extent to which a system can be used by groups of identified users to achieve targeted goals with efficiency, effectiveness, and satisfaction (Hussain & Kutar, 2009; Helander, 2014). Usability also refers to the methods of improving the ease of use and ease of learning of a system or product (Maguire, 2001; Helander, 2014). A design for usability research focuses on how best to develop a usable system. Human Computer Interaction (HCI) experts propose various research designs and methodologies. For example, Maguire (2001) advocates UCD as the most common method that is used to support usability design, as described in the previous section.

The major aim of HCI is to improve the interaction between users and computers or mobile devices by making devices more usable and applicable to users' needs (Churchill, Bowser & Preece, 2013). This study therefore is concerned with the HCI aspect of designing a GBR system that will attempt to achieve a level of efficiency and effectiveness in use as well as ease of learning.

This section discussed the approach for software design of this study, the following section presents the processes of "Visual Aids for Communication" theory, as discussed in Section 4.2 and how they are associated with the development of GBR applications of this study.

4.4 Implementation of the Processes of Visual Aids for Communication Theory that Support Developments of GBR Applications

The following sections provide the description of each process of Visual Aids for Communication Theory and how it is applied in the development of the technology in this study.

i. **Attentional Process**

This is a sense-making process because it draws the attention of the user to the designed graphic object. It is also one of process management because it requires the graphic components that can attract the user to focus on the technology so that the user can effectively make sense of how the graphic generates the intended information. The process also makes sure that the user concentrates on the developed graphics. This process can be achieved through the use of relevant graphics layout such as applying the appropriate ways of principles of the graphic designs (contrast and similarity) in colour, shape and size.

ii. **Retention Process**

In order to support sense-making, representation and specification language were chosen as part of the designing requirements. This was used to bridge the user's understanding of the content of messages in such a way that the designed graphics can easily allow the user to structure the information in order to retain and remember the aspects of the technology's behaviour. Users' requirements for the development of the technology were also considered to support process management. These requirements can be achieved using graphic design approaches, as described in the following sections.

iii. **Reproduction Process**

In order to provide representation and specification language to bridge users' understanding, and in order to provide users' requirements for the development of the technology, graphic objects must be designed in a way that they simply reproduce the information. This allows users to think about deeper concepts and meanings. Such an approach can enable users to retrieve the content of messages properly. This process can be achieved by making every component of the graphic

(such as pill, clinic and sputum bottle icons) has an area of communicative commonality.

iv. **Motivational Process**

In order to ensure that users are able to retrieve the information easily and remember what is observed, the graphics must be designed in a simple layout that supports users' ability to see and remember what they have observed. This helps to make them feel that the graphics are designed for them and support effective use of the technology. Additionally, it also could reduce the complexity and enhance the users' understanding of the content. In additional the graphics must be designed in such a way that the interface parsimony for continued use should be put into consideration in order to attain the motivation.

In order to provide a representation that bridges users' understanding, these processes were implemented by providing a layout of the graphics showing the most basic units of the TB treatment environments. The graphics were designed in a simple layout and parsimony of interface that supports a user easily view and use the objects. Figures 5.2 to 5.11 present the designed graphic reminders of this study.

Further, the graphics layout depends on two factors: consistency and contrast (Lester, 2013; Impekable, 2013).

i. **Consistency** requires creating graphics that fit the size of a screen and are compatible with users' reading distance, both in vertical and horizontal directions. It also included making sure that similar elements are repeated to match each graphic symbol, such as the same typeface or colour.

ii. **Contrast** is when two or more related elements are different. Great contrast means great difference. In order to ensure contrast of the graphics, the differences between them must be obvious. The differences can be in size, colour or type.

To ensure the graphic reminders adhered to the principles of consistency and contrast, colour and typeface choices were made carefully in order to make sure the graphics would be clearly understood by everyone and subsequently convey the correct meaning, as shown in Figures 5.2 to 5.11.

The graphic reminder interventions were then integrated with an m-health GBR prototype application. This application will be used to remind patients for improving compliance with their treatment regimens through mobile phones. Section 5.3 presents the development process of the GBR application. The main idea of this application is to work offline without being connected to the network provider. Graphic reminder messages are triggered based on the TB treatment schedule as predefined and suggested by TB healthcare workers, as discussed in detail in Chapter 5.

4.5 Evaluation

This section presents the evaluation procedures used to investigate the effectiveness of the GBR system, including evaluation methodology and metrics.

4.5.1 Randomized Control Trial

A small-sample short-term Randomized Control Trial (RCT) was used in this study to test the effectiveness of the GBR system. A short-term study is a study conducted within a short period of time that usually takes from a week to months, while a long-term study takes a year and more (Scott, 2002). There were two separate experiments (tested prototype IIA and IIB), which were carried out in different periods. The aim of both experiments was to evaluate the effectiveness of the technology. Both experiments were conducted in periods of five weeks each – the first experiment was deployed for 36 days and the second for 34 days.

In the first experiment, the participants were equally categorised into three allocated groups: a control group and two intervention groups (n=12 each group). To measure the effects of the technologies, each intervention group's participants were given both prototypes (speech reminder systems and GBR systems). This means that each participant in the intervention groups was given a GBR prototype for the first half of the experiment and a speech reminder for the second half, or vice versa. In the second experiment, participants were also equally categorised into three groups (n=10 each group). As in the first experiment, the intervention participants were given both prototypes: a GBR prototype for the first half of the days and then the speech reminder for the second half, or vice versa. The control group participants were not given any mobile reminder.

The two prototypes (IIA and IIB) tested in the first and second experiments had the same content. A major difference between them was the procedure of sending reminder messages. During the first experiment, patients in the GBR group and speech-based reminder group received *different* audio in each reminder message (*with* content of the message), which directed them to action, for example, *"Habari! Huu ni mfumo wa TB, unakumbushwa muda wa kunywa dawa zako umeshafika"* (take pill reminder). The English translations of these texts are presented in Appendix B4. The users in the GBR group were given an additional graphic message.

In the second experiment, all patients in the GBR group and speech-based reminder group, first, received the *same* audio - notification alerts - in each reminder message (*without* content of the message), telling them that they have received an important reminder message, for example *"Habari! Huu ni mfumo wa ukumbusho, umepokea ujumbe muhimu wa picha, tafadhali angalia simu yako"* (you have received the important message), as shown in Table 4.2. After this, the users of the GBR system were directed to view graphic messages, and those receiving the speech-based reminder were directed to press a button to listen to speech messages, as indicated in the prototypes in Chapter 5.

The second procedure of sending reminders – in the second experiment - was used in order to increase the acceptance of the system and incorporate some participants' suggestions from the first experiment. These participants suggested that it would be best if the notification messages did not contain the words such as TB, medications or pills, clinic, and sputum. They indicated that these words directly represent a sign of a patient, as described in detail in Section 6.3.4.

Privacy and information security are crucial issues in any healthcare system. Privacy is defined as the ability of an individual or group to disclose information about themselves (Bennett & Raab, 2006). When something is considered as private to a person or group of people, it generally means that something is essentially sensitive or special to them (Bennett & Raab, 2006). In order to maintain privacy, the graphic reminders of this study are designed in such a way that they did not contain any sign or information related to TB or any other illness. Doing this may

also motivate patients to use the system more frequently, as they do not have fear about disclosing their information to unintended people.

Table 4.2: Notification messages for GBR and speech-based reminder systems

	Kiswahili Audio	**English Translation**
GBR system	Habari! Huu ni mfumo wa ukumbusho, umepokea ujumbe muhimu wa picha, tafadhali angalia simu yako	Hi! This is the reminder system, you have received the important picture message, please check your phone
Speech-based	Habari! Huu ni mfumo wa ukumbusho, umepokea ujumbe muhimu wa sauti, tafadhali bonyeza kitufe kuusikiliza	Hi! This is the reminder system, you have received the important sound message, please press a button to listen

4.5.2 Schedule of Reminders

Participants in the control group received the traditional care (routine medical procedure) provided to all TB patients. Participants in this group did not receive any mobile reminders, but they were followed up as a baseline every week, either at the clinic during their appointment times or at their homes.

Participants in the intervention groups received daily mobile reminders regarding their treatment regimens. The participants in the GBR group received speech and image messages and those in the speech-based group received only speech messages. The reminder messages were triggered at the same times in all mobile groups. Table 4.3 shows the times and days on which the reminders were triggered. Participants in the intervention groups were also followed up every week, as in the control group, either at the clinic during their appointed times or at their homes. Due to the suggestions from healthcare workers, only seven reminders were included in these trials. The other three reminders of “consult a doctor”, “not to cough in this manner”, and “sputum”, as listed in Chapter 5, were excluded.

Table 4.3: Defined times and days of reminder messages

Time of reminder	Reminder type	Status
7h00	Take a pill	Daily
10h00	Cough manner	Daily
12h00	Feel unwell	Daily
14h00	Eat healthy meal	Daily
18h00	Clinic appointment	Weekly
19h00	Refill pills	Weekly
20h00	Drink milk	Every two days

4.5.3 Mobile Phone Model Used

Since the reminder system was built for the Android platform, the participants were issued with Android phones with these reminder systems installed on them. Some participants already had Android phones. Both prototypes (GBR and speech reminder) were tested on the same platform. The issued phones were of different models, including Samsung Galaxy S (GT-19003), Samsung Galaxy Pocket (GT-S5300), Samsung Galaxy SIII mini (GT-18190) and Smart Kicka (VF685).

4.5.4 Evaluation Criteria

The proposition posed is that a mobile GBR system can be effectively used to support both literate and illiterate TB patients in improving compliance with their treatment regimen. To test this proposition and therefore seek to answer the second research question (RQ2): "*How effective are mobile graphic-based reminders in supporting treatment adherence for TB patients*?" the following three supporting sub-questions were posed:

(a). Does using mobile graphic-based systems support TB patients for treatment adherence?

(b). What is the effectiveness of mobile graphic-based reminders in comparison to that of mobile speech-based reminders in supporting TB patients' treatment adherence?

(c). Which mobile reminder systems did patients find useful for supporting their treatment regimen?

To answer these questions, an evaluation was conducted with TB patients who were given mobile phones installed with GBR applications and speech-based reminder applications. Data was collected while the participants interacted with the applications. The user interaction evaluation model examines the individual activities of the system users. The users' interactions with the application were recorded.

Treatment adherence, number of reminder responses (or response rate) and time taken to respond (or response time) were used as evaluation criteria in this study to measure the effectiveness of the technology. Such an evaluation was also done by Amico et al. (2006), Mbuagbaw et al. (2011) and Mavhemwa and Muzurura (2013). Mbuagbaw et al. (2011) and Nackers et al. (2012) have used different treatment adherence measurements, such as VAS, Self-Reported (SR), and Pill Count (PC) to estimate a patient's adherence to treatment. These methods were also adopted in this study, as described in the next section (4.5.4.1).

Table 4.4 summarises the evaluation metrics and question addressed, and the descriptions of how these criteria were used to address the supporting sub-questions are provided in the following sections.

Table 4.4: Evaluation metrics of each hypothesis and sub-question addressed

Evaluation metric	**Supporting sub-question addressed**
▪ Treatment Adherence rate *-SR (self-reported)* *-PC (Pill count)*	(a) and (b)
▪ Number of reminder responses ▪ Time of reminder responses	(b)
▪ Users' Preferences and satisfactions	(c)

4.5.4.1 Evaluation criteria to address sub-question 1

(a). Does using mobile graphic-based systems support TB patients for treatment adherence?

To address this sub-question, improving treatment adherence between the control group (without mobile reminders) and mobile GBR group were measured. The adherences to treatment were measured using SR and PC. This was done by comparing the adherence rate of the patients before and after the trial between these groups.

Self-reported

SR is a commonly used method to measure the treatment adherence of a patient by self-evaluation. The SR data can be collected through interviews or questionnaires. In interviews, patients are asked to describe how they feel about the treatment, while in questionnaires they are asked to mark the point on a line (or image icon) in a VAS item, as shown in Figure 4.3. This mark represents the amount of pain that a patient feels, from none to extreme. This method has accumulated considerable support as an efficient and valid tool for use in the assessment of treatment adherence (Nackers et al., 2012; Bediang et al., 2014).

In this study, SR was conducted through face-to-face interviews with respondents. Patients were asked to report how they felt about the treatment adherence at each appointment. The patients' responses were marked (on a paper) based on a range (as shown in Figure 4.3) of feelings. The results were then analysed in term of adherence rate before and after the trials. The SR adherence rate was calculated by dividing the number of patients who reported treatment improvement by the total number of patients in each group. The following example was used to calculate the adherence by the VAS scale.

> Assume that the treatment adherence of patient X before the trial was marked at number 3, and after the trial at number 4. The conclusion of this patient is then that his adherence has improved. If the adherence of a patient was still at number 3, or less, after the trial, it is then concluded that there was no adherence improvement by this patient. The SR adherence equation is presented below.

$$\%\ SR\ adherence = \frac{number\ of\ patients\ with\ improved\ adherence}{total\ number\ of\ patients\ in\ a\ group}\ x\ 100$$

The SR method has been ranked as the simplest, cheapest and easiest method to assess patients' adherence (Garfield et al., 2011). Furthermore, this method of SR can also reveal reasons for poor or non-adherence and therefore challenges can be addressed.

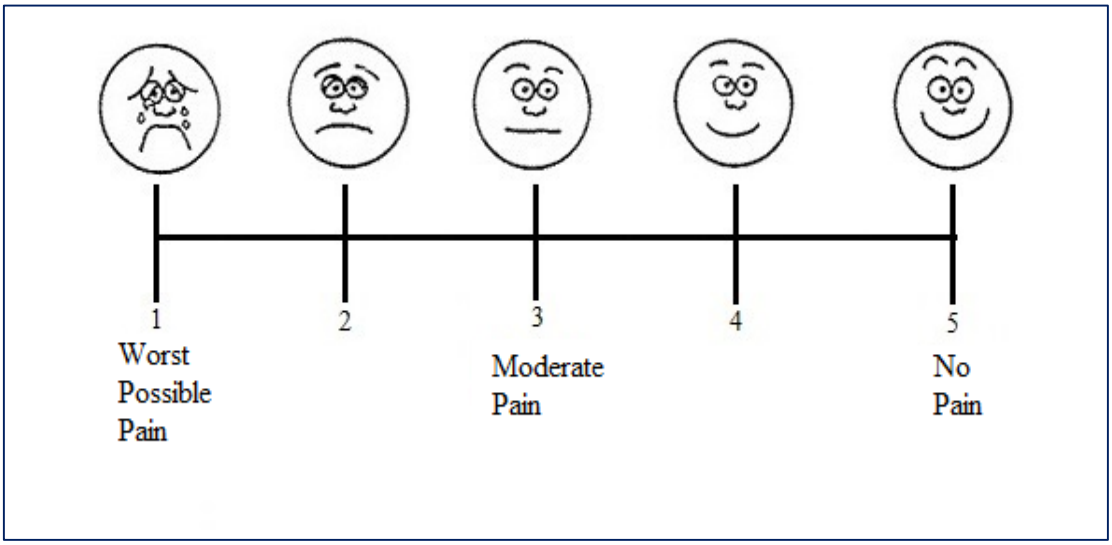

Figure 4.3: Sample of VAS tool of image icons and line

Pill count

PC method is used to estimate the medication adherence of patients. This method has been widely used to measure the outcome of patients' adherence, particularly for HIV treatment (Nackers et al., 2012; Achieng et al., 2013). The patients were asked to complete their record book (green card) with spaces to indicate if the pill was taken. Record books for those illiterate patients were completed by their family members or friends who support them in their treatment regimens. Every time the patients attended the clinic for medication, refills were registered and pills that were not taken were counted. Patients were also asked to describe whether that medication was taken in full or less than the prescribed amount. The following equation was used to determine the PC adherence rate for TB treatment.

$$\%\ PC\ adherence = \frac{(quantity\ pills\ dispensed) - (quantity\ pills\ not\ taken)}{(no.of\ pills\ per\ day)\ x\ (trial\ days)\ x\ (no.of\ patients)}\ x\ 100$$

Note: *no. of pills per day* is a prescribed number of pills per day - as described earlier, adult TB patient is asked to take from three to four tablets daily, depending on his weight - and *no. of patients* is a total number of patients in a trial group.

The SR and PC adherence variables were conducted with assistance of healthcare workers.

4.5.4.2 Evaluation criteria to address sub-question 2

(b). What is the effectiveness of mobile graphic-based reminders in comparison to that of mobile speech-based reminders in supporting TB patients' treatment adherence?

To address this sub-question, two prototypes were investigated: GBR and speech-based reminder systems. The following null and alternative hypotheses were investigated:

Null hypothesis (Ho)

The treatment adherence rate in the mobile GBR group is not greater than the mobile speech-based reminder group.

Alternative hypothesis (Ha)

The treatment adherence rate in the mobile GBR group is greater than the mobile speech-based reminder group.

These hypotheses were tested to measure the adherence rate to TB treatment, comparing GBRs and speech-based reminders.

Two further supportive questions were posed to address this question.

i. *What is the effect of graphic-based reminders on the rate of feedback responses, when compared to speech-based reminders?*
ii. *What is the effect of graphic-based reminders in comparison to speech-based reminders when considering the time taken to respond?*

When evaluating which reminder system was more effective in supporting adherence to treatment, two criteria were derived: (1) efficiency in terms of response time - time taken by users to respond to the system; and (2) effectiveness in terms of

response rate - how many users responded to the system. Efficiency and effectiveness are among the commonly used evaluation criteria to measure a technology's performance (Kruk & Freedman, 2008).

Efficiency can be defined as the time taken by a user to do something (Helander, 2014), or ability to do things well in the context of use. In this study, the context of use is TB patients using the system on a mobile phone as a tool for supporting them in their treatment regimen. Effectiveness, on the other hand, is about how perfectly users can achieve the intended goal using the system (Helander, 2014). In relation to m-health technology, effectiveness from the users' perspective is the ability of the system to produce the desired result of patients using the system for their health status.

These two factors determine motivation to use the system and are associated with qualities of usability. Therefore, in order to identify which mobile reminder system was more popular amongst patients, each response to the reminder system was recorded. Each question is evaluated separately below.

i. *What is the effect of graphic-based reminders on the rate of feedback responses, when compared to speech-based reminders?*

To address this question, the number of patient responses to the system was measured. The response rate to each reminder was recorded. Then the total numbers of responses to the GBRs and speech-based reminders of each participant were compared.

The following null and alternative hypotheses were investigated:

Null hypothesis (Ho)

The number of responses in the GBR is not greater than the number of responses in the speech-based reminder.

Alternative hypothesis (Ha)

The number of responses in the GBR is greater than the number of responses in the speech-based reminder.

ii. What is the effect of graphic-based reminders in comparison to speech-based reminders when considering time taken to respond?

To address this question, the time taken by users to respond to the technology was measured. Thus, the response time of each reminder was recorded. The objective of this was to determine in which mobile reminder group the users responded faster.

The following null and alternative hypotheses were investigated:

Null hypothesis (Ho)

The time taken to respond to the GBR is not less than the time taken to respond to the speech-based reminder.

Alternative hypothesis (Ha)

The time taken to respond to the GBR is less than the time taken to respond to the speech-based reminder.

4.5.4.3 Evaluation criteria to address sub-question 3

(c). Which mobile reminder systems did patients find most useful for supporting their treatment regimen?

This question used subjective qualitative feedback. In addressing this question, the patients' preferences and satisfaction with the technology was investigated. Using the interview method at the end of the experiment, patients were asked which mobile reminder system they found useful for supporting their treatment regimen. Patients were also asked about their perceptions and the challenges that occurred while using the applications.

4.6 Ethical Clearance and Consent

The University of Cape Town and the Ministry of Health and Social Welfare in Zanzibar granted ethical clearance for this study. Before the experiment began, participants were briefed on the purpose of the research and were requested to complete consent forms and permission forms for the researchers to record the interviews using image/video and audio. The consent forms for those illiterate participants were signed by their volunteers who support them in their treatment regimens, such as family members or friends.

The participants were provided with full information about the research, including the research title, objective and expected outcome. The participants were also given adequate time to ask the researchers questions. They received clear answers and were given time to reflect on the information before agreeing to participate. All communication processes between the researchers and the participants were kept confidential.

The researchers ensured that the information provided was understood by the participants and that the participants were empowered on the subject so that they could make a voluntary decision about whether to participate in the study or not. The participants were told that they could stop participating at any point in time. Polit and Beck (2013) indicate that autonomy is one of the ethical principles to consider when conducting a study. Autonomy implies that a participant has the right to voluntarily decide if he/she wants to participate in the study or to terminate his/her participation.

The researchers ensured that the participants were granted privacy and confidentiality. No participant was forced to reveal information to the researchers that they did not wish to reveal. The researchers ensured that the participants' anonymity was maintained. No personal identifiers, such as names or phone numbers, were linked to any participant. The researchers were aware that they were in a position of responsibility as they were dealing with personal information that the participants had agreed to disclose.

The participants were approached taking into consideration the ethical clearance of each area of study. The Cape Town participants were approached during the graphic evaluation time (Phase II). The Cape Town area also helped with understanding the issues for TB treatment. In comparison, The Zanzibar site involved participants in each phase, and helped with understanding the issues for the TB treatment regimen as well, as indicated in Table 4.1.

The ethical clearance letters from the University of Cape Town and the Ministry of Health of Zanzibar are attached as the Appendices B1 and B2, respectively. The consent form is in Appendix B3.

4.7 Data Collection Methods

As mentioned earlier, data for this study was collected through semi-structured interviews, focus group discussions, standardised questionnaires, observations, documents and the application responses. Field notes, photographs, audio recordings and event logs were used as data collection tools. The interviews and questionnaires were initially prepared in English and then translated into Kiswahili by the researchers to be used with the Kiswahili-speaking healthcare workers and patients in Zanzibar.

The following sections describe the methods of data collection used in each phase of the study, as summarized in Table 4.1.

4.7.1 Phase I of the Study

Phase I consisted of semi-structured interviews, site observation and documents. These data collection tools were used to increase understanding of the key issues facing TB patients and health workers during the treatment processes. The interviews also aimed at achieving an understanding of users' perceptions of mobile GBR systems in supporting TB treatment.

The participants in this initial investigation study were TB healthcare workers, patients and patients' supporters. The healthcare workers included a TB regional coordinator, pharmacist, data manager and healthcare providers (including a clinical officer, health officer, community health workers and nurses). The TB health workers were included from different sections in order to gain a broad understanding of the existing knowledge and views regarding TB and its treatment regimen. This helped the researchers to formulate a starting point and to consider how to address the current challenges. The patients were both home-based care patients and in-patients. The interview was conducted in groups and individual face-to-face settings.

Each interview session lasted between 30 and 45 minutes and was recorded by a voice recorder and in a notebook. In each patient's interview session, a healthcare provider assisted the researchers. This was to ensure that the interviews were conducted in a safe environment for both the patients and the researchers. All interview sessions were conducted in a hospital setting because it was the most convenient place for the participants. Healthcare workers were interviewed in a

room that was prepared for this purpose. Home-based care patients and patients' supporters were approached prior to their appointments at the hospital. In-patients were interviewed in the wards where they were admitted.

In total, 29 participants were interviewed, 59% of them were female, and 10% were illiterate. 52% were health workers, 45% were patients, and 3% were patients' supporters. 69% of patients were home-based (details of participants' demographic information is presented in Appendix B5). The findings of this initial investigation study are presented in Chapter 6. The interview questions of this phase (phase I) are attached in Appendix B6.

4.7.2 Phase II of the Study

Phase II consisted of unstructured interviews and observation. These data collection tools were used to gather user feedback regarding the development of the graphic reminders. The aim of this survey was to find out whether the sketched graphics could be clearly understood by every person, and whether they conveyed the correct and intended meaning of a particular reminder.

The participants in this survey were TB health workers, TB patients, postgraduate students from different academic disciplines, and researchers from Cape Town and Zanzibar. The participants from Zanzibar had similar culture and language - Swahili, and those from Cape Town had different languages and cultural background. However, all participants from Cape Town understood English. At each research area there were two rounds of evaluations. The evaluation was first conducted in Cape Town then in Zanzibar and then again in Cape Town. The patients were both in home-based care and in-patients. The Cape Town participants were from the University of Cape Town and they were made up of students and researchers. The Zanzibar participants were from the State University of Zanzibar and the group included researchers and TB patients and healthcare workers at Mnazi Mmoja Hospital. The TB patients and healthcare workers were the target users of this system, but input from students and researchers helped ensure that the graphics were understood by everyone. 34 people participated in this trial. 47% were females, and about one-third (32%) of respondents were patients. 15% of participants did not know how to read or write (details of participants' demographic information is

presented in Appendix B7). The evaluation processes of graphic reminders are presented in Chapter 5.

4.7.3 Phase III of the Study

Phase III consisted of questionnaires with structured questions, focus group semi-structured interviews and observation. The aim was to improve the development of the GBR system. Formative evaluation was used to test the applications. This evaluation is conducted during a system development process for improvement of the design and performance of the system (Boulmetis & Dutwin, 2014; Mertens, 2014). Boulmetis and Dutwin (2014) described the formative evaluation as a system evaluation rather than summative process. Mertens (2014) highlighted that the formative evaluation allows both the researchers and participants to work together as the main clients of the project. ISO9241-11 (for usability measurement) was applied during the evaluation of this study to measure the usability of the prototype application (Hussain & Kutar, 2009).

The questionnaire was designed with closed-ended and open-ended questions. The closed-ended questions were measured on five levels (using the Likert scale), whereby 1 represented 'strongly disagree', 3 represented 'neutral', and 5 represented 'strongly agree'. The Likert scale was used to measure the usability and design considerations of the m-health GBR prototype. The questionnaire also contained open-ended questions that asked subjects to provide their suggestions regarding the system. The interviews were used to measure the usability and design considerations of the prototype, as well as to assess users' perceptions and acceptability of the mobile GBR system. The questions were prepared in simple language for clarity and easy understanding.

The questionnaires were used to collect data from health workers and interviews from patients. Both the questionnaire and the interviews were intended to obtain similar information. The patients were approached one-by-one, either at the hospital during their appointment, or at their homes on different days. Face-to-face interviews were used for the patients. It was therefore easy and comfortable for them to answer the questions using the interview. There were both literate and illiterate patients. Text notes and audio recordings were used to capture patients' feedback. The health workers, on the other hand, were approached at the hospital in their

working areas. They suggested the time that was most convenient to carry out the evaluation session, and this was conducted in a day. In all evaluation sessions, a short training was carried out to explain and demonstrate the system before the evaluation took place. The health care providers helped to organize the patients and introduced the researchers to them before the session began. 38 participants were recruited during this phase of prototype testing. 66% of participants were females. Their median age was 26 years (range 16-55). All patients were in home-based-care (out-patients); details of participants' demographic information are presented in Appendix B8. Detailed evaluation processes of the GBR prototype are presented in Chapter 5. The Phase III questionnaire and interview are attached in Appendices B9 and B10, respectively.

4.7.4 Phases IV and V of the Study

Phase IV and V consisted of application event logs, focus groups and unstructured interviews. The aim was to investigate the effectiveness (including feasibility and acceptability) of the m-health GBR system and determinants of mobile phone utilisation in supporting TB patients' treatment adherence.

An application event log was used to collect data that was generated from responses while patients were using the applications. A feedback button was created that appeared immediately after a reminder message has been triggered and dismissed. Patients were instructed to press this button only after taking their medication. This button was used to capture user responses. The application event log was used because it is easy to understand and captures data quickly. It was also simple to create a button in Android.

Apart from the advantages of using application event logs, there was one challenge. Sending the users' responses to the database server required an Internet connection. In order to address this challenge, SQLite[10] database was created to store the responses offline and automatically forward these as soon as an Internet connection becomes available, as described in detail in Chapter 5. At every appointed time, the respondent's phone was connected to the Internet using the hospital's wireless connection or mobile data. Once connected to the Internet, the data was

[10] http://www.sqlite.org/

automatically synchronised with the database server at the Department of Computer Science at the University of Cape Town.

Unstructured interviews were conducted post-survey to measure the users' satisfaction while using the technology. The interviews were conducted with individual respondents, face-to-face. The interview questions included, for example, user's perception (how the user perceived the technology), and usefulness (which mobile reminder system of the two interventions the users found more useful for supporting their treatment).

Field/text notes and audio recordings were used to capture the participants' feedback. Text notes are a type of transcription data produced by researchers while in the field (Wallen & Fraenkel, 2001). The researchers write what they see, hear, and experience from participants. Audio recording is mostly used for individual interviews as a way to record what participants say during the interview.

In this study the researchers directly took field notes and audio recordings at the time of the interviews with respondents. This was done in order to obtain the participants' feedback regarding the system. Wallen and Fraenkel (2001) say that taking notes and recording an interview provides a good continuing record. The written and recorded data were then analysed by researchers as described in Section 4.8.

The participants in the experiments were TB patients who had started taking TB medications. The target population was all TB patients nationally. However, sampling was used in order to identify a subset of the total population. Sampling is defined as the process of selecting a finite part of the population for the purpose of determining characteristics or parameters of the whole population (Teddlie & Yu, 2007). Multiple cluster sampling was used in this study in order to generate a useful sample. Since the participants of this study were under supervision of healthcare workers, cluster sampling and using a random number generator was used to randomly select the participants according to the desired sample size. After participants showed an interest in participating in the study, they were randomly sampled within the clusters, and assigned to three groups: a control group, a speech-based group, and GBR group, as described in the previous section.

To ensure balanced representation and ensuring the validity of the research, each group contained both males and females, literate and illiterate patients, patients of different age groups, rural and urban residents, and patients from different treatment phases (i.e. intensive or continuation). Only patients who understood Kiswahili local language in Zanzibar and who are undergoing home-based care (out-patients) were included. Healthcare workers assisted to categorize the patients into groups identified by who is literate, illiterate, receiving intensive care, continuation care, etc.

After completion of the sampling process, another stage was participants' recruitment. Participants were briefed on the purpose of the research and were trained on how the system works and assigned tasks such as pressing a 'feedback button' (see Chapter 5) once a reminder has been triggered and only after taking their medications. In order to ensure the participants were comfortable and convenient to the study, they were approached either at the clinic during their appointed times or at their homes in the presence of a healthcare worker. The recruitment sessions were conducted: in groups of more than one participant; or with individuals, one participant at a time. Each participant received a gift or small payment to offset the transportation cost, or provision of lunch, when participating in the study.

Out of 66 participants who took part in the experiments, 59 were finally analysed. 29 participated in the first experiment: control group (n=12), first intervention group (n=8) and second intervention group (n=9), 30 participated in the second experiment: control group (n=10), first intervention group (n=10) and second intervention group (n=10). Seven participants from the first experiment were not included in the analysis due to various reasons, including loss of phone (n=1), declined to continue (n=1), and missed some data (n=5). The average age of participants was 40 years (ranging from 18 to 72 years), and 51% were females. 39% participants were either illiterate or semi-literate, and 37% resided in rural areas. The overall distribution of participants' demographic information is presented in Appendix B11.

4.8 Data Analysis

The study generated two types of data: quantitative data, resulting from experimental event logs; and qualitative data, resulting from observations, questionnaires and semi-structured interviews. The quantitative data, obtained from event logs was converted into numerical form. The numerical data was then entered and analysed using SPSS software (version 21) in order to generate descriptive information. The qualitative data was systematically analysed by the researchers, subjecting it to a three stage analysis method: data reduction, display and conclusion drawn. All transcripts were read individually by the researchers and every interesting idea or concept was written using analytic memos. The data was then discussed in detail by the researchers, including healthcare workers, to obtain reliable concepts. SPSS and Microsoft Excel were used to present findings in graph form. To reduce the participants' response bias, the study tried to minimize the differences between the interviewers and the interviewees, including language, education, gender, race, socio-economic class and culture (Dell et al., 2012).

The Mann-Whitney U test was used to compare the number and time of responses between the GBR and speech-based reminder groups (quantitative data). This non-parametric test - Mann-Whitney - is more appropriate to use in this analysis than parametric tests such as the t-test. This is because, firstly, the variances of the data between the two groups were very different. Secondly, this data was made up of independent random samples obtained from populations of the same characteristics.

A p-value of less than 0.05 (95% confidence interval) was considered to detect a significant difference for all analyses. According to Johnson (1999), a significance level is a value for which a p-value is less than what is defined in a given hypothesis test ($p<0.05$). Usually, the p-value corresponds to the probability of observing the values by chance.

4.9 Chapter Summary

This chapter discussed the theoretical framework and research methodologies of the study. The chapter began by describing the theoretical framework, research design, approaches and methodology for system design. It then presented the implementation of the processes of theory supporting this study. This was followed by a presentation of the evaluation processes to measure the effectiveness of the

GBR system. The chapter then presented the ethical clearances, data collection methods and concluded by presenting the data analysis approaches.

The next chapter discusses the processes of the development of m-health GBR applications, which are used to support patients with TB for compliance with treatment regimens.

CHAPTER FIVE

DESIGN AND USABILITY OF M-HEALTH GBR APPLICATIONS

5.1 Introduction

This chapter describes the processes of development of a GBR application for supporting TB treatment. The main objective of the study was to propose a language and literacy level universal mobile application that could be used to support TB patients, including illiterates, to comply with their treatment. The findings of the initial investigation study, which are presented in Chapter 6, together with the literature review (Chapter 3), are used to propose mobile GBR applications. The chapter begins with a description of how graphic reminders were developed. This is followed by a description of the process of development and usability evaluation of the GBR application. This chapter answers the first research question (RQ1): *What*

are the factors that contribute to the design and usability of graphic-based reminder systems.

5.2 The Development of Graphic Reminders

After users proposed ten reminder notifications to be included in this study, as listed in the results chapter (Section 6.2), the researchers then briefed a designer who developed the graphics, based on user needs and requirements. The following sections describe the development tools and testing processes of graphic reminder interventions.

5.2.1 The Development Tools

The Wacom tablet and Adobe Photoshop software were used as tools in developing the graphics. The Wacom tablet was used to sketch prototypes while Adobe Photoshop was used to finalize the graphics. These tools were used because they allow the designer to easily clear up blemishes and imperfections in graphics, as well as remove, edit, colour, crop and change the background. Figure 5.1 provides illustrative examples of the prototypes.

The prototype sketches were designed in a way that avoids ambiguity. They helped to identify and address problems of confusing, missing and misunderstanding of features (Berenback et al., 2009). A total of ten graphics were developed as proposed by the study participants. These graphics are shown in Figures 5.2 to 5.11.

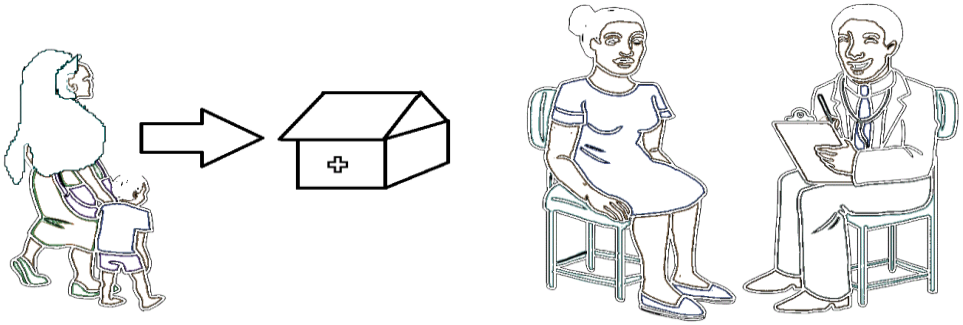

Figure 5.1: Sample of prototypes

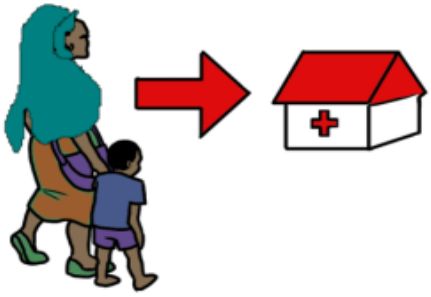

Figure 5.2: Patient reminded to go to the clinic

Figure 5.3: Patient reminded to consult a doctor

Figure 5.4: Patient reminded to take medication

Figure 5.5: Patient reminded to submit his/her smear sputum to doctor for checking

Figure 5.6: Patient reminded to take a glass of milk

Figure 5.7: Patient reminded to eat a healthy meal

Figure 5.8: Patient reminded to cough in this manner

Figure 5.9: Patient reminded not to cough in this manner

Figure 5.10: Patient reminded to collect medication for upcoming days

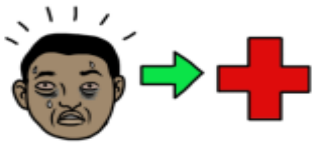

Figure 5.11: Patient reminded to visit a clinic when feeling unwell

After completion of sketching the graphics, they were then passed on to a number of people for testing. The next section shows how the testing of the graphics was conducted.

5.2.2 The Graphic Reminders Testing

In order to test the processes of Visual Aids for Communication Theory, the study determined if the graphics are simple to be understood and if they relate to the patients' needs and requirements related for TB treatment.

The following key processes were investigated:

Did users pay attention to the graphic objects?

Did users retain the observed graphic objects?

Did users reproduce the observed graphic objects?

Are users motivated by the learned elements from graphic objects?

To easily facilitate the testing, all graphics were printed in colour and circulated to each participant. Each participant was asked to provide his/her interpretation of each graphic. Figure 5.12 shows sample evaluation sessions. A paper-based evaluation was used because, once a participant provided the feedback, it was easy to improve on the graphic using a pencil, before using Adobe Photoshop for modification. There were two rounds of the evaluation process. The process was repeated so that, at each evaluation stage, the graphics were improved towards the final design.

Figure 5.12: Examples of the evaluation sessions

The participants' demographic information in this evaluation (Phase II) has been described in Chapter 4. The participants were from two areas: Cape Town, South Africa and Zanzibar, Tanzania. The participants from Cape Town were of different nationalities. They were from different African countries, including Tanzania, Uganda, Kenya, South Africa, Ghana, Gambia, Nigeria, Zimbabwe, and Zambia. On the contrary, all participants from Zanzibar were the native to Zanzibar - an autonomous part of the United Republic of Tanzania. The reason for including participants from different nationalities was to ensure that the graphics conveyed the same intended meaning regardless of the participants' languages and cultural background. The evaluation sessions in Cape Town were conducted in English and those in Zanzibar were conducted in Kiswahili, and re-translated in English by researchers for analysis.

The results showed that participants interpreted the meaning of most of the graphics correctly, though there were some graphics that were not clearly understood by some participants. All the participants interpreted Figures 5.2, 5.3, 5.8, 5.9, 5.10 and 5.11 correctly. The majority of participants understood the content of Figures 5.4,

5.5, 5.6 and 5.7, but these were found to be more confusing, especially for patients, students and researchers. The respondents suggested improving these graphics in order to make them clearer to everyone.

In order to meet user requirements, graphics that were identified by participants as confusing were improved. The first modification was made in Figure 5.4 as most of the respondents suggested adding a glass of water. They indicated that only showing a pill does not give a clear message that the patient is being reminded to take the medication. Some respondents said it looks like the patient is being reminded to take the medication as they would take a sweet. Instead, they suggested adding a glass of water as now shown in Figure 5.13.

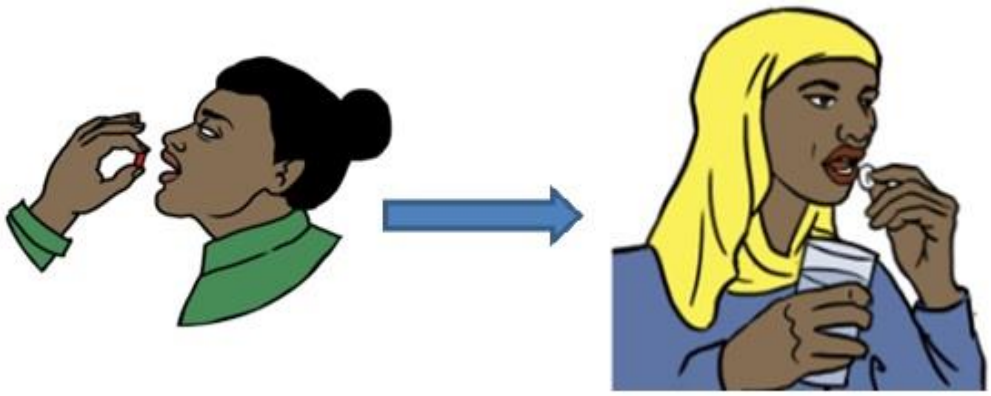

Figure 5.13: Medication reminder refined

Another improvement was made in Figure 5.14, which reminds the patient to collect his/her smear sputum and submit it to the doctor. Before the improvement, sputum bottles were shown in both the hands of the patient and the doctor, as shown in Figure 5.5. The participants suggested that the bottle in the doctor's hand should be removed. This means that the reminder now is clearly interpreted as the patient submitting the sputum bottle to the doctor, as shown in Figure 5.14.

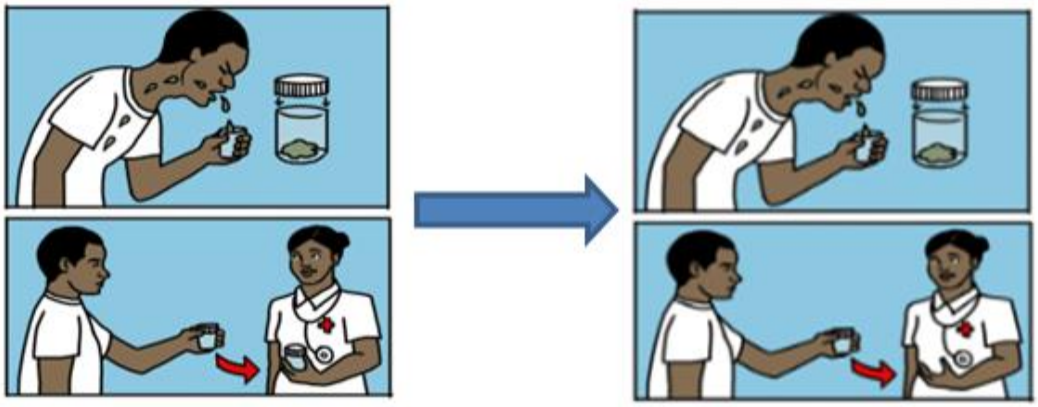

Figure 5.14: Submit sputum reminder refined

Based on the respondents' feedback, the glass of white liquid in Figure 5.6 did not give a clear enough message. Instead, the respondents suggested adding an image of a cow in the graphic. They said that if an image of a cow is added, it will clearly represent that a patient is reminded to drink a glass of milk, as shown in Figure 5.15.

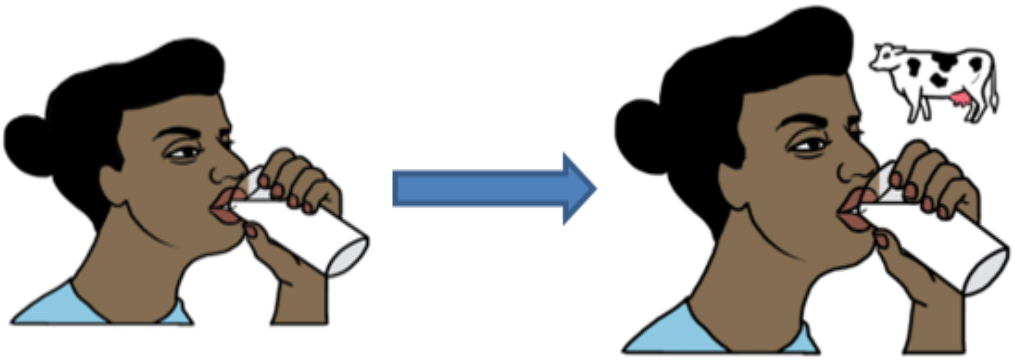

Figure 5.15: Drink milk reminder refined

The last improvement was in the meal suggestion reminder, as shown in Figure 5.16. This graphic (Figure 5.16) was obtained after making an improvement to Figure 5.7. The majority of the participants from all groups, including illiterate patients, suggested that Figure 5.7 was not clear. They suggested removing the spoon icon as they said usually African people do not eat vegetables with a spoon. Instead, they suggested improving the image in such a way that the person eats vegetables with their hand, as is now shown in Figure 5.16.

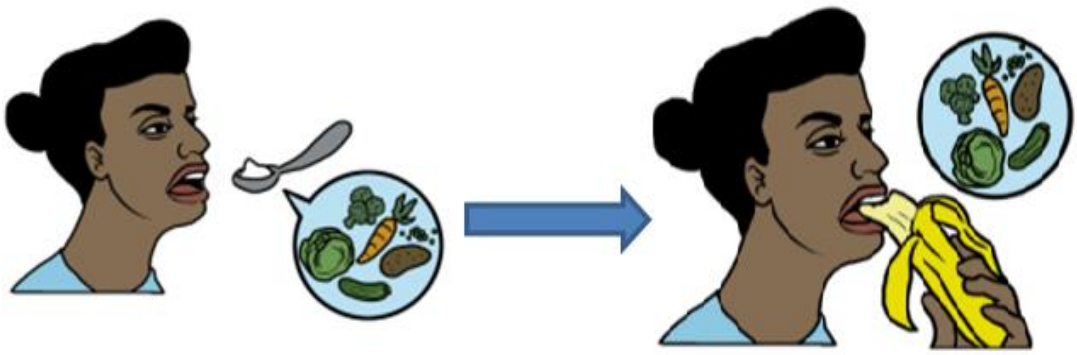

Figure 5.16: Eat vegetables reminder refined

Based on the participants' feedback, four graphics - Figures 5.4, 5.5, 5.6 and 5.7 - were re-developed. The other six graphics - Figures 5.2, 5.3, 5.8, 5.9, 5.10 and 5.11 - stayed the same. Participants' feedback indicated that there was no need to come up with new graphics, though there were particular suggestions made, regarding the colour, margin and image size.

After the modifications, a second round of graphic evaluations was conducted. The same process used in the first round was also applied in the second round. The graphics were printed and circulated to individuals. The four new images (Figures 5.13, 5.14, 5.15 and 5.16) were added to Figures 5.2, 5.3, 5.8, 5.9, 5.10 and 5.11. At this time, the results showed that all images were interpreted correctly by all participants from all groups. However, there were some suggestions proposed by the minority of students and researchers. For example, two participants indicated that Figure 5.2 looks like a "mother is reminded to send her child to the clinic and not an adult." However, the majority of participants were comfortable with the image as they said that the image produces a clear message that a patient "of each age group" is reminded to go to the clinic.

Ensuring the participants' feedback was addressed and graphics met their needs, the majority of the participants who participated in the first round of evaluations were also involved in the second round. The second round of testing also involved new participants, including three patients, one health worker, and six students and researchers. In total, there were 34 participants, as shown in Appendix B7.

People from different nationalities across Africa were involved in order to provide their opinions on the technology. As discussed earlier, the majority of the participants suggested that eating with a spoon is not in part of African values.

However, there are different levels of culture, including national, regional, social, language and gender (House et al., 2013). This study did not find a difference in interest of these levels of culture among our participants during the interpretation of the graphics. The participants clearly interpreted the meaning of each graphic correctly. Here is some of the verbatim feedback from respondents.

> "These graphics are really good. I like the design of them. Hopefully these would be well used to support patients to remember their treatment regimens",
> "I like these graphics. These looks nice. Good colours. All graphics are clear and easy to understand",
> "These looks perfect. All of the graphics are clear represent about TB treatment",
> "All of these graphics are well designed, I am sure these will help us to adhere the regulation of TB",
> "I would definitely be more likely to use something like that [graphic reminders] in supporting TB treatment".

The intention of the evaluation was to understand if the graphics adequately represent the messages that relate to the TB treatment environment. After conducting the second round of evaluations, almost all participants suggested that the graphics contained the correct message related to the TB patients' environments and needs.

Did users pay attention to the graphic objects?

The results indicated that there was a high degree of acceptance of the graphics amongst the participants. All participants paid attention well to the graphics and they had high enthusiasm for learning something new. It was found that the participants from all groups, including patients, healthcare workers, students and researchers concentrated on the graphics. These results, therefore, suggest that the graphics

generated the intended information and this had important implications for GBR system.

Did users retain the observed graphic objects?

The results indicated that the participants effectively retained the observed graphic objects. It was found that the participants were easily able to store and retrieve information about the graphics. The participants suggested that the graphics were designed in such a way that they were easy to remember. This result was very important as it shows that the graphics would enable users to retrieve the contents of messages properly.

Did users reproduce the observed graphic objects?

The results indicated that all participants, regardless of their level of education, age, gender, occupation, and cultural differences, were capable of reproducing the observed graphics similarity. The participants clearly understood the messages and suggestions contained in each graphic. It was also found that the participants agreed that the graphics were related to the message about TB treatment. The participants hoped that these would be helpful for supporting TB treatment.

Are users motivated by the learned elements from graphic objects?

The results indicated that the participants were well motivated and learnt a lot from the graphics. This was evident as it was found that the participants were able to easily see and remember what they had observed. The participants felt that the graphics were designed for them and support effective use of the technology.

These results indicated that the graphics were developed based on the four processes of the Visual Aid for Communication Framework (Ngoh & Shepherd, 1997). This is proved by the fact that the participants paid attention well, learnt, understood, reproduced and refined the meaning of each graphic correctly. Therefore, it can be concluded that the graphics are acceptable and can potentially be used to support the treatment of TB.

After the development of the graphics was completed, they were then combined with voice. Kiswahili was used because it is the main language of Tanzania. This enabled participants in Zanzibar to understand the meaning of the voices that they heard once a message was loaded onto the phone as a notification. The audio told the user that a reminder has been triggered on his/her phone and it was time to take

action. The texts of all audio messages were in Kiswahili and their translations in English are presented in Appendix B4.

In the next section m-health GBR applications is presented.

5.3 Development of m-Health GBR Applications

After visiting the TB clinics in Zanzibar, reviewing literature (in Chapter 2 and 3), and analysing the data collected in an initial investigation study (in Chapter 6), we noted three important themes that could further support the development of a possible m-health GBR application. The three themes were: design for low or illiterate users; design for offline access of reminder system; and design for cost-effective reminder applications. The themes helped to design technology that was better suited to the objectives and capabilities of the people for whom the system was designed. Therefore, three design decisions for a GBR application are apparent. These are:

i. Design a technology that overcomes the challenge of illiteracy and language barriers,
ii. Develop a mobile application that can work locally offline on a mobile device in order to limit engagement with mobile service providers, and
iii. Develop a mobile intervention that is cost-effective.

In order to address item 1, the application was designed such that it could use visual graphic communication as opposed to text and language applications. Visual graphic communication is a form of a language- and text-free communication. This type of communication can be used to help people with limited literacy to clearly understand the content of the message. To achieve this, the application was designed simply to be engaging and easy to use for users of all literacy levels.

In order to address item 2, the application was designed in such a way it could be used offline as opposed to SMS text messages, MMS messages and phone calls. The offline application is a mobile application that runs locally on mobile devices regardless of mobile network availability. The offline system enables users to work offline locally on the device at anytime and anywhere. When needed, periodically, data synchronize with backend systems.

In order to address item 3, the application was designed in the way it could not require charge driven by the mobile service providers. Mobile service providers were not included in the communication between the client and the server/hospital, as with SMS and phone call reminder systems. Low cost or cost-less mobile applications may have a positive impact on supporting TB patients' treatment compliance, as the patients can use the system without fear of any charges by a mobile phone provider. For example, in the study by Lester et al. (2010) many participants were either late or did not respond to the SMS inquiries from their intervention due to financial problems such as their phones running out of airtime.

5.3.1 Overview of m-Health GBR Applications

Figure 5.17 presents a system overview of the m-health GBR applications. It is a two module architecture that provides communication between the user and the server. The user side is the mobile phone that contains a GBR application. The phone communicates with the server only when downloading the reminder system and forwarding the feedback responses.

Once the reminder system has been downloaded to the mobile phone, it works offline. The server side contains the Structured Query Language (MySQL) database and PHP script (hypertext preprocessor). The client side also contains an Android SQLite database. SQLite is used to store the user responses temporarily before passing them to MySQL. SQLite is an in-process library that implements a self-contained, zero-configuration and server-less transactional SQL database engine. The advantage of using SQLite is that the code for SQLite is free and easy to use. SQLite is also a compact library with all features enabled. Its library size is very small-about 300KB to 500KB. This program is made to run on minimal stack space, which works well on memory-constrained devices such as cell phones and PDAs without disturbing other applications. The next section describes how the system works.

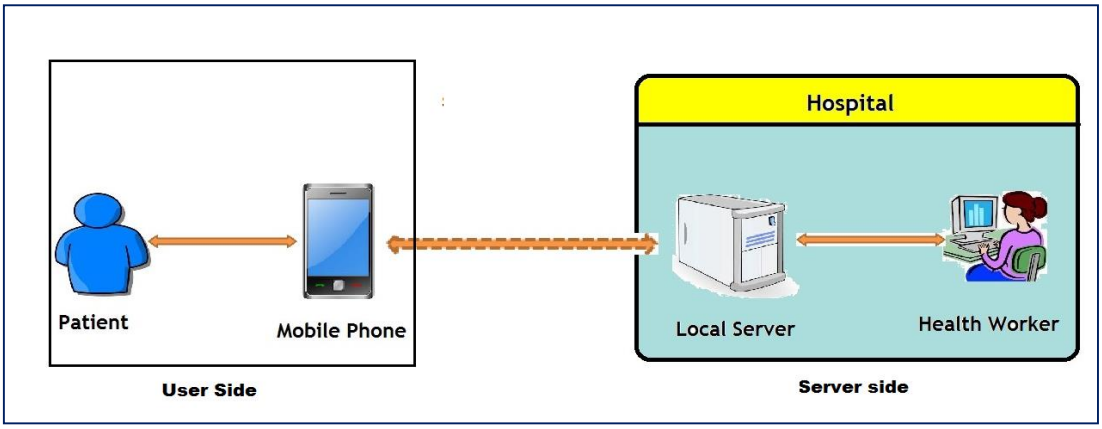

Figure 5.17: System architecture showing the connection between mobile device and server

5.3.2 System Usage Scenario

The usage scenario for the m-health GBR application was based on the assumption that the patient owns a mobile device to support his/her treatment. The patient using WiFi or mobile data downloads the system from a given link at the hospital, or the health worker assists the patient to download the system directly from the server. In order to access the system, the patient is asked to enter his/her credentials (patient ID and password). The patient ID is created once a patient is registered at the hospital and a password is generated by the database as a default.

Once the user has successfully logged in to the system, the reminder system containing the graphic messages are sent to the user's phone and are triggered based on the TB treatment schedule. The system contains various reminder messages, as listed in Section 5.2. These reminders were categorized into four groups: (1) medication reminders such as take pills, refill medications and submit smear sputum; (2) clinic follow-up reminders regarding clinic appointments or consultations; (3) education reminders for behaviour improvement, such as avoiding pain or spreading the disease to others; and (4) health reminders to improve eating habits. These reminders are set to automatically activate on different days and times based on the TB treatment regimen, which include daily, after every two days, weekly, etc. The system also contains an 'update' option, which allows a registered user to update his/her password information.

The m-health GBR system is a two-way communication system in which a patient is asked to respond by pressing a 'feedback button', as shown in Figure 5.19 (5) to

indicate that he has received the reminder and the medication has been taken. The response is then sent to the local hospital database. When disconnected, a SQLite database stores the feedback offline for automatic forwarding as soon as the connection is available, as shown in Figure 5.19 (7). The medication response reports can then be viewed by a health care worker for further treatment processes. This will also help the health care worker to follow the routine of a patient's treatment regimen. Figure 5.18 illustrates the flow of information of the GBR system.

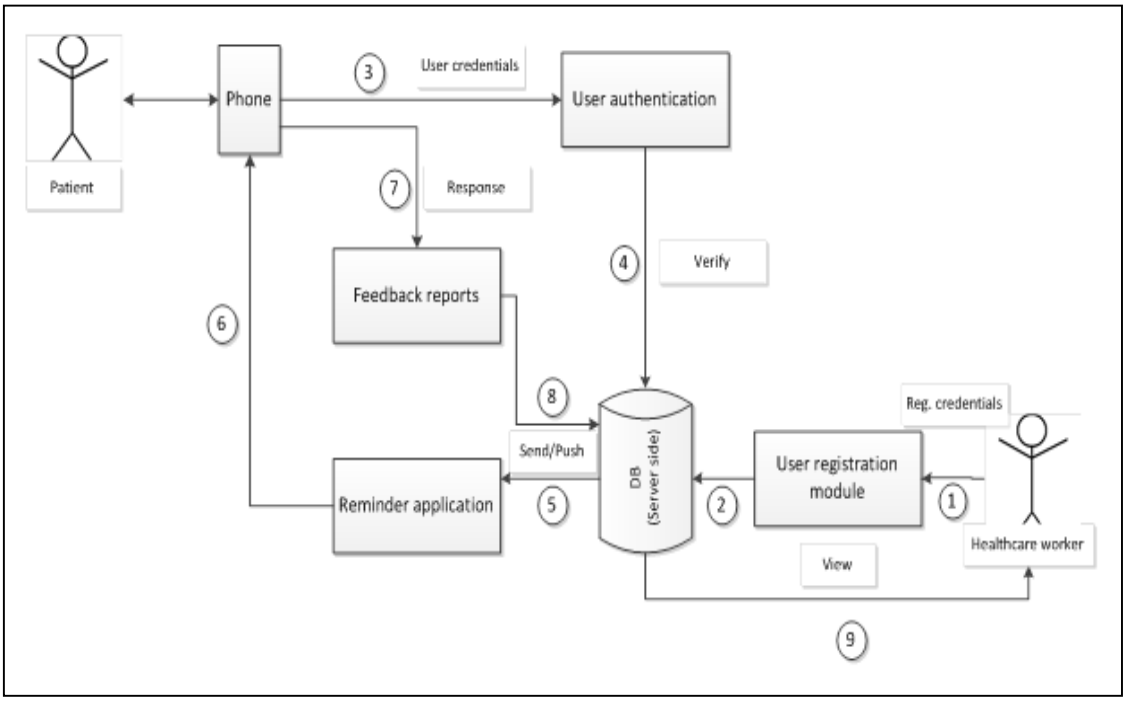

Figure 5.18: The scenario of the mobile GBR applications

5.3.3 Implementation of the m-Health GBR Applications

The prototype application was developed using the Java programming language for the Android platform. Android for mobile devices was selected due to two main factors. First, Android was chosen because it is open source (Rogers et al., 2009) and, second, it is the most popular operating system that runs on smartphones, as described in detail in Chapter 1.

The aim was to provide a user friendly system that enables patients to easily use and understand the meaning of reminders. The first interface after the system is launched is the log in screen, where the user is asked to enter his/her credentials (Figure 5.19 (1)). If the user's credentials match those in the database, then the main screen will

appear (Figure 5.19 (2)). Otherwise, the system will tell the user that he/she has not presented the right credentials[11]. The home screen provides instructions about the system. It also contains two buttons for adjusting sound. The first button is mute. This button allows the user to mute the sound. The second button is unmute, which allows the user to activate sound. This is in case the user does not want to disturb others.

[11] During the experiments, the participants were directed on how to present their credentials; for those participants who needed assistance such as illiterates, healthcare workers were helping them access to the system.

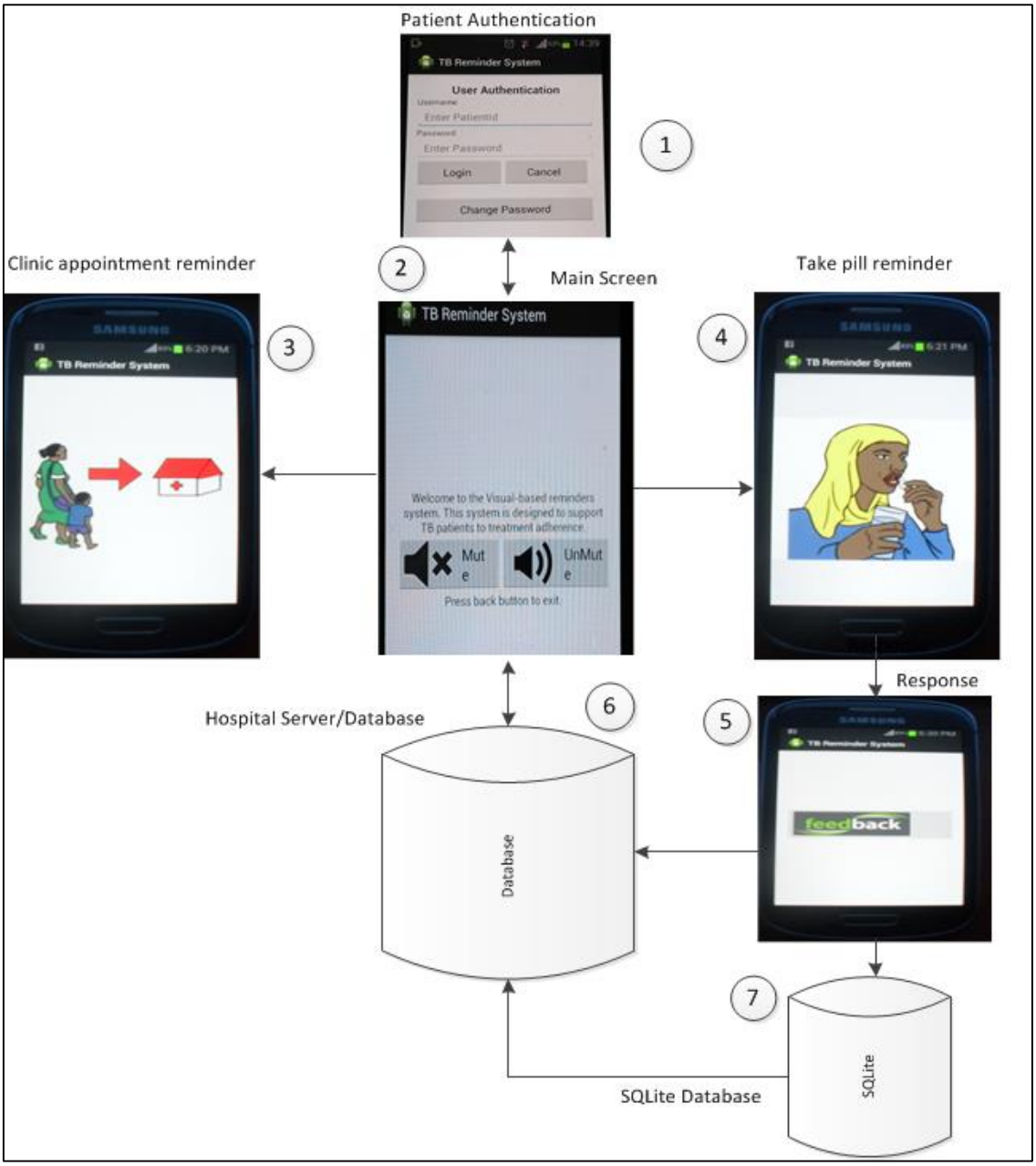

Figure 5.19: The components of m-health GBR applications

(1) patient presents his/her authentication details (2) the main interface after a user logs in to the system (3) example of a reminder message (clinic appointment reminder) (4) example of reminder message (take pill reminder reminds patients to take medication) (5) feedback button screen[12] (6) hospital server/database in which mobile application and users responses are stored (7) SQLite database, which stores responses offline.

[12] Appendix C1.1 presents a sample of the code in Android used to capture the data that was recorded in the database. These include user ID, reminder type, date and time of response.

In order for the reminder message to be activated, an alarm manager service with a broadcast receiver was implemented. Appendix C1.2 presents examples of the code for the implementation of the alarm broadcast receiver. A broadcast receiver can be defined as a component that responds to system-wide broadcast notifications (Rogers et al., 2009). This allows a reminder message to be activated at a defined time. For instance, if a user's phone clock is the same as the time of the reminder (i.e. 7h00 or 7:00AM), then the broadcast receiver class in Appendix C1.2 is activated. This process then calls a reminder class (activity class) that contains a graphic message, as presented in Appendix C1.3.

Furthermore, a 'reboot' (boot completed) function that allows the reminder application to automatically start was implemented. This allows the application to continue running after the device is rebooted. The idea is that, when a mobile phone is switched off, all applications are terminated. The 'boot completed' function allows the application to self-restart and work as usual. Sample code for the implementation of this process is presented in Appendices C1.4 and C1.5.

In order to comparatively measure the effectiveness of the GBRs, the speech-based reminder system was used. This system was used instead of other reminder methods that are text-based, because some participants were illiterate and therefore unable to read the texts but could understand verbal communication. This application worked similarity to the GBR system shown in Figures 5.18 and 5.19. The difference between them is that in the GBR prototype, graphics with audio for notification are triggered as reminder interventions, while, in the speech-based prototype, only audio (speech) is triggered as reminder interventions. The same audio clips were used in both GBR and speech-based prototypes. The texts of these audio clips are provided in Appendix B4. Figure 5.20 shows the processes of the speech-based prototype and findings are presented in Chapter 6.

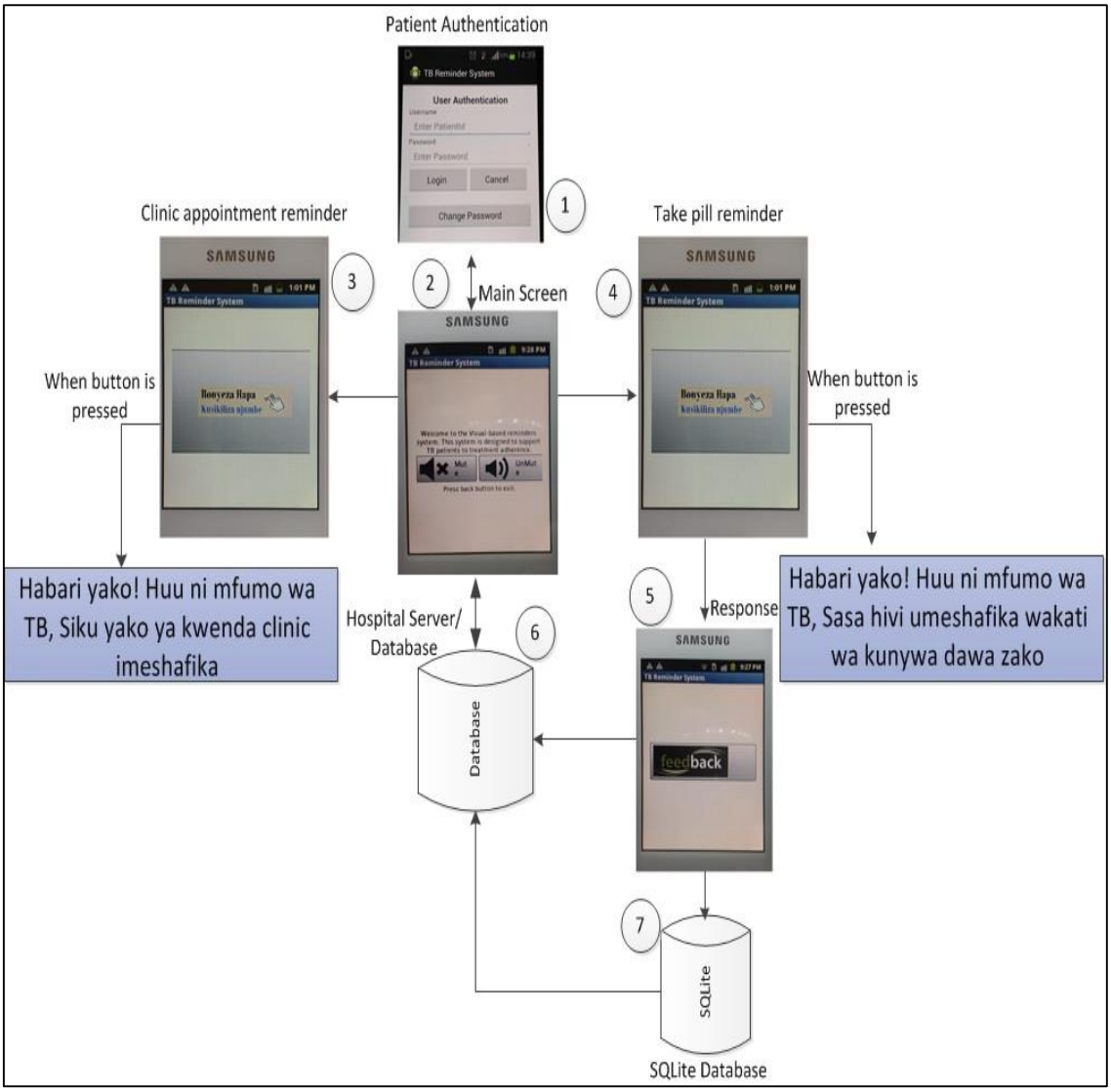

Figure 5.20: The components of the speech-based reminder system

(1) patient presents his/her authentication details (2) the main interface after a user logs in to the system (3) example of clinic appointment reminder; a user is asked to press this button to listen to a reminder message (4) example of take pill reminder; a user is asked to press this button to listen to a reminder message (5) feedback button screen (6) hospital server/database in which mobile application and user responses are stored (7) SQLite database, which stores responses offline.

5.3.4 Automatic Data Synchronization

One of the features of the reminder system is automatic synchronization with the database. As described earlier, if the Internet connection is not available at the time of sending feedback, SQLite stores the feedback for automatic forwarding when the

Internet is available. The code for the implementation of this process is presented in Appendix C1.6.

5.3.5 Periodic Checking of the Phone Clock

The reminder system also contains a function that periodically checks the phone clock. Every reminder message is set to trigger at a different time based on the TB treatment regimen. To ensure that the system works correctly, a clock checking system was implemented to ensure that the user's phone time is correct at all times. The system checks the phone clock every 30 minutes, to confirm that the phone time is the same as the time zone of a particular country. Mobile network time was used to manage the phone clock. Figure 5.21 shows an example of network provider time control. In this case, the GBR system periodically ticks this box to always ensure that the phone clock is correct. The code for the implementation of this feature is presented in Appendix C1.7.

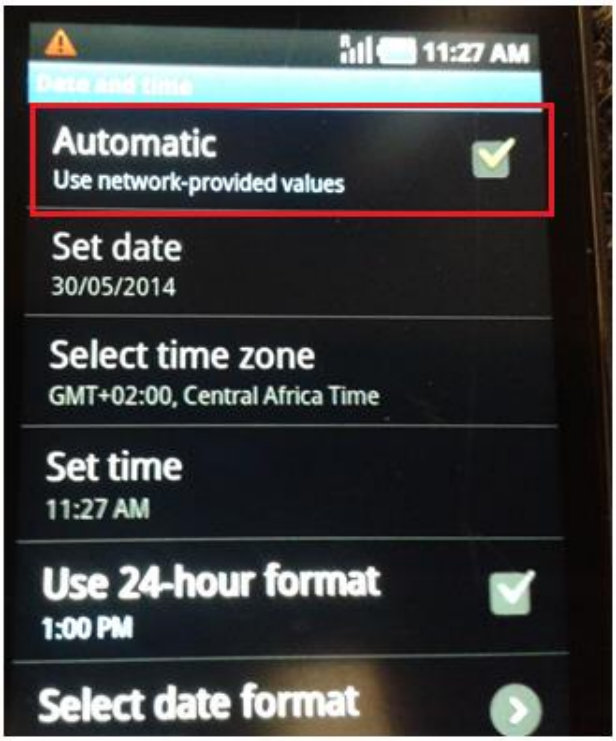

Figure 5.21: Screen shot of network provider options time

5.3.6 Usability Evaluation of the GBR Application

To ensure that the GBR system meets users' needs, a formative evaluation was conducted to test its functionalities, as described in Section 4.7.3. The formative

evaluation helps to understand whether a system works or doesn't, and tries to refine the specifications.

To achieve this objective, the following main questions were investigated:

i. Did users understand the application?
ii. Do the graphics illustrate the intended purpose?
iii. Did the application provide clear and understandable sound?
iv. Are reminder notifications triggered properly?
v. Is the application relevant to the purpose and TB patients' needs?
vi. Is the application easy to use?
vii. Did it show any inconsistencies?

In addition, the evaluation also investigated whether the prototype application could run without disturbing other programs (allowing running simultaneously), for mobility and providing easy access to other pages such as the home page screen.

In order to better evaluate the download performance of a GBR system distributed on mobile phones, the researcher first measured the downloading time based on the speed of network. Different Android phone models running different Android OS versions were used. The evaluation was conducted using two different network connections (Wireless and Mobile data) at three different times: morning, afternoon and evening. The result shows that the average downloading time of the application ranged from 5 to 17 seconds. This finding therefore suggests that the application can be efficiently downloaded within 30 seconds.

During the usability evaluation, two sets of actual users were involved: TB patients and health care workers. The demographic information of the participants is described in Chapter 4.

The participants were given mobile phones with the m-health GBR prototype on them. The issued phones were of different models, including Samsung Galaxy S (GT-19003), Samsung Galaxy Pocket (GT-S5300) and Samsung Galaxy SIII mini (GT-18190). The majority of them were Galaxy Pocket Phones.

The usability evaluation was first conducted by health workers before moving on to patients. The health workers' evaluation was conducted within a day. The reminder

messages were set to trigger at an interval of five minutes. The researchers observed the health workers and how they interacted with the application. Figure 5.22 shows screenshots of the health workers evaluation session.

For patients, the reminders were set to trigger based on the TB treatment regimens, as scheduled by healthcare workers. For example, a current TB treatment timeline in Zanzibar is to take pills once a day in the morning at 7am. During the trial, each patient was given a mobile phone for the duration of one week. The researchers distributed mobile phones to participants and they were returned on the last day of the trial, to get feedback. Figure 5.23 and Figure 5.24 show screenshots of patients signing consent forms for participation.

Figure 5.22: Sample health workers group usability evaluation session

Figure 5.23: Sample literate patient group usability evaluation sessions (read and sign consent forms)

Figure 5.24: Sample illiterate patient group usability evaluation sessions (read and sign consent forms with their assistants)

Table 5.1 indicates the agreed rate by participants. The results based on the key usability themes are presented in the following sections. These results are derived from questionnaires and the interviews of health workers and patients.

Table 5.1: The agreed response rate by participants of the usability evaluation key questions

Key question	Agreed rate by participants
The users understood the application	100
The graphics illustrated the intended purpose	100
The application provided clear and understandable sound	97
The reminder notifications triggered properly	97
The application is relevant to the purpose and TB patients' needs	95
The application was easy to use	95
The application did not contain any inconsistencies	89

5.3.6.1 Understanding the purpose of m-health GBR applications

The results revealed that the participants believed that the system has a potential to help TB treatment. All participants (100%) agreed that the graphics of the application conveyed the intended meaning (Table 5.1). 95% of participants found the system relevant to TB patients' needs. Some of the participants' comments were:

"I found this system to be helpful in supporting my treatment regimens",
"I really appreciate this system. I understood the meaning of all graphics",
"The application seems to be worthwhile in helping us", and
"This kind of system is what we want, this is very exciting".

However, two patients were unsure if the system could help them. It was found that these two participants were fishermen. Their reason is that, due to their work, it was difficult to carry cell phones, particularly during the rainy season. Thus, they said that they were missing some reminders because most of the time they were far from their phones. However, they mentioned that the system could have benefits for those take their mobile phones with them every time.

Overall, the participants who understood the purpose of the m-health GBR system said that the application is simple to understand and contained the relevant features for TB patients.

5.3.6.2 Technical performance and design

Table 5.1 shows that the majority of survey participants (97%) found that the reminder messages were triggered properly and 97% of them found the voice to be good and clearly understandable. Only one healthcare worker reported the problem of sound. During the trial, this participant mentioned that she had difficulty in hearing the voice. At the end of the trial it was found that the phone used had its volume set too low.

During the patients' interview sessions, it was found that some participants received reminders, and they were properly interacting with the system. One participant responded that he received a reminder around 9pm, which was an inconvenient time for him. It was found that the participant had changed the phone clock when he interacted with other applications. To ensure that the reminder messages are triggered at the expected time, the m-health GBR system was designed to automatically correct a phone clock every 30 minutes; the reminder was triggered before the phone clock was corrected. To solve this problem, the checked time interval was reduced from 30 minutes to 10 minutes.

5.3.6.3 Analysing challenges

Most of the challenges within the system were observed with the medication confirmation feedback. It was found that although the majority of participants (84%) sent the "take pills" confirmation feedback to the server, 16% of them did not frequently press the feedback button that sent the confirmation responses. They responded by giving the reason that they did not see the feedback screen (as shown in Figure 5.19 (5)). This is because the participants did not discard the "take pill" reminder screen (as shown in Figure 5.19 (4)) by pressing the back key of the mobile phone. The response screen appears once the "take pills" reminder is triggered and disposed.

On the other hand, two patients (5%) had difficulties using the application. They noted that the short time allocated for training on the use of mobile phones was not enough to help them understand the system well. It was found that these participants had never used mobile phones before. It can be suggested that the training sessions have to be adjusted to accommodate participants who do not have prior experience of using cell phones.

The results further indicated that 11% of participants reported inconsistences while using the application, as indicated in Table 5.1. These participants reported that the most challenge was on the sending feedback. To address this challenge, the feedback button will also be embedded on the same screen as the "take pill" reminder. There will be two modes of sending the feedback: first, by pressing the feedback button that appears once a user presses a back key (Figure 5.19 (5)); and, second, by pressing the same screen of the "take pill" reminder. This will help the users to grasp the technique.

At the end of the trial all mobile phones were connected to the Internet using hospital WiFi or mobile data for forwarding the feedback reports. Some participants were found to frequently use the Internet.

5.3.6.4 Acceptance of m-health GBR systems

It was evident from the analysis of the participants' feedback that many participants appreciated the m-health GBR systems. 95% of the participants found the application easy to use and they believed it could support TB treatment regimens (Table 5.1). The patients' feedback on the m-health GBR intervention after the trial

indicated that they were pleased to receive visual reminders. However, two patients and one healthcare worker suggested that 'feedback button' be improved by making it more visible as now proposed in Section 5.3.6.3. Most participants expressed similar opinions about the usefulness of the GBR system, such as:

Respondent [5A] said:

> "I am very glad to see this system, and hopefully, it will be implemented as soon as possible. I really like it. Currently our patients are faced with the problem of missing the taking of pills. This system is very important; it can support the patients by reminding and encouraging them to follow the routine of treatment."

Respondent [5B] said:

> "This system is very useful; it contained simple and understandable graphics. This kind of system is what we want. It could motivate patients to take their medication on time, and also help them to come to the clinic on time. Recently, most of the patients missed to attend the clinic because of forgetfulness. I hope this system has a big impact on supporting them and us (health workers), as well as to achieve the adherence of TB treatment."

Respondent [5C] said:

> "This system is very good, see this picture show woman cough and cover her mouth [laughing] very interesting. It encouraged me a lot including taking pills, cough in a proper manner, drink milk and so on. I like this system very much. Is it possible this system to be continued? [she asked]… because since you gave me this phone it reminds me and I always take my medication on exact time compared in normal days (usual care) without mobile reminder."

Other verbatim feedback from respondents is attached in Appendix C2.

5.3.6.5 Most helpful messages

During the individual patient interviews, participants indicated that the most helpful messages were “take pill,” “cough manner,” and “feeling unwell.” The majority of participants responded that the m-health GBR application was helpful in reminding them to take their medication. These are verbatim feedback:

Respondent [5D] said:

> “One day I was going to my farm and I forgot to take the pills, when I was about 500 metre from home I received a reminder. Then I returned home to take my pills.”

Another respondent [5E] said:

> “I was in my work. I slept at my work. In the morning I received a take pill message. Actually I was forgetting; the system reminded me! I really like it.”

Two participants indicated that they shared the educational messages “proper manner to cough”, and “feeling unwell” with family and friends to help educate them about the disease.

One respondent [5F] said:

> “I was in public transport with my friends. Suddenly, I received a cough manner message. Later I showed it to my friends and they really appreciated it. One of them even said it is a very good system. This system could be indeed educational.”

In addition, the participants were asked for their opinion on whether the application contained simple enough features and are usable by every person. The results show that all participants (100%) suggested that the application contained simple features and all are able to use the system. Both patients and healthcare workers believed that TB treatment can be improved by this system.

In short, the results indicated that the system is well understood and adequately conveyed the graphic reminder messages for supporting TB treatment. It was noted that almost all participants were able to understand the benefits of the research. Most

of the participants easily identified the GBR content, functionality and its purpose. The participants mentioned that the application contained features that are simple enough for them to understand. As indicated in the previous sections, the results reflect the fact that users thought the system was relevant to their needs, understood the purpose and found it easy to use and thought it worked properly.

The results also revealed that users agreed that the graphics used in the system conveyed the proper meaning of the TB reminders and the sound was clearly understandable and without inconsistencies. However, 11% of participants indicated inconsistencies while using the application and most of them were reported during the time of sending feedback, as discussed in the results section.

The study also involved participants who had no experience in using mobile phones. Before the trial period, a short training session was provided on the simple tasks of mobile phone use, such as accessing previous pages by pressing the back-key button and switching the phone on and off. The objective was to understand whether all the participants were able to use the application regardless their literacy levels. The results showed that participants reported that the training helped them understand the important things to do while using the system, such as pressing back on the keypad and accessing the feedback button. Some of them reported that future training sessions have to be increased for those who do not have experience in using mobile phones to make them familiar with mobile phone use.

To ensure that the prototype was working properly on the mobile devices, they were allowed to run simultaneously, which did not interfere with other mobile programs. The researchers first tested the application by running them on their phones for several days before the users' evaluation was done. No participant reported a technical problem during the use of the application. Additionally, the majority of participants found that the system provided easy and quick navigation to other pages including the home page screen, and only a few reported challenges when sending feedback.

After the formative evaluation with the users of the technology, we identified two major challenges to address in order to meet their requirements and needs:

i. **Feedback button:** It was not visible for some participants. This was addressed by linking a feedback button on the same screen as the "take pill" reminder, as discussed in Section 5.3.6.3.

ii. **Check phone time:** It was found that the phone clock check intervals of 30 minutes was too long. To address this challenge, the automatic check phone clock time was reduced to 10 minutes, as previously discussed in Section 5.3.6.2.

Based on the feedback from the study participants, the first version of the GBR prototype was improved with minor updates, as discussed above, before the second version was developed. This version (prototype II) was tested in Phase IV and IV - prototype IIA and IIB, respectively. These prototypes (IIA and IIB) had the same contents; they only differ on the procedure of sending reminder messages (see Section 4.5.1). Detailed descriptions of the evaluation processes are provided in Chapter 4 and findings are presented in the next chapter.

5.4 Chapter Summary

This chapter began with a discussion on the development tools used in the design and an evaluation of the graphic reminder interventions. A detailed explanation of the implementation of the m-health GBR application for supporting TB treatment was then provided. This application was developed by considering the challenges faced by TB health workers and patients and based on their requirements and the literature reviewed. The chapter also presented the speech-based reminder system. This system is used to measure the effectiveness of the GBR applications. The chapter then described evaluation approaches used to evaluate the usability of the application and concluded with the presentation of the evaluation results.

After the first prototype was improved based on the users' feedback, the second prototype was then implemented. The usability evaluation processes of the m-health GBR system were discussed in Chapter 4 and next chapter (Chapter 6) presents the findings.

CHAPTER SIX

RESULTS

6.1 Introduction

This chapter presents the results of the study. The chapter begins with the presentation of the findings of an initial investigation study that was conducted to gain an understanding of the user requirements for GBR systems. These include: scope of the knowledge, challenges and views of TB and its treatment regimen by TB health workers and patients; and reminder notifications suggested by participants to be used in this study. The chapter then presents the findings of an evaluation of the effectiveness of the GBR system as per the evaluation metrics and concludes with a description of the findings related to evaluation of applicability of the Visual Aids for Communication Theory for supporting TB treatment. This was used to address the second research question (RQ2): *How effective are mobile graphic-based reminders in supporting treatment adherence for TB patients?*

6.2 Findings of Initial Investigation Study

The processes of how the initial investigation study (Phase I) was conducted, organized, study areas, participants and data collection methods are presented in Chapter 4. The following sections present the findings of the challenges to healthcare. It then presents the reminder notifications suggested by participants to be used in the study. This is followed by discussions of the perceptions and concerns regarding systems and concludes with the implications of the initial investigation study.

6.2.1 Challenges to Healthcare

During the time of the field study in Zanzibar, the researchers observed various challenges that hinder the TB healthcare workers and patients from achieving their goals. The most common challenges are a shortage of healthcare workers and lack of financial support, forgetfulness, and limited knowledge of the TB disease. These challenges were also reported by various official TB documents and publications. More challenges like high HIV prevalence, patients not starting treatment, incomplete treatment, substance abuse and smoking were found in the documentations and publications. It was also found, particularly in the documentations and publications from South Africa, that poverty and stigma are the other challenges that hinder patients complying with the TB treatment. The public documents and publications that were reviewed to help to identify problems are listed in Appendix D1.

6.2.1.1 Lack of TB health workers and financial support

The lack of adequate healthcare workers was a very common challenge in every TB healthcare centre visited during the field study in Zanzibar. The current number of healthcare workers are not sufficient to manage all patients. For example, in Zanzibar, every TB patient is expected to have a health worker visiting him or her every two weeks to check his/her progress. However, due to the limited number of health staff, a visiting system becomes very challenging. During the field study, all health workers indicated that lack of sufficient staff and limited funds for transport as some of the challenges behind their failure to achieve their goals as planned. The researchers observed that sometimes health workers were unable to visit patients as proposed due to being overwhelmed by work.

6.2.1.2 Forgetfulness

The poor adherence to anti-TB treatment among patients with TB is a major problem. This present study found that the major challenge facing TB patients who fail to comply with their treatment is forgetfulness. The majority of patients responded that they often forget to take medication or attend clinics for their appointments. Other reasons, such as poor health, work and family commitments were also mentioned as barriers to TB treatment.

One patient mentioned that she sometimes forgets to take her medication before she leaves home. Once she is at work (which is about 15 km away from her home) she sometimes remembers. Because she works far from home, she fails to take the pills at that time. She further indicated that, when she returns home early, she takes her medication. However, if she returns late, she does not take the pills on that day. According to WHO, a patient who does not take medication properly greatly risks treatment failure, relapses and developing drug-resistant TB (WHO, 2013).

Four patients mentioned that forgetting is the major reason for them not visiting the hospital as scheduled. Another patient noted that work commitments are the major reason why he does not effectively comply with treatment. He mentioned that he is tired after work and so sleeps longer. As a result, he takes his medication late when he wakes up or he totally forgets to take them at all.

6.2.1.3 Lack of knowledge of the TB disease

Poor education about TB among patients, families and community leads to difficulty in curing the disease. This challenge is mostly caused by lack of knowledge about treatment regulations. People are unaware about the correct behaviour, such as proper conduct in order to avoid spreading the disease. The study found that many patients argued that they had not received the correct information about TB, and others indicated that they did not understand the information well enough to share it with other people. One patient expressed that she was not fully aware of the importance of the treatment while others felt that the information provided was not enough. The health workers noted that not understanding the information is a challenge to compliance with TB treatment. Two healthcare workers further mentioned that if patients do not receive the right information about TB, they would increase the risk to spread it to others. An inadequate dissemination of education and

information regarding TB among patients and their families is one of the challenges causing increased non-adherence to anti-TB treatment (WHO, 2012).

One of the participants indicated that she got TB from her sister. She added that she got the disease because, at that time, she had little knowledge about TB. Health education is an essential tool among TB patients and communities to avoid the spread of the disease (Kiros et al., 2014).

6.2.2 Reminder Notifications

The initial investigation study also aimed at revealing the appropriate reminder notifications that could be used to support TB patients in adhering to treatment. The participants suggested various types of reminder notifications to be included in the study. Table 6.1 shows the final ten reminder notifications suggested by the majority of participants and agreed to by the TB healthcare workers. The purpose of these reminder messages was to support TB treatment and reduce the risks of disease transmission. These reminders are categorised into four groups:

i. Medication reminders for patients who take medication, such as take pill, refill drugs and submit smear sputum.
ii. Clinic follow-up reminders that remind patients to attend the clinic for appointments and consultations.
iii. Educational reminders that remind patients of the correct conduct to avoid pain and spreading the disease to others.
iv. Healthy reminders that remind patients about eating healthy meals.

Table 6.1: The suggested reminder notifications and who proposed them

No.	Reminder notifications	Health workers	Patients
1	Patient reminded to take pills	√	√
2	Patient reminded to submit his/her smear sputum to clinic for checking	√	√
3	Patient reminded to collect his/her medication for upcoming days	√	√
4	Patient reminded to go to clinic for appointment	√	√
5	Patient reminded to visit a clinic when feeling unwell	√	
6	Patient reminded to consult a doctor at any time		√
7	Patient reminded to cough in the proper manner	√	√
8	Patient reminded not to cough in the wrong manner		√
9	Patient reminded to take a glass of milk	√	
10	Patient reminded to eat a healthy meal	√	

6.2.3 Perceptions and Concerns Regarding GBR System

The prior perceptions toward using a mobile GBR system to support TB treatment were overall positive. Findings showed that 93% of participants had mobile phones and use them for various purposes, such as receiving and sending SMSs, making and receiving calls, getting news, paying bills, and sometimes for sending and receiving images.

The interviewees had different levels of education, and were a combination of literate, semi-literate and illiterate ones. The findings show that the participants who have mobile phones and were illiterate, unsurprisingly, used mobile phones as literate patients for communication, such as making and receiving phone calls. This finding concurs with the study of Person et al. (2011) in which the frequency of mobile phone use did not correlate with educational level.

The participants were further asked about their awareness regarding the use of cellular phones for healthcare purposes. All participants responded that the mobile phone could support them to comply with treatment. The participants were then asked about a type of mobile intervention, including SMS, phone call and graphic application, they would have preferred to be used for supporting their treatment.

Interestingly, almost all participants suggested the idea of the use of a GBR system to support the TB treatment. The participants made comments like:

Respondent [6A] said:

> "This is a great idea. The GBR system may be really helpful to support TB treatment, especially for patients who are unable to read text. A major problem we face here is that many patients do not attend the clinic as recommended! When you ask them why? They said that they often forget the day and time of appointments. So, I hope that the establishment of this system will help them remember their clinic appointments, and time of taking medication. Especially, nowadays that many of the patients already own mobile phones."

Respondent [6B] said:

> "This is a very good idea. It will help me a lot, as currently I forget to comply with my treatment regimen."

Respondent [6C] said:

> "This is a fantastic idea, we like it, it will help both us (healthcare workers) and patients to follow the TB treatment regimen."

Respondent [6D] said:

> "The idea of the use of mobile GBR system to support TB treatment is very good and I think it will be very effective in supporting the TB treatment process."

All participants even the patients who were unable to read and write made comments that the idea of a graphic application was very interesting and that they would be able to clearly understand the content of the messages. All patients asserted that they would like to use a GBR system reminding them to take their medication and follow-up their clinic appointments. The TB coordinator, pharmacist, data manager and three healthcare workers mentioned that the idea of a

visual application could be more effective for reminding the patients who are unable to read and write to follow the routine treatment regimen for TB. Additionally, a GBR system does not require the network communication fees – charges by mobile network provider - as in the SMS and phone call systems.

The health workers further noted that a GBR system could support patients in remembering their clinic appointments. Two healthcare workers noted that a reminder system could contain a feature that asks patients to send feedback after they have taken medication. This was considered during the prototype development. A 'Feedback button' was created, which is pressed by the patients after taking the medication and sends a medication confirmation message to the database.

Furthermore, a patient's care expressed that a system would help him as currently he always ensures that his brother (a patient) remembers to take his medication on time. He mentioned that mobile reminder systems may help his brother remember the time of medication and he would then not have to worry about visiting his brother every morning to remind him.

Three health workers further voiced a concern about the type of mobile phones that support graphic applications as not every patient has a smartphone. This is a challenge at the moment as the application was developed on the Android smartphone platform. However, the findings show that 55% of participants had smartphones and about 70% of these were Android phones.

6.2.4 Implications of Initial Investigation Study

Results from the initial investigation study show the patients had desire to receive reminders through mobile phones. The general suggestions made during the initial investigation study in relation to mobile reminder systems indicate that patients are more willing to use mobile phones as a supportive tool, reminding them of times for medication and follow-up on clinic appointments.

The findings of this study also showed that there are various challenges and barriers facing TB patients when complying with their treatment regimens. The challenges included forgetfulness, lack of knowledge of the TB disease, work and family commitments. These challenges are a global concern, as currently many projects have been proposed and implemented to address these challenges (Akhter et al.,

2012; Adane et al., 2013; Kiros et al., 2014). Most of the patients in this current study mentioned that forgetfulness is the major reason for them failing to comply with the TB treatment.

Participants indicated that mobile a GBR system could support them to remember their treatment regimen. The motivation of proposing a GBR system is due to the fact that visual communication is easy to understand and a more effective way of communicating than texts and words (Marsh & White, 2003; Gupta, 2008). Visual communication does not rely on literacy and language barriers and can enable everyone to clearly understand the content of messages, in comparison with SMS text message and speech reminder systems.

Furthermore, SMS and phone call reminder systems require the cost of mobile operator charges or network communication fees. There are various studies reporting cost as a reason hindering the implementation of SMS text messages and telephone calls as reminder systems for supporting healthcare (Prasad & Anand, 2012; Caldwell, 2013). The system of this study can work without being connected to a mobile service provider. The system anticipates working offline locally on mobile phones, as opposed to SMS, phone call or MMS applications, which all require a mobile phone network operator. This challenge was described in greater detail in the Chapter 3 and possible solutions to address this challenge are provided in Chapter 5.

6.3 Findings: Effectiveness of the GBR System

The evaluation process of the GBR application, including evaluation methodology, participants, and data collection methods are presented in Chapter 4. The data from application event logs are presented in Appendix D2 and those from the SR and PC adherence variables are presented in Appendix D3. The following sections present the findings as per the evaluation metrics, including the effect of reminders on improving adherence to treatment, effect of reminders on the number of responses, efficiency of response time to reminders, and patients' preferences and satisfaction.

6.3.1 The Effect of Reminders on Improving Adherence to Treatment

Treatment adherence rate was measured by SR (self-reported) and PC (pill count) between the three study groups of control, speech-based and GBR groups. The

results of each experiment are presented separately, and these findings are used to answer the following question:

"Does using mobile graphic-based systems support TB patients for treatment adherence?"

To recap, this question was addressed by measuring the improving adherence to treatment between the control group and mobile GBR group.

The SR and PC adherence variables were used to indicate the treatment adherence rates for the control groups and intervention groups in both experiments. The findings presented in this section help to indicate the effectiveness of the mobile reminder systems over traditional care in supporting TB treatment. In line with a period of six months TB treatment, this study argues that the timeline of capturing the life cycle of patients' adherence to treatment was indeed short which was five weeks for each experiment.

6.3.1.1 First experiment

Results: Treatment adherence rate

Figure 6.1 shows the treatment adherence rates for the control, speech reminder and GBR groups.

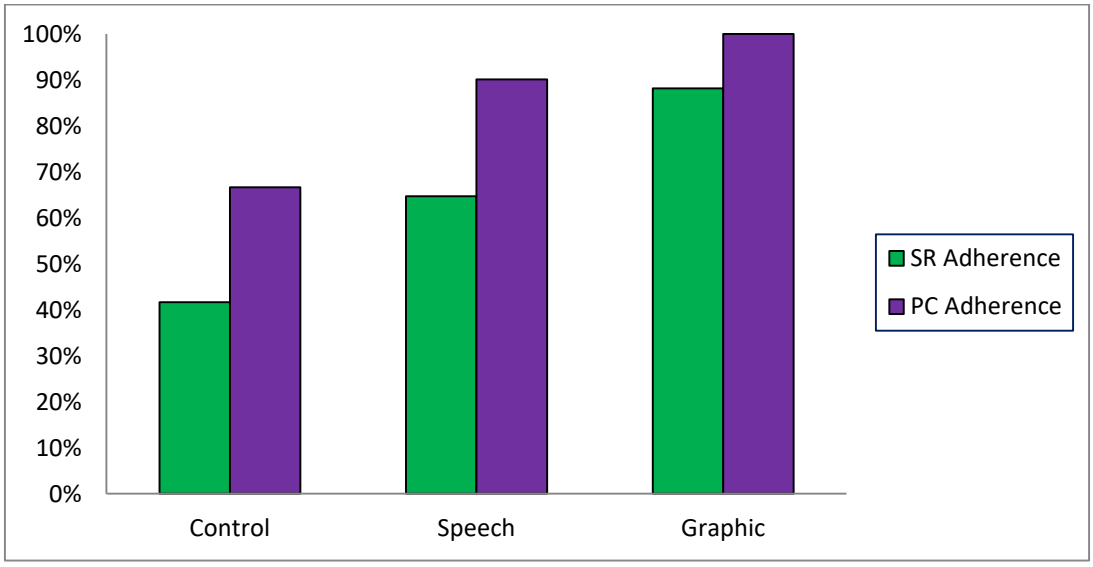

Figure 6.1: Treatment adherence rates for control, speech-based and GBR groups

There was a difference between the adherence rate to the treatment in the control group, speech group and GBR group. The patients' SR adherence rate for the control, speech and GBR groups were 41.7%, 64.7% and 88.2% respectively. The PC adherence rates were 66.7% in the control group, 90.5% in the speech reminder group and 100% in the GBR group. Both SR and PC variables show that treatment adherence rate was higher for GBR group than for control group.

Similarly, the SR and PC variables show that treatment adherence rate in the GBR group was higher than in the speech reminder group. Thus, the treatment adherence rate in the mobile GBR group is larger than in the speech reminder group and control group.

6.3.1.2 Second experiment

Results: Treatment adherence rate

Figure 6.2 shows the treatment adherence rates for the control group, speech reminder group and GBR group.

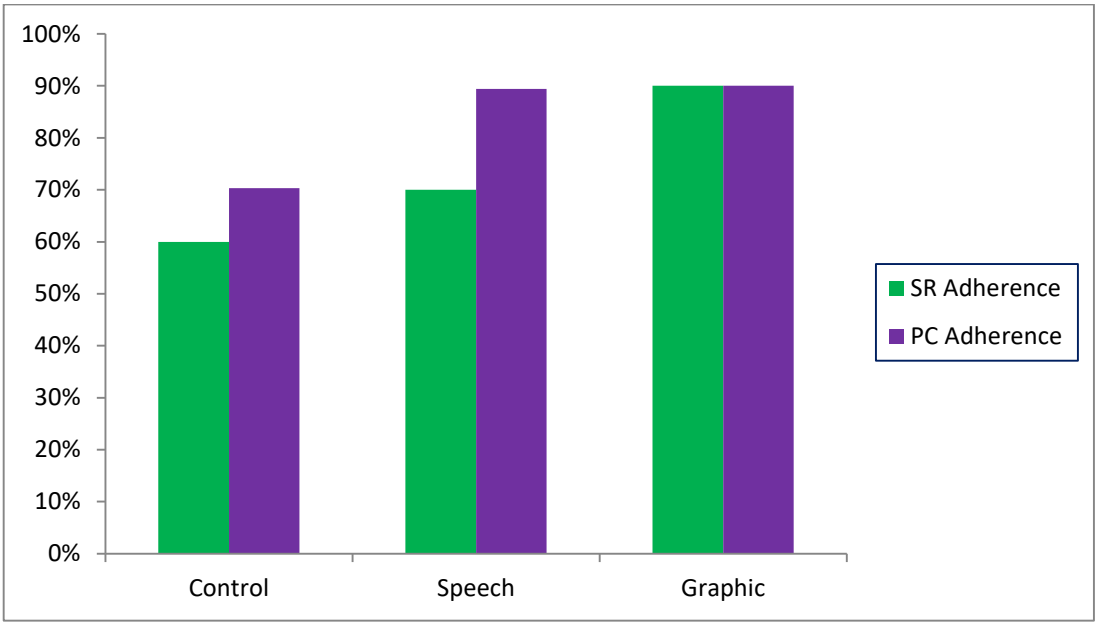

Figure 6.2: Treatment adherence rates for control, speech-based and GBR groups

There was a difference between the adherence rate to the treatment in the control group, speech group and GBR group. The patients' SR adherence rates were 60% in the control group, 70% in the speech reminder group and 90% in the GBR group. The PC adherence rate for the control, speech reminder and GBR groups were

70.3%, 89.4% and 89.9%, respectively. The SR and PC variables show that the treatment adherence rate was higher in the GBR group than in the control group.

Similarly, the SR and PC variables show that treatment adherence rate in the GBR group was higher than in the speech reminder group. Thus, the treatment adherence rate in the mobile GBR group is larger than in the speech reminder group and control group.

6.3.2 The Effect of Reminders on the Number of Responses

Number of responses was measured by comparing the number of reminder responses between the speech reminder and GBR groups. The results of each experiment are presented separately, and these findings are used to answer the following question:

"What is the effect of graphic-based reminders on the rate of feedback responses, when compared to speech-based reminders?"

To recap, the derived hypothesis for comparing the number of patient responses to the system between the GBR group and speech reminder group were:

> H_0: The number of responses in the GBR group is not greater than the number of responses in the speech-based reminder group.
>
> H_a: The number of responses in the GBR group is greater than the number of responses in the speech-based reminder group.

A Mann-Whitney U test was conducted to compare the number of responses for the GBR group and speech reminder group.

6.3.2.1 First experiment

Results: Number of responses

Figures 6.3 and 6.4 show the number of reminder responses for the speech reminder and the GBR groups.

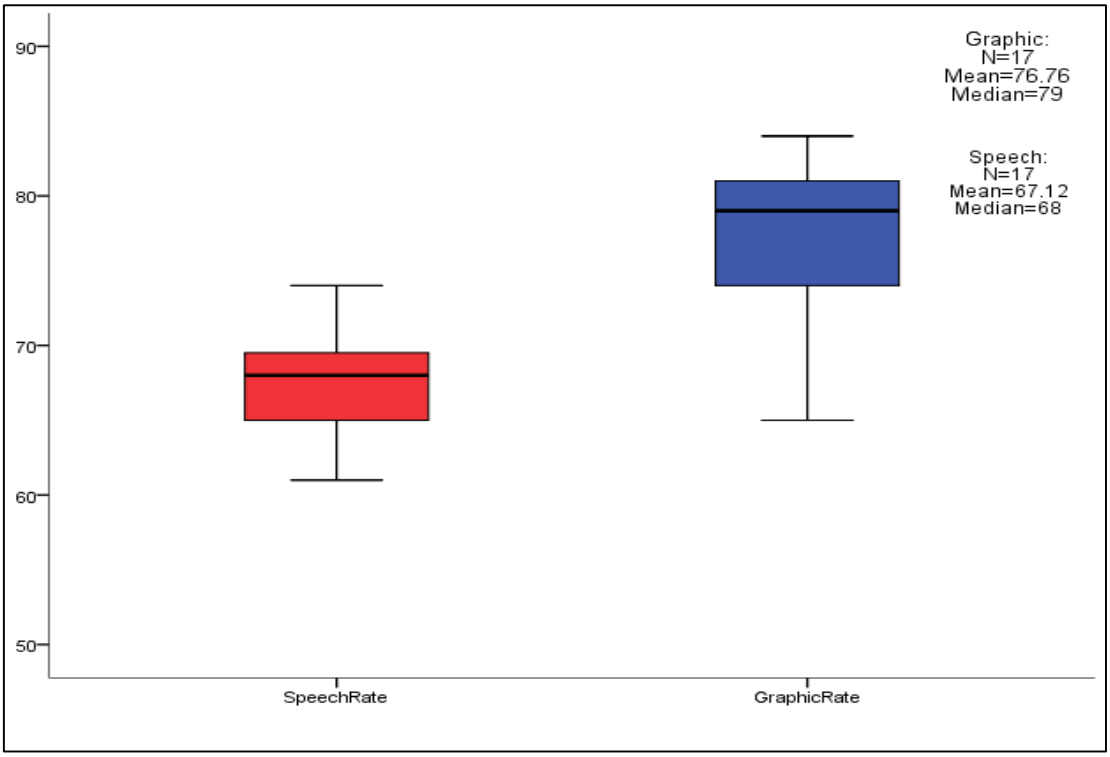

Figure 6.3: Box plots showing mean and median of number of responses to the system for speech-based and GBR groups

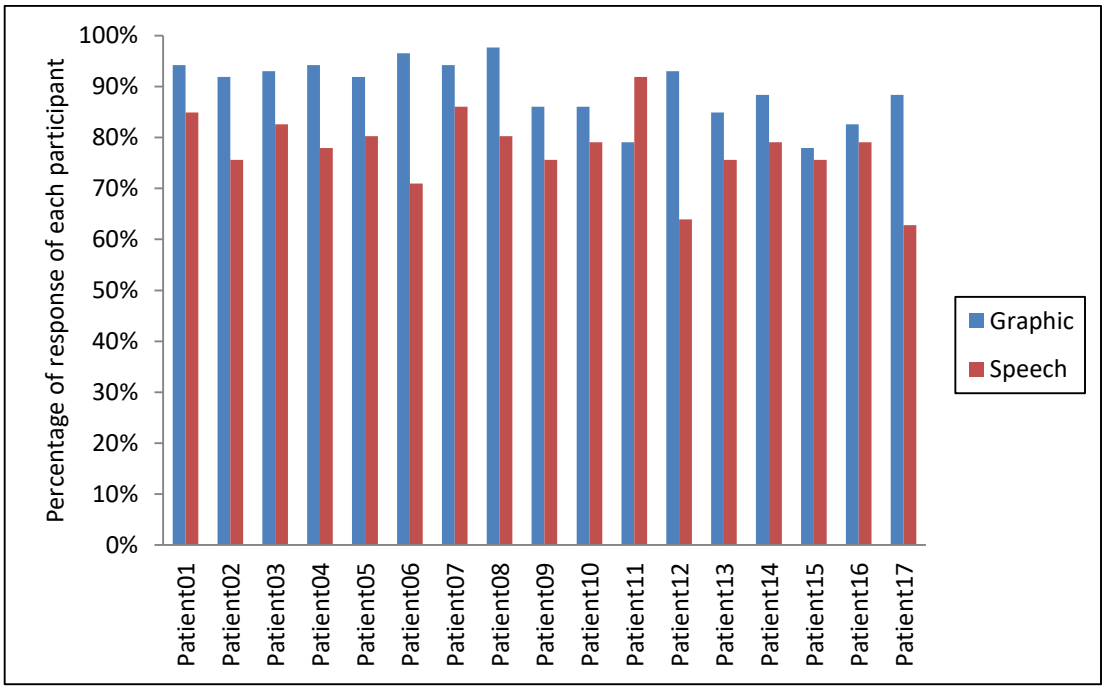

Figure 6.4: Bar chart showing percentage response of patients for speech-based and GBR groups

A Mann-Whitney U test indicated that the number of responses to the system was significantly higher for GBR group (mean ranks=24.06, median=79) than for speech reminders (mean ranks=10.94, median=68), U=33.0, Z=-3.85, p=0.00012, r=-0.660.

This analysis reveals that there was a higher response to the system in the GBR group than in the speech reminder group. As shown in Figure 6.4, this was the case for all patients who sent more feedback for the GBR than speech reminder groups, except for one patient (patient11) who sent more feedback during the speech reminder group than the GBR group.

Results from this experiment indicate that there was a significant difference in the number of reminder responses between the GBR and speech reminder groups. With $p<0.001$, therefore, the null hypothesis is rejected in favour of the alternative hypothesis. Thus, the number of reminder responses in the GBR group is greater than the number of reminder responses in the speech reminder group.

6.3.2.2 Second experiment

Results: Number of responses

Figures 6.5 and 6.6 show the number of reminder responses received for the speech reminder and GBR groups.

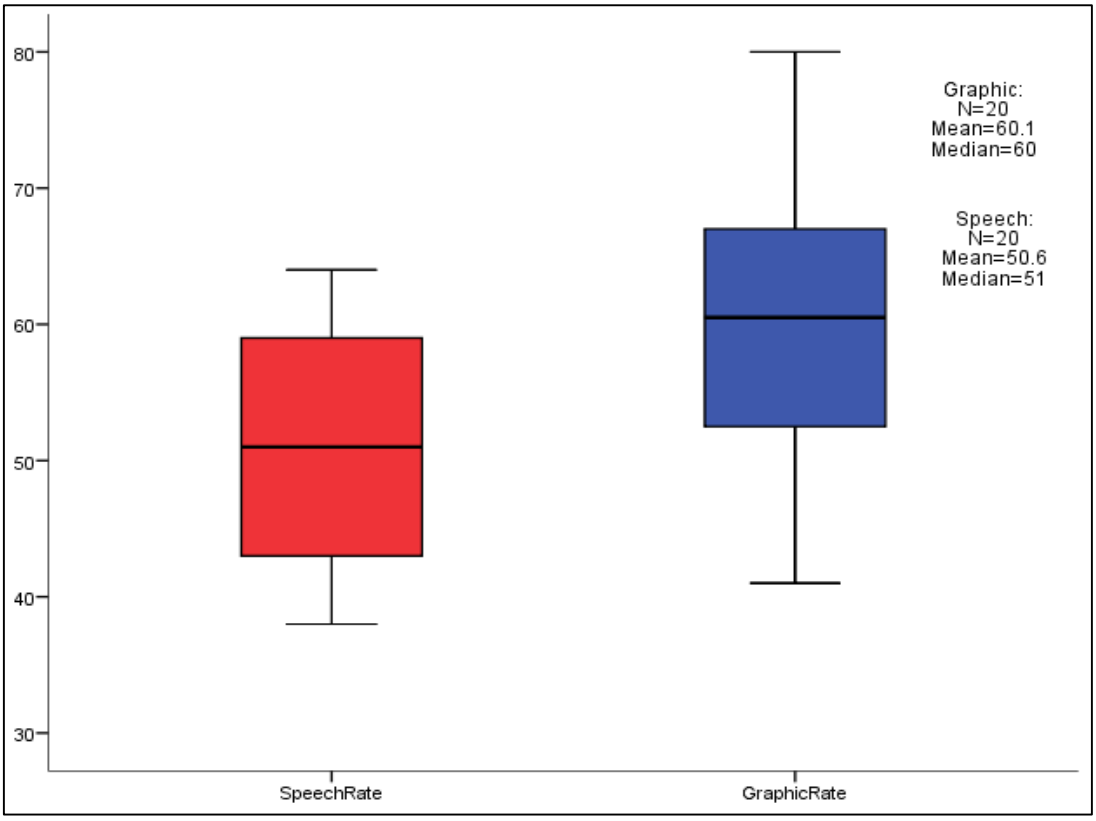

Figure 6.5: Box plots showing mean and median of number of responses to the system for speech-based and GBR groups

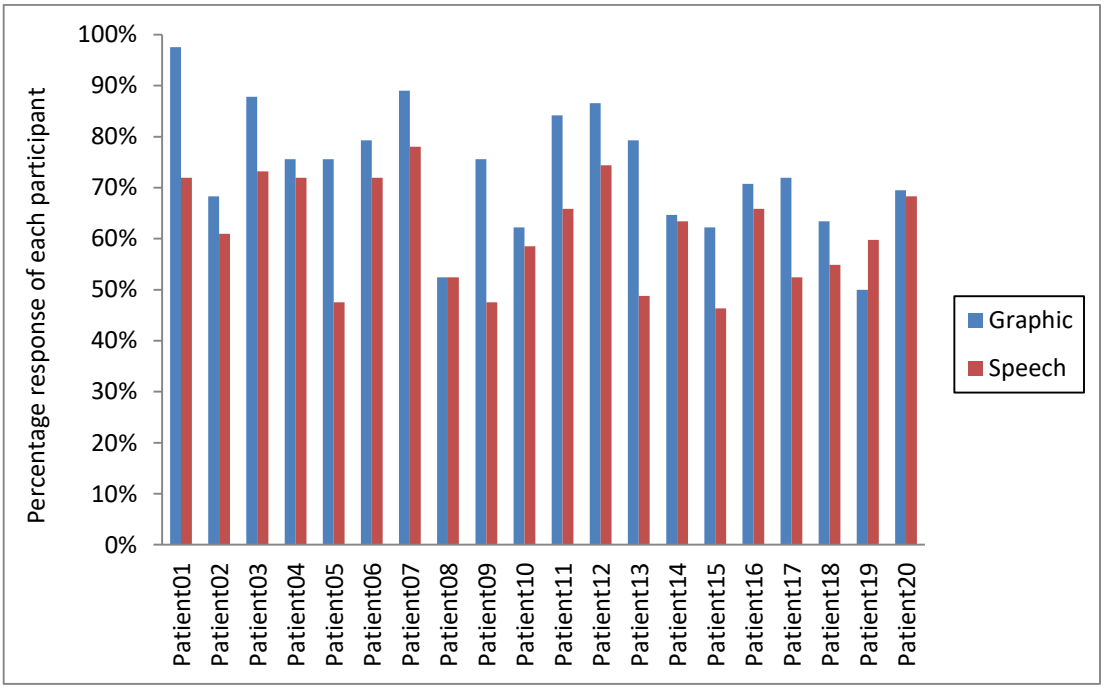

Figure 6.6: Bar chart showing percentage response of patients for speech-based and GBR groups

A Mann-Whitney U test indicated that the number of responses to the system was significantly higher for GBR group (mean ranks=25.58, median=60.5) than for the speech reminder group (mean ranks=15.43, median=51), U=98.5, Z=-2.75, p=0.006, r=-0.435.

The findings in Figure 6.6 indicate that the majority of the patients sent more feedback for the GBR system than speech reminders, except for two participants. One, patient19, sent more feedback during the speech than GBRs. Secondly, patient8 sent equal feedback for both speech reminder and GBR groups.

These results show that there was a significant difference in the number of reminder responses between the GBR group and speech reminder group. With $p<0.01$, therefore, the null hypothesis is rejected in favour of the alternative hypothesis. Thus, the number of reminder responses in the GBR group is greater than the number of reminder responses in the speech reminder group.

6.3.3 The Efficiency of Response Time to Reminders

Response time was measured by comparing the time taken by patients to respond to the system in the speech reminder and GBR groups. The results of each experiment are presented separately, and these findings are used to answer the following question:

"What is the effect of graphic-based reminders in comparison to speech-based reminders when considering the time taken to respond?"

To recap, the derived hypothesis for comparing the time taken by patients to respond to the system between the GBR group and speech reminder group were:

> H_0: The time taken to respond using the GBR system is not less than the time taken to respond when using the speech-based reminder.
>
> H_a: The time taken to respond to the GBR system is less than the time taken to respond to the speech-based reminder.

A Mann-Whitney U test was conducted to compare the response time for the speech reminder group and GBR group.

6.3.3.1 First Experiment

Results: Response time

Figures 6.7 and 6.8 show the mean time taken by patients to respond to the system for the speech reminder and the GBR groups.

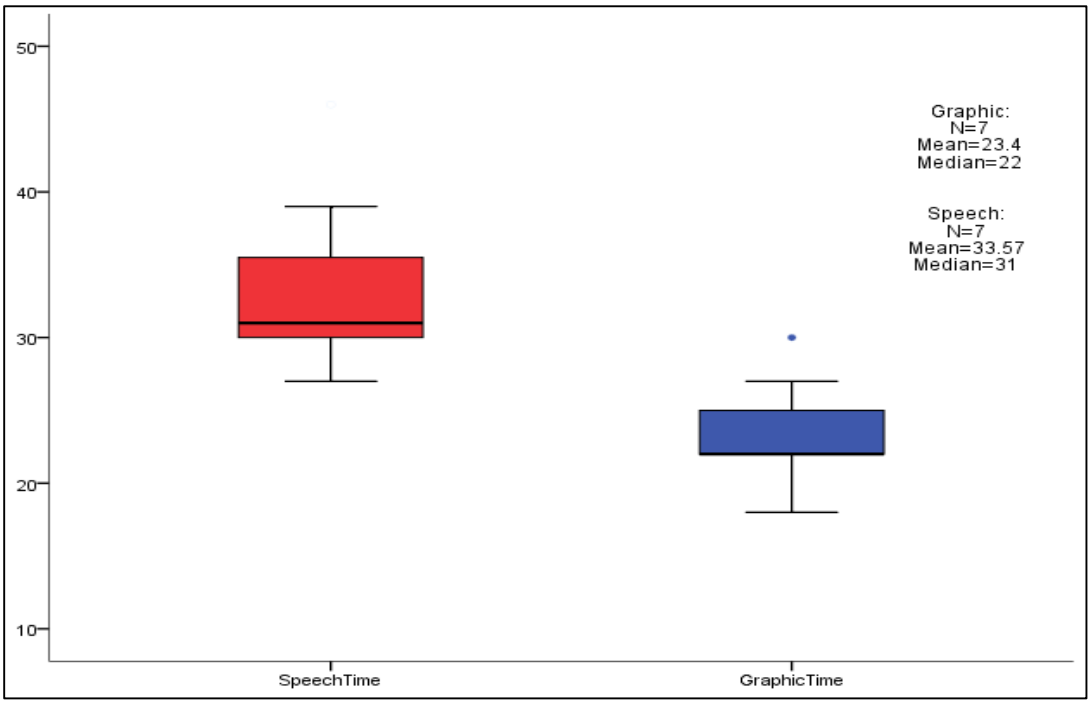

Figure 6.7: Box plots showing mean and median of time taken by patients to response to the system for speech-based reminder and GBR groups

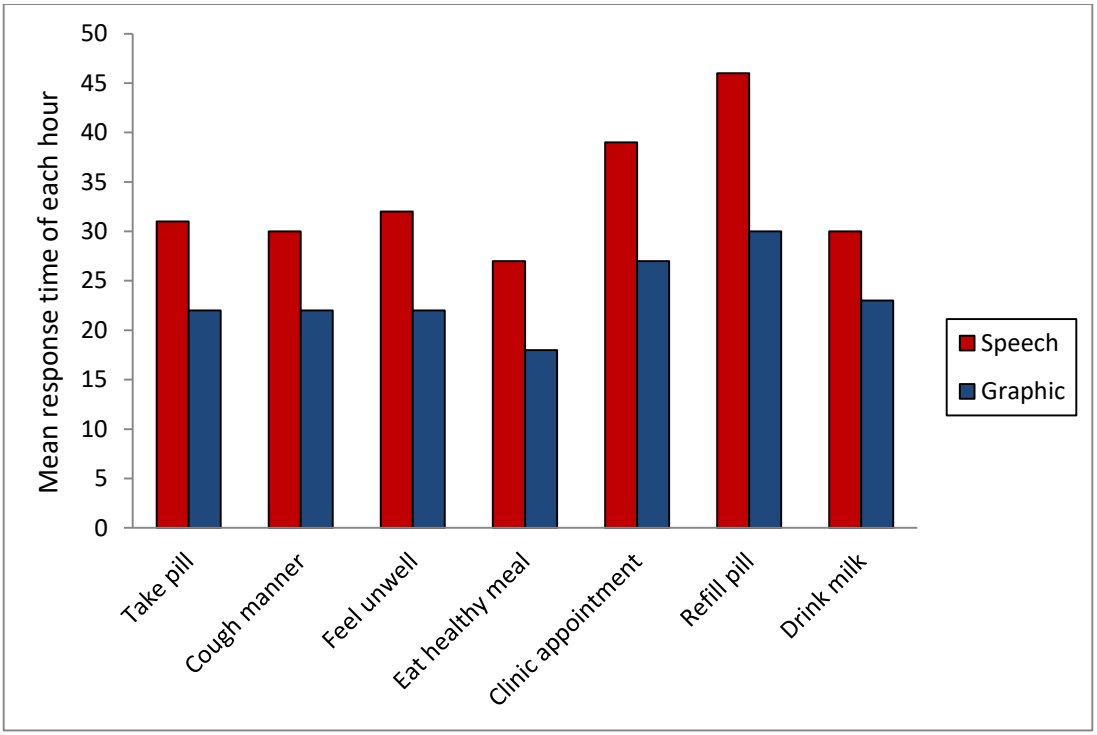

Figure 6.8: Bar chart showing mean response time for each reminder for speech-based reminder and GBR groups

The analysis reveals that the response time to the system was significantly lower for the GBRs than the speech reminders (Mann-Whitney U test: the mean ranks of the GBRs and speech-based reminders were 4.36 (median=22) and 10.64 (median=31), respectively; U=2.5, Z=-2.84, p=0.005, r=-0.761).

These results indicate that the patients using GBRs responded significantly faster than the patients who used speech reminders. This was the case for all reminder times, as shown in Figure 6.8.

These results therefore indicated a significant difference in response time between the speech and the GBR group, with $p<0.01$. The null hypothesis is rejected in favour of the alternative hypothesis. Hence, the time taken to respond to the GBR is less than the time taken to response to the speech-based reminder.

6.3.3.2 Second experiment

Results: Response time

Figures 6.9 and 6.10 show the mean time taken by patients to respond to the system for the speech reminder and the GBR groups.

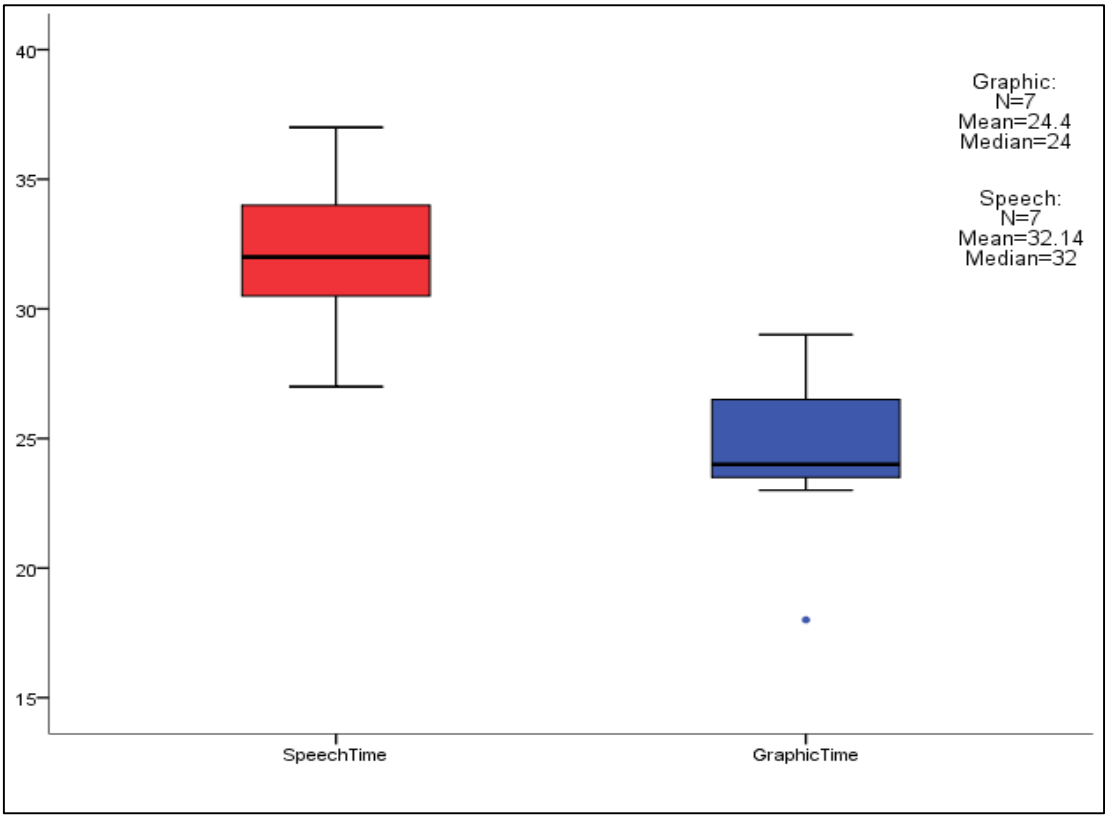

Figure 6.9: Box plots showing mean and median of time taken by patients to response to the system for speech-based reminder and GBR groups

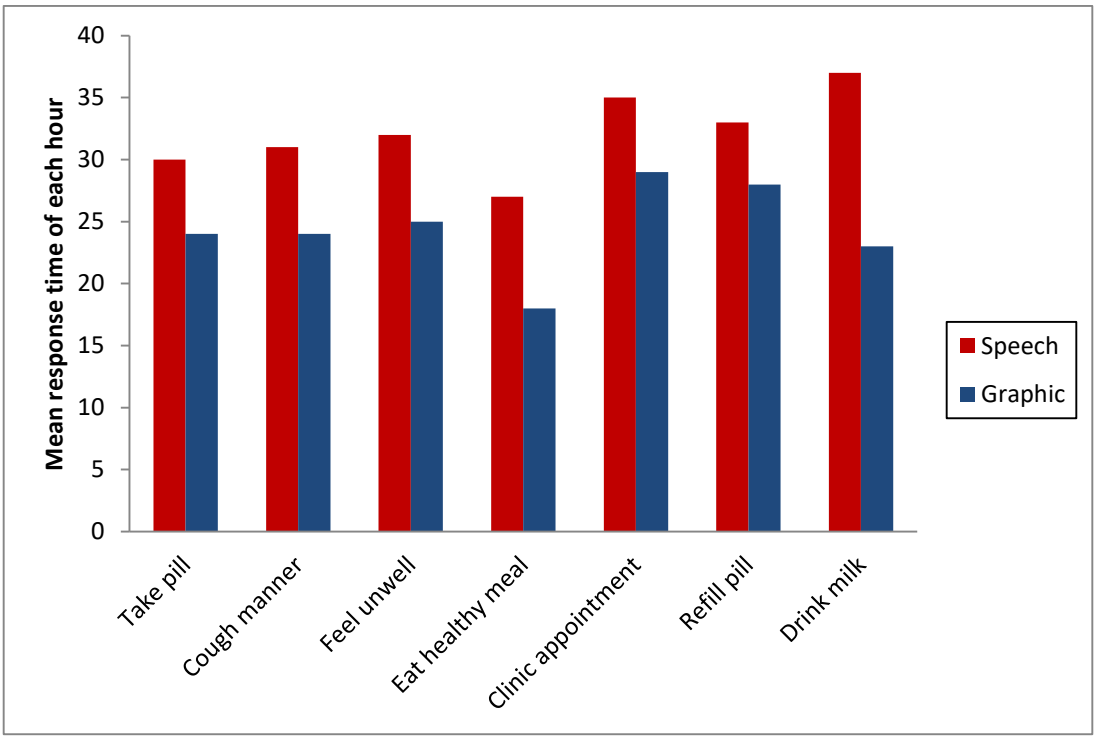

Figure 6.10: Bar graph showing mean response time for each reminder for speech-based reminder and GBR groups

The mean response time to the system was 24 in the GBR group and 32 in the speech reminder group. A Mann-Whitney U test indicated that the response time to the system was significantly lower for the GBR than the speech reminder (the mean ranks of the GBR and speech reminder were 4.29 and 10.71, respectively; U=2.0, Z=-2.88, p=0.004, r=-0.769).

This finding shows that patients in the GBR group responded significantly faster than the speech reminder group. As found in the first experiment, this was the case for all reminder times, as shown in Figure 6.10.

These findings therefore show that there was a significant difference in the response time to the system between the speech and the GBR groups, with $p<0.01$. So, the null hypothesis is rejected in favour of the alternative hypothesis. Thus, the time taken to respond to the GBR is less than the time taken to respond to the speech-based reminder.

6.3.4 Patients' Preferences and Satisfaction

The patients' preferences and satisfaction were measured by subjective qualitative feedback. Face-to-face interviews with respondents were conducted to find patients' preferred mobile reminder system, between the speech reminder and the GBR, to support their TB treatment. The interviews were conducted at the end of the experiment periods. The users' feedback was analysed based on their preferences, perceptions and satisfaction with the technology. The findings presented in this section are used to answer the following question:

"*Which mobile reminder systems did patients find useful for supporting their treatment regimen?*"

The qualitative findings from both experiments (first and second) show that the GBR system rated highly on indicators of preference and satisfaction. The patients felt that the graphic reminder can be useful in supporting them to remember taking their medication and follow-up clinic appointments. Almost all participants indicated the graphic application as being more helpful as a TB reminder system, although few participants found both interventions helpful in supporting the TB treatment. Here is some of the verbatim feedback from respondents (other verbatim feedback is presented in Appendix D4):

Respondent [EXPI_1] said:

> "I really appreciated the system, all images gave clear messages. This application seems to be worthwhile in helping us in treatment regimen. I think this idea should be used also for management of other disease such as HIV, leprosy and diabetes."

Respondent [EXPI_2] said:

> "This is a fantastic idea. I really enjoyed the system, because it has made my life easy. It helped me remember taking my medication and clinic appointment days. The graphic system was most helpful and I wish this system to be implemented. The problem with speech system was that when it was too noisy you wouldn't be able to hear what a person said (speech reminder)."

Respondent [EXPII_1] said:

> "Compared to speech system, the GBR system was very good, I liked it ... *(during the interview, she received an image message, then she said)* … look …! This picture is clearly interpreted that I am reminded to eat vegetables" *(she was pointing at the GBRs – it was of a healthy meal).*

The findings further suggest that a GBR system could be used, even for patients who have problems with hearing. For instance, respondent [EXPII_2] said:

> "I have a hearing problem. I don't hear well. I always set my phone to vibrate mode, if I do not hear a phone alert I feel the vibration. During the speech system, I missed the content of several reminders, but in GBR system, I understood the content of every image."

The qualitative feedback also conveyed the patients' experiences with the mobile reminder systems. For example, one patient indicated that the system helped him to experiencing that 7AM is the time to take the medication. This was a different from the traditional care, with which he was taking his medications irregularly. The target of the system is not only to remind patients to take their tablets and attend clinic appointments, but also to help them change their behaviour. For instance, one patient reported that, although he had a habit of remembering to take his tablets, the reminder system supported him in complying with other treatment behaviours. He further added that the system could be beneficial to others, especially those who have a habit of forgetting their medication and clinic appointments.

Other participants indicated that the system encouraged them to eat vegetables. The participants suggested that the GBR system was more effective and easier to understand than the speech reminder.

Patients were also asked whether they were taking their tablets before or after the reminder. More than 80% said that they took their tablets after the reminder arrived. The rest said that they either took their tablets before or after the reminder. Of those who took their medication before, nearly half of them indicated that they usually remembered to take their medication even though the reminder did not come. Some patients responded that they immediately sent feedback after taking their tablets, while others said that it took them approximately five to ten minutes to send feedback after taking their medication. Usually, the majority of patients who claimed taking their tablets before the reminder arrived were the ones who had a habit of remembering, and others family members remind them to take their medication.

The qualitative findings also indicated that the main reasons for patients missing some pills were: forgetting to take the pills, being away from home, and a few cases of patients running out of tablets. Those patients who reported running out of tablets explained this as a loss of pills or missed appointment, particularly for the patients in the control group.

There were some challenges reported by participants during the speech reminders. Participants said that if they did not hear speech they were not able to identify which reminder was triggered so they were not able to retrieve the content of the message.

This mostly happened in busy areas where the background noise was at high levels. However, this did not necessarily mean that they did not take their medication.

The patients expressed that, during the GBR system, even if they did not hear a notification alert, they did not consider it a problem because they were then able to retrieve content of the image message. Patients hoped that such a system would encourage them to comply with the TB treatment as well as educate them on good behaviours about the disease.

Some participants in the first experiment further suggested that it would be worthy if the notification messages did not contain any word related to disease or patient, so as not to reveal their health status. Participants indicated that some notification sounds contained words that they would prefer not to disclose with other people due to the possibility of stigmatisation. They mentioned that words such as TB, medication, sputum, and clinic as directly representing a sign of a patient. This was a major reason why they missed some reminders, as their phones were on mute mode. Consequently, a notification alert in the second experiment did not contain these words, as indicated in Section 4.5.1. The qualitative findings indicated that all participants in the second experiment were satisfied with the second prototype, as described in Section 7.3.2.

6.4 Findings Related to Evaluation of Applicability of the Visual Aids for Communication Theory for Supporting TB treatment

As described in Section 4.2, this study has adopted Visual Aids for Communication Theory as a guiding lens to investigate the GBR system for supporting TB patients to treatment adherence. In order to test the theory, the mobile GBR system was developed based on the processes of Visual Aids for Communication Theory. The participants were then given the system to measure its effectiveness in supporting TB treatment. Related this measure, it determined whether the system is useful and contained understandable features for TB treatment. Sections 5.2.2, 5.3.6 and 6.3 presented the findings related to the applicability of Visual Aids for Communication Theory.

Section 5.2.2 presented the results of testing the graphic reminders for supporting TB treatment. It was shown how each process of the theory is related to participants'

responses. The findings indicated that the participants who came from different nationalities, languages and level of educations paid greater attention, retained, reproduced and performed the meaning of each graphic correctly. However, it is clear that the way a person interprets or understands a graphic depends on his/her behaviour and preference. For example, when some participants interpreted a health meal graphic (Figure 5.7), responded that eating with a spoon is not part of their values. The impact on the way a person interprets the graphic could be logical and have an emotional appeal in order to motivate change in behaviours, beliefs and attitudes.

Section 5.3.6 presented the results of usability evaluation of the GBR system. As it was found in Section 5.2.2, the participants of all literacy levels found the GBR system useful, well understood and adequately conveyed the graphic reminder messages for supporting TB treatment. The participants mentioned that the GBR system contained features that are simple for them to understand, and therefore retain the information they learned.

Section 6.3 presented findings of the effectiveness of the GBR system compared to speech reminder system. The findings indicated that participants performed better in the GBR system than speech system, including number of reminder responses, time of responses and treatment adherence rates. The qualitative findings also indicated that nearly all participants mentioned the GBR system more helpful as a TB reminder system. The participants indicated that the visual system (GBR) clearly depicted the messages' focus than speech system. Thus, the findings of this study are correspondent with the theory that people understand the information better through visual aids than words or texts.

This study therefore, suggests that the applicability of Visual Aids for Communication Theory in investigating the GBR system was feasible for supporting TB patients to compliance with treatment regimen.

6.5 Chapter Summary

This chapter presented the findings of the research. The chapter began by presenting the findings of user requirements obtained from the participants, the study area, and reviewed documents, including the healthcare challenges facing TB health workers

and patients in their treatment processes; the reminder notifications suggested by study participants to be included in this study; and, the findings on the users' perceptions and their concerns regarding a mobile GBR system. The chapter then presented the findings used to measure the effectiveness of the mobile GBR system in comparison with speech-based reminder system and traditional care. The chapter concluded with the presentation of the findings related to evaluation of applicability of the Visual Aids for Communication Theory for supporting TB treatment. The next chapter provides the discussion of research findings.

CHAPTER SEVEN

DISCUSSION

7.1 Introduction

This chapter presents the discussion of research findings. The chapter begins with a description of the analysis of the results as per evaluation metrics, including treatment adherence rate, number of responses, response time and patients' preferences and satisfaction. The chapter then discusses the findings related to considerations for GBR implementations. These include: contextual significance and potential to provide TB patient support; acceptability and preferences of the interventions to supplement TB treatment; challenges and benefits of collaborative system implementation; and the GBR system content and theoretical considerations. This is followed by a comparison of the GBR system study with other TB adherence studies. The chapter concludes with a presentation of the summary of findings.

7.2 Analysis of the Results

This section presents an analysis of the results as per evaluation metrics from the first and second experiments.

7.2.1 Analysis: Treatment Adherence Rate

Section 6.3.1, Figures 6.1 and 6.2 presented the findings of the treatment adherence rates of patients from the three study groups. The findings from both experiments indicate that both SR and PC adherence rates in the GBR groups were higher than the control and speech reminder groups.

It is important to note that the PC adherence was assessed based on the pill refill behaviours, such as calculating the number of pills that were not taken compared to those that were collected. Pill-taking behaviour was not directly measured. The pill-taking behaviour can only be measured by observing while a patient is taking the tablets.

The SR adherence was assessed through face-to-face interviews with patients. Patients were asked to report how they felt about the treatment adherence. However, the SR method is the most feasible to use in clinical practice settings (Hawkshead & Krousel-Wood, 2007; Nackers et al., 2012), although the SR data might be limited by the fact that it can contain recall bias, the possibility of overestimating adherence, and the tendency to advocate socially acceptance responses (Hawkshead & Krousel-Wood, 2007).

These findings that mobile reminder systems help to improve the patients' treatment adherence have been reported by various studies. For instance, Iribarren et al. (2013) and Hardy et al.'s (2011) studies, which assessed adherence to TB treatment and ARV treatment using a SR patient survey, found that mobile reminder systems were more effective for improving the patients' adherence rate than traditional care. The findings of this present study, also indicated that, in comparison to traditional care and speech reminders, a GBR system improved treatment adherence among TB patients.

7.2.2 Analysis: Number of Responses

Section 6.3.2 presented the findings of the effect of reminders on the number of responses. The mean number of responses to the system between the speech

reminder and GBR groups are presented in Figures 6.3 and 6.5, and percentage responses of each participant are presented in Figures 6.4 and 6.6.

In both experiments, the Mann-Whitney U analysis indicated that there was a significant difference in the number of responses between the speech and GBR groups ($p<0.01$). The number of responses to the system was higher in the GBR group than speech reminder group. The finding that some patients sent either equal or more feedback during the speech reminder group than GBR group does not necessarily mean that they found speech to be more useful. The data indicated that some participants reported problems with their cell phones, such as it being switched off. This was due to it running out of battery or being switched off during meeting or prayer times.

A number of studies have also assessed the effectiveness of the mobile reminder between two mobile interventions. For example, Chen et al. (2008) investigated the effectiveness of a mobile reminder - between SMS and phone call reminders - for improving patients' clinic attendance. Their study found one intervention, which was SMS, to be more effective than a phone call to support patients in clinic attendance. Sidney et al. (2012) investigated usefulness between SMS text messages and voice reminders in supporting HIV patients, where patients preferred the speech system over SMS text messages. The participants responded that SMS messages contained personal information that they are not willing to share with anyone. They highlighted the issue of stigmatized patients fearing SMS reminder messages containing TB related symbols or information.

In the same way, this current study found that one intervention – the GBR system – to be more useful to support TB treatment than the other – the speech reminder system.

7.2.3 Analysis: Response Time

Section 6.3.3 presented the findings of the efficiency of reminder feedback in terms of response time. Figures 6.7 and 6.9 indicated the mean response time to the system between the speech reminder group and the GBR group. Figures 6.8 and 6.10 presented the mean response time of feedback in each reminder message. The mean response times in the first experiment they were 34 and 23 minutes in the speech and

GBR groups, respectively, and in the second experiment were 32 and 24 in the speech and GBR groups, respectively.

The findings indicated that in both experiments, the times taken by patients to respond to the system between the speech reminder group and the GBR group were significantly different, with $p<0.01$. This result illustrated that the patients using GBRs replied faster to the system (replied sooner after having received reminders) than that with the speech reminders. It is worthwhile to note that the patients receiving GBRs may have taken medication sooner after receiving the reminder messages than with the speech reminders. This finding concurs with the findings of Vervloet et al. (2012), who found that the majority of patients responded quickly to the system and 30.1% of doses were taken within 15 minutes of the SMS reminder being sent. Their study investigated the effect of SMS reminders on adherence to oral anti-diabetics.

7.2.4 Analysis: Patients' Preferences and Satisfaction

The qualitative findings in Section 6.3.4 indicated that the patients found the GBR system to be useful in supporting them to remember the days and times of taking medication and clinic appointments. The participants' feedback showed a preference for the GBRs over speech and traditional care. Nearly all patients in the first experiment and all patients in the second experiment preferred receiving GBRs, compared with speech reminders. Finkelstein et al. (2013) indicates that if the participants show preferences for a technology, they will be more likely to use and respond to the system. Finkelstein et al. (2013) further mentions that when the patients are using a method they prefer, they will be more likely to comply with the treatment regimen.

The findings of participants who reported taking their medication before the reminder arrived were related to Huesler's (2005) study. Her study also found that some participants, who had the habit of remembering to take their medication before a reminder arrived, were those who were setting their mobile phone alarm to remind them. The findings further indicated that one of the challenges facing the patients in adherence to their treatment is missing taking some pills. This is mostly caused by forgetting to take the pills, being away from home, and a few cases of patients

running out of tablets. Nackers et al. (2012) also found this challenge to be barriers causing non-adherence to TB treatment.

It was also found in qualitative findings that the clinic attendance rates among patients in mobile reminder groups were higher when compared to those in the control groups. Other previous studies have reported similar results. For example, Chen et al. (2008) found that the clinic attendance rate amongst outpatients was significantly higher in the mobile groups than in the control group. Prasad and Anand (2012) found similar results: that mobile SMS reminders increased the rate of clinic attendance of patients in their treatment when compared to traditional care.

Apart from the positive responses, in first experiment there were some challenges experienced by participants. The participants raised issues of stigmatization when notification messages contained words that directly represent a sign of a patient. This concern was taken into consideration as the second experiment did not contain any word related to disease or patient, as previously described in Section 6.3.4.

In addition, this study found that some participants shared mobile phones with their family and friends. No participant complained about stigma issues on the topic of sharing mobile phones.

7.3 General Discussion

The following sections present the discussion of the findings related to considerations for the GBR implementations.

7.3.1 Contextual Significance and Potential to Provide TB Patient Support

Mobile phone reminder systems are increasingly relevant, particularly in developing countries. Researchers recognise that mobile phone reminders are a contextually significant tool for supporting TB treatment. The findings of this study confirm the potential of mobile reminders for improving TB treatment adherence. It was found that the mobile reminders highly improved patients' adherence over traditional care. On the numbers of reminder response, the findings revealed that, in both the first and second experiments, patients performed better during uses of the GBR than the speech reminder systems. The numbers of reminder response were higher in the GBR than the speech reminder groups. The qualitative data shows that this was

because the patients found the GBRs more useful and help them with their TB treatment.

The total percentage response was lower in the second experiment (69.2%) than in the first experiment (86.3%). The qualitative findings show that some challenges occurred with the mobile phones, and this might have resulted in the lower response rate. These challenges are described in Section 7.3.3. While in the study by Mohammed et al. (2012), the mean number of responses to the reminder system was only 57%, the findings of the current research indicate a high response rate from both experiments. In addition, the findings indicated that there was no big difference in the time taken by patients to respond to the system between the two experiments - first and second. Table 7.1 and Table 7.2 show a summary of the findings.

Table 7.1: Summary of the results of number and time of reminder response for GBR and speech reminder groups in first and second experiments

		First Experiment	**Second Experiment**
Total percentage response (%)		86.3%	69.2%
The mean response rate	Graphic	76.8	60.1
	Speech	67.1	50.6
The mean response time (min)	Graphic	23.4	24.4
	Speech	33.6	32.1

Table 7.2: Summary of the treatment adherence rate for control group, speech reminder group and GBR group in the first and second experiments

		First Experiment (%)	**Second Experiment (%)**
SR adherence	GBR group	88.2	90
	Speech reminder group	64.7	70
	Control group	41.7	60
PC adherence	GBR group	100	89.9
	Speech reminder group	90.5	89.4
	Control group	66.7	70.3

The findings further indicate that the response rate was constant over the duration of the trials. This finding contradicts the study of Mohammed et al. (2012), in which the response rate decreased over the duration of the trial, and where the mean response rate was higher in the beginning of the study (57%) and decreased at the end of the study (49%). Although in the second experiment diversity was observed in the number of reminder replies, it was noted that the response rates for some participants were greater during the morning and evening times than in the afternoon. This happened particularly during rainy seasons. The participants said that when they travelled to the farms in the rain, they usually left their mobile phones at home, for fear of them being damaged by water. This might have had the result of lowering the mean responses to the system in the second experiment to below that of the first.

Furthermore, the results show that none of the patients complained about getting tired or bored of receiving the mobile reminders. Most participants responded to the system rather than ignoring the reminders. Although it was a small study – in terms of sample size and deployment time compared to previous TB studies, such as those by Tanke and Leirer (1994) and Kunawararak et al. (2011), these findings suggest that a two-way reminder communication system may potentially support TB treatment better than one-way systems.

7.3.2 Acceptability and Preference of GBR Interventions to Supply TB Treatment

Patients perceived the mobile reminders to be useful in supporting them to remember taking their medication, attend clinics, as well as encouraging good habits. The GBR system was preferred over the speech reminders and supported the patients' compliance with their treatment regimen. Almost all patients, including literate and illiterate (or semi-literate), showed acceptance of the GBR system. A possible explanation for this finding could be attributed to the acceptability and awareness of the technology, as the patients believed that this technology could be more useful to support their treatment. These findings concur with the findings of Sidney et al. (2012) and Rodrigues et al. (2012), that participants showed high acceptance of IVR reminders over SMS in supporting them for treatment adherence.

Amongst important finding was that to ensure that the participants' concern was addressed, some participants who reported stigmatisation issues during the first experiment, who were also included in the second experiment, felt comfortable with the second prototypes (particularly the GBRs) and suggested that the application was interesting and helpful. As mentioned earlier, during the second experiment, those words related to TB or any other illnesses were not used in the message notification alert. This means that the second mode of GBRs that was used in the second experiment might be the choice of the majority of patients and this can motivate and support them to adhere their treatment regimens.

Furthermore, based on the feedback from patients, it was found that something entertaining, such as a graphic or video (multimedia), would encourage more patients to comply with their treatment regimen than the text or speech application. This was evident in this study as the majority of patients showed more interest in the GBR system. Some participants suggested that, if the graphics were animated, it might enhance their understanding of how they are meant to perform an action (by seeing an example), such as how to cough in a proper manner, take their medication, etc. This thought was considered and suggested as a future direction. Generally, there was great support for the system from patients as well as healthcare workers, largely because they felt it helped make TB treatment more appropriate.

7.3.3 Factors of Collaborative GBR Implementation

The basic concept of the study was to propose a GBR system to support both literate and illiterate (or semi-literate) TB patients in compliance with their treatment regimen. A major challenge was the selection of patients to enrol in the study. This included allocating a number of patients who were literate, illiterate or semi-literate to ensure balanced representation. The majority of semi-literate or illiterate TB patients resided in remote rural areas.

The GBR system requires Android smartphone. The system is developed on Android so as to reach the vast majority of the people, as Android covers over 86.8% of the smartphone market (IDC, 2016). However, the results of this study showed that 55% of participants had smartphones and about 70% of these were Android phones.

Amongst the study's objectives was to be able to provide everyone, even people living in rural remote areas, with healthcare services through mobile phones. The key objective of mobile technology is to provide a service remotely in order to facilitate services for all that is cost effective (Mthoko & Pade-Khene, 2013). This is evidenced in this present study as it was found that the use of an offline mobile reminder system to support the treatment of TB is effective. Unlike SMS text messages and phone call reminders, the system is disengaged from the mobile service provider. As previously described in Chapter 5, the system does not engage network providers because it works offline on mobile phones. It is cost saving, as the system does not require fees paid to a mobile provider as in the case of SMS text messaging and phone call reminder systems. As such, the study findings show that the applicability of this system can be potentially high in increasing TB adherence in Zanzibar, Tanzania, South Africa as well as other countries with similar infrastructures. Table 7.3 shows a characterisation of costs in South Africa and Zanzibar, Tanzania for SMS[13], MMS[14] (Hellstrom & Troften, 2010, p.30) and GBRs.

Table 7.3: Characterisation of costs in South Africa and Zanzibar, Tanzania for the costs of SMS, MMS and GBRs

	South Africa	Zanzibar, Tanzania
SMS (less than 161 characters)	ZAR 0.33 ($0.022),	TZS 87.5 ($0.04)
MMS (300KB or less)	ZAR 0.80 ($0.05)	TZS 135 ($0.06)
GBRs (the application is installed on mobile phone)	No cost required*	

* The GBRs had limited engagement with mobile network providers, the application works offline and does not require payment to a network provider, as described in detail in Chapter 5.

Furthermore, the study measured a quality of service by asking for a level of satisfaction with the technology. This was done using qualitative interviews as

[13] https://www.twilio.com/sms/pricing (costs of SMS for the time of this study)
[14] http://www.vodacom.co.za/vodacom/terms/promotions/vodacom-prepaid-79c (costs of MMS in South Africa)

described in previous sections. The patients responded that they were satisfied with the technology, especially the GBR system. Interestingly, among participants, there were three who also participated in the 'wired mothers' project (Lund et al., 2012). This project was designed to provide health education and appointment reminders to encourage pregnant mothers to attend the routine antenatal care and delivery attendance using SMS text message reminders. These participants reported that compared with text and speech reminders, the GBR system was more useful in supporting their treatment regimen. Almost all patients stated that they had no problems with using the systems.

Prior to the deployment of prototypes, no technical issues relating to the functionality of the systems were observed, such as error rate and transmission delay. Both prototypes were working fine and reminders were triggered as defined. Some participants reported cell phone problems; the patients expressed that sometimes the phone's battery would run out. This was mostly caused by frequent blackouts. Another reason mentioned was that the phone was muted or switched off, particularly during meeting or prayer times. These challenges may contribute to a lower average number of responses, particularly in the second experiment.

Findings further indicated that no patient reported difficulty on the system use. It was found that all patients, including those who had no experience of the mobile phone use, interacted with systems as suggested, including opening reminder messages and feedback delivery. This finding, therefore, indicated that the GBR system could be used by everyone regardless of his/her literacy level or experience with using cell phone. It is noteworthy that the GBR prototype application was designed based on the user needs and requirements, which facilitated easy to use – such as easy navigating to other pages -, easy to understand the contents and useful to provide TB treatment support.

7.3.4 The GBR Application Content and Theoretical Considerations

The decision for GBR content has been made by health care workers and patients. The process began with a designer who sketched several graphic objects and then passed them on to different people, including patients and health care workers, for improvement. Gaining insight from various people was essential and this added the step of connecting a theory. The theory of Visual Aids for Communication helped to

develop the GBR system to guide decisions, users' needs and requirements. This process helped make the graphic content development more comprehensive, accepted and systematic.

To find out if the GBR system is helpful and contained understandable features, the patients were given mobile phones that contained reminders on them. The findings suggest that the GBR system was well comprehended and accepted by every patient. The patients used the application as directed. The patients with different literacy levels reacted, interpreted, and used the application in a similar way. The patients responded that the application contained simple features that can be easily understood by everyone.

The original idea of using graphic objects as the reminder approach for supporting TB treatment was to mitigate literacy and language barriers. Various works also suggested the potential of visual aids to support patients, particularly semi-literate or illiterate patients, in treatment adherence (Ngoh & Shepherd, 1997; Seth & Sorathia, 2013). Ngoh and Shepherd (1997) investigated visual objects' ability to help illiterate women in following drug dosage instruction. Seth and Sorathia (2013) proposed 'Parichaya' as a system designed to educate TB patients using the medical kit so as to increase medication adherence. The studies found that visual applications are useful in improving medication adherence amongst patients. The overreaching results of this present study are in line with what is suggested in the literature, particularly works on visual aids for communication. For instance, the patients of this present study felt that, contrary to the speech-based system and traditional care, GBRs could be more encouraging and support them in their treatment regimens.

7.3.5 Comparison with Other TB Adherence Studies

To the researchers' knowledge, this is the first effective experimental study assessing the ability of a mobile GBR system to support TB treatment in a resource-limited setting. However, SMS text messages and speech systems, such as phone calls, have been studied previously. For example, the following studies have provided much information for assessing SMS text reminders in promoting TB treatment adherence. The assessment of these studies yielded new insights into the technology used, number of participants, and the analysis methods made possible by reporting inequality.

The first study, which was conducted in Argentina by Iribarren et al. (2013), assessed the effect of text messages in supporting TB patients who owned or had access to mobile phones and who were text literate. The adherence rate of patients assessed by SR was higher in the SMS texting group (77%), compared with 53% in calendar group. The study involved specific patients only. Involving particular participants suggests that the technology was developed for a specific group of people. This was different from our study as it included participants from different groups, including: literate and illiterate or semi-literate; owned or not owned/had access to mobile phone; and urban or rural patients.

A second study from Pakistan presented by Muhammed et al. (2012) measured user acceptance, perceptions and engagement with an SMS text message reminder system designed for supporting TB treatment. The SMS reminders were found to be helpful and encouraging to TB patients. The response rates to the system were higher with participants who had some schooling and amongst females. Furthermore, the mean response to the system decreased over the study period, from 57% during the first ten days to 49% during the last ten days. This shows that if the trial was deployed within a long period, it is possible that the mean response rate may be further diminished. This was different from this study as the numbers of responses was nearly the same and participants' involvement was constant over the duration of the study.

A third study by Albino et al. (2014) investigated the perceptions related to acceptability and feasibility of SMS text messages in improving treatment adherence among TB patients in Callao, Peru. The study found positive perceptions of the use of SMS and indicated that the SMS technology may be an efficient way to spread motivational texts on treatment, health education information and reminders to increase treatment adherence for TB patients. However, the study only involved patients who were actively on treatment and were smear sputum negative. This was different from current study as it included both patients who were smear sputum negative and positive. Furthermore, the study sample was very limited and the participants were from a single town (Callao region). This may contain people with the same interests and, as a result, the findings may not be generalised. The current study included patients from different areas, including rural and urban.

Hoffman et al. (2010) assessed technical feasibility and receptivity of mobile video DOT in supporting treatment adherence for TB patients. The study was conducted at Mbagathi District Hospital in Kenya. Though the results of the study showed that the majority of patients agreed and preferred the mobile video DOT, as an effecting tool to be used in supporting TB treatment, there were some patients who felt video DOT is not viable option. The study reported that several challenges hindered the video DOT system. This included cost, as the use of MMS video clips is very costly, particularly in developing countries where resources are limited. Other challenges reported by the study were unreliable Internet access to send the videos, lack of people who can assist patients with video-recording at home and lack of video enabled phones within the community (Hoffman et al., 2010). This shows that the implementation of video DOT is costly and requires high resource settings. The difference of this study and the current study was the technology used. The current study used GBR in which the system installed on mobile phone and reminder trigged without being connected to mobile network provider. Furthermore, Hoffman et al.'s study did not evaluate the medication adherence improvement.

Other studies from the developing world have also suggested that mobile reminder approaches, using a telephone call can improve compliance to treatment for TB patients (Tanke & Leirer, 1994; Kunawararak et al., 2011). The participants in these studies were given a daily phone call reminder to take their tablets. Kunawararak et al.'s study assessed the effects of telephone reminders for promoting TB treatment. Noteworthy advantages of the current study compared with these studies include the assessment of the effects of a reminder system by capturing the patients' response rate, and the use of more personal measures such as weekly reports, and objective measurement of SR and PC to assess patients' adherence. More importantly, this current study involved patients with different literacy levels.

In addition, lack of follow ups and missing data were low in this present study. However, the study population was only from two nations: Zanzibar, Tanzania and Cape Town, South Africa. Table 7.4 shows a summary of comparison of the present study with other TB adherence studies.

Table 7.4: Summary of comparison with other TB adherence studies

Study	Mobile intervention used	Methods/results	Comparison to the present study
Iribarren et al. (2013)	SMS text messages	Methods: The study involved patients who owned or had access to mobile phones and who were texting literate patients.	This study included patients who owned and not owned/had no access to mobile phone and who were texting literate and illiterate patients.
Muhammed et al. (2012)	SMS text messages	The results: The response rates to the system were higher with participants who had some schooling and amongst females. The mean response to the system decreased over the study period	The response rates to the system were higher in the GBRs group than in the speech reminder group in which each group contained literate and illiterate, male and female patients. The mean response to the system - participant's involvement - was constant over the duration of the study.
Albino et al. (2014)	SMS text messages	Methods: The study involved patients who were smeared sputum negative. The study sample was very limited and the participants were from a single town.	The participants of this study were smeared sputum negative and positive. This study included patients from different areas, including rural and urban.
Hoffman et al. (2010)	MMS video clips	The results: The implementation of video DOT was costly and	The system in this study – GBR system – is cost-effective, the system was

		required high resource settings, including unreliable Internet access to send the videos and lack of supporters at home who could assist patients with video-recording.	installed on a mobile phone and reminders were triggered without being connected to a mobile network provider as it could avoid the charge driven by the mobile providers.
Tanke and Leirer (1994)	Phone calls	Methods: The impact of telephone reminders to patients' clinic appointment attendance was assessed using questionnaires.	In this study the impact of mobile reminders was assessed using face-to-face interviews with patients. More importantly, this study involved patients with different literacy levels.
Kunawararak et al. (2011)	Phone calls	Methods: The study outcome was "sputum conversion rate," which was accessed for polymerase chain reaction (PCR) technique and performed drug sensitivity testing (DST)	The outcome of this study was treatment adherence rate, which was assessed for a number of response, and the use of more personal measures such as weekly reports, and objective measurement of SR and PC.

7.4 Chapter Summary

This study adds to existing knowledge surrounding supporting TB patients - both literate and illiterate - with compliance to treatment regimens. Literature found that reminding patients by mobile phone has had an impact of increasing both medication adherence and clinic attendance (Barclay, 2009; Bediang et al., 2014). In the past, mobile-related TB studies have used SMS text messaging (Muhammed et al., 2012; Iribarren et al., 2013) and phone call reminder systems (Tanke & Leirer, 1994; Kunawararak et al., 2011), which face literacy and language barriers. No

documented study was identified using GBR to support TB treatment. To date, only a limited number of studies have been focused on promoting illiterate or semi-literate patients to follow their treatment regimen, using pictures and graphic objects (Ngoh & Shepherd, 1997; Seth & Sorathia, 2013). The aim of this present study was to evaluate the effectiveness of a GBR system and its impact on TB patients and system outcomes at a TB treatment level, especially for semi-literate and illiterate patients.

This chapter presented discussion of the research findings. The chapter began by presenting analysis of the results as per evaluation metrics, including treatment adherence rate, number of responses, response time and patients' preferences and satisfaction. The chapter then presented discussion of the findings related to considerations for GBR implementations. The detailed description of the findings and their relation to the research questions is provided in the next chapter. This chapter, together with Chapter 6, answered the second research questions (RQ2) and main research question (RQM). The next chapter presents the conclusions of the study.

CHAPTER EIGHT

CONCLUSION

8.1 Introduction

This chapter presents the conclusion of this study. The chapter is organized into seven sections. The first section presents a discussion of the design process. The second section discusses questions addressed in this study, highlighting how each of the questions has been answered. The third section provides a summary of the contributions of the research. The fourth section discusses the implications of the research. The fifth section presents the limitations of the research. The sixth section discusses the validation of the framework for GBRs development, and the seventh section provides possible directions for future work.

8.2 Design Process

Chapter 4 presented a detailed design process of the mobile GBR system. First, graphic reminders that are used to support patients for compliance with their treatment regimens were designed. The graphics were designed based on the four

processes of the development of a technology within the Visual Aids for Communication Framework. These are: (1) attentional process; (2) retention process; (3) reproduction process; and (4) motivational process, as described in detail in Chapter 3. In order to achieve these processes, the graphics were designed in such a way that they enhanced the users' understanding of the content of message.

After a design process was completed, the graphics were then passed to various people, including patients, healthcare workers, students and researchers, for evaluation. The aim of evaluation was to determine if the graphics are simple to understand, and if they conveyed the intended meaning of the TB treatment. Users provided feedback, which helped to improve the graphics.

After users were satisfied with the graphics, the m-health mobile GBR prototype was developed and tested. Two prototypes were developed; the second prototype was developed based on the modifications from feedback by participants on the first prototype. This follows the UCD process, which is highly recommended when developing for novice users. Apart from a modification of 'feedback button' that was not visible for some participants, and reduced automatic checking of phone clock time to 10 minutes instead of 30 minutes, the designed mobile GBRs in the second prototype remained the same as the first prototype.

The second prototype was then evaluated by primary users using a small-scale RCT approach to measure its effectiveness in supporting TB treatment. In order to comparatively measure the effectiveness of the GBR prototype, the speech-based reminder system was used instead of other reminder systems such as text-based. This was because the study included illiterate participants who were unable to read or write. Both prototypes were tested on the same platform for Android smartphones. The users were given both prototypes for testing, as described in the evaluation section in Chapter 4.

8.3 Questions Addressed in the Research

The main research question addressed in this research is:

Can mobile graphic-based reminders be used to support treatment compliance for tuberculosis patients in resource-limited and mixed literacy settings?

To address this question, first, an initial investigation study was carried out to gain an understanding of current TB treatment regimens, and patients' needs and requirements. Then, the mobile GBR system for supporting TB treatment was developed, implemented and evaluated.

The following two specific sub-questions are the supporting questions suggested to answer the main research question.

RQ1. What are the factors that contribute to the design and usability of the graphic-based reminder systems?

This question was addressed in Chapter 5, which presented the development of a mobile GBR system for supporting TB treatment. The findings indicated that all the participants found the GBRs contained in the message to be related to the TB patients' environments and needs. There was a high degree of acceptance of the GBRs amongst the participants. Regardless of the participants' level of education and geographical location, all of them interpreted the graphics similarly.

Although the participants found the GBR application easy to use and it contained simple features such that everyone was able to use the system, this study found various factors that contributed to the design and usability of GBR systems. Among these factors are those related to users, including personal users' characteristics and cultures, and those related to the objects, which is graphic characteristics - such as colour, margin and size, as indicated in Sections 5.2.2 and 5.3.6. These factors are difficult to predict in advance. The same as how users will respond to certain graphics. Stigma is another issue that contributed to the design and usability of GBR systems. This study found that symbols, words or information that directly represent a sign of a patient are associated to stigma. The patients suggested that graphic reminder messages should not contain any TB related symbols or information due to stigma, as described in Section 7.2.4. Therefore, it is suggested that the factors be taken into consideration when designing graphic reminders used to healthcare communications.

RQ2. How effective are mobile graphic-based reminders in supporting treatment adherence for TB patients?

This question was addressed in Chapter 6, which presented the findings of evaluating the effectiveness of the mobile GBR system for supporting TB treatment. Below are the various supporting sub-questions posed to address this question:

Does using mobile graphic-based systems support TB patients' treatment adherence?

The results of this question revealed that the use of mobile GBRs by the patients had improved treatment adherence compared to those in the traditional care.

What is the effectiveness of mobile graphic-based reminders in comparison to that of mobile speech-based reminders in supporting TB patients' treatment adherence?

The results of this question revealed that the use of mobile GBRs by the patients had improved treatment adherence compared to the ones using the speech reminder system.

Two further supporting questions were posed to address this sub-question:

> *What is the effect of graphic-based reminders on the rate of feedback responses, when compared to speech-based reminders?*

Patients using GBRs resulted in a higher number of responses to the system than for those using speech reminders. This means that patients using the GBRs may lead to receiving/seeing more reminder messages compared to those using speech reminders.

> *What is the effect of graphic-based reminders in comparison to speech-based reminders when considering the time taken to respond?*

Patients using the GBRs responded faster than those using speech reminders. This means that patients using the GBR may take action earlier, soon after receiving reminders (such as taking pills) than for those using the speech reminders.

Which mobile reminder systems did patients find useful for supporting their treatment regimen?

The findings of this question indicated that the patients were more interested in the GBR system than in the speech reminder system. Nearly all patients suggested that the GBRs be used as reminder system to support their compliance with their treatment regimens.

The success of the GBR system might be dominated by applicability, where success is determined by cost-effectiveness - engagement of mobile network, simplicity of use, and applicability to the majority of patients regardless of their literacy level. It can also be used to support patients with hearing difficulties, as shown in Section 6.3.4. This shows the potential of the implementation of GBR systems in the context of low-resource countries and mixed literacy settings like Zanzibar, Tanzania and beyond.

8.4 Research Contributions

This study recognised the importance of visual graphic reminders via mobile phone for supporting TB patients' compliance with their treatment regimens. Visual Aids for Communication Theory was used in two ways: (1) to investigate how the acceptable graphic reminders are designed; and (2) to investigate how the designed graphics become a tool to support and motivate patients on behaviour changes. The use of the Visual Aids for Communication Theory is crucial for understanding mobile health in developing countries, where resources are limited. This study has confirmed that the Visual Aids for Communication Theory enables the development of mobile technology crucial for supporting TB patients to adhere to treatment within the context of resource-limited and mixed literacy settings.

The main contribution of this study is the development of an m-health GBR system for supporting TB treatment in mixed literacy and resource-limited settings. By considering the theory of Visual Aids for Communication, a mobile GBR system was developed in relation to users' needs and requirements. When evaluating its effectiveness for supporting TB treatment, including empirical evidence assessed the difference between a GBR system and speech reminders in supporting the treatment of TB, it was found that the application can be adapted to the needs of low-resource settings and mixed literacy environments.

This study also contributes to the field of m-health in an ICT4D setting. ICT4D includes the use of Information and Communication Technologies such as mobile phones to support lives of people, particularly living in poorer areas of the world (Heeks, 2008; Ponelis & Holmner, 2015). Its objectives may include, among others, education, health and government services delivery (Prakash, 2007). In this study, the m-health GBR application was designed to support adherence to TB treatment. The application developed in this study could be used to support TB patients' treatment adherence, particularly in the context of a developing countries where resources are limited and in areas where mixed literacy exist. Thus, the results of this study may be relevant to the field of ICT4D.

8.5 Research Implications

The study has provided insight into the support of TB treatment using GBR systems in low resource settings and mixed literacy contexts. It also employs the Visual Aids for Communication Theory, which impacts the development of graphic reminders that can be used as reminder notifications for supporting TB treatment.

The study might benefit the understanding of treatment for TB patients of all literacy levels in a way that mobile GBR systems provide reminders about TB treatment regimens and helping to improve compliance with treatment and influence behaviour. Unlike speech- and text-based reminder applications, the graphic application may be more readily accepted, as well as easier to use and understand by a majority of patients with diverse characteristics, needs and requirements, including patients with physical disabilities, such as the hearing impaired, patients of all ages, patients with different skills and levels of experts and patients from all over the world with different languages, cultures and educational backgrounds.

The reminder response role (as described in Chapter 5) could also be important factor. This is because when a patient miss to send response the health worker can contact the patient to confirm whether he/she has received the reminders by completing an action.

Graphic applications can also be used to support the treatment of other diseases such as HIV and Diabetes. Furthermore, graphic and other forms of visual communication could be prioritized over other forms of electronic communication

for areas with mixed literacy where there are urgent development needs. Graphic applications can also be applied to other areas such as education, disaster management, transportation, communication and agriculture.

However, research indicates that graphic objects are cross-cultural and a universal language that can easily be recognised by every person (Gupta, 2008; Kheir et al., 2014). It is recommended that to be accepted, the graphics must be developed based on the users' requirements and needs.

8.6 Limitations of the Research

The research had some limitations. The duration of the implementation of the trial (five weeks) was short, considering the timeline of a six months TB treatment. This was due to limited resources, and the context of a PhD study that involves limited time. Patients' satisfaction could have increased or decreased - due to familiarity or initial enthusiasm - if the research was conducted over a longer period of time. In order to compensate for this, the study did not measure the treatment outcome, such as success rate, failure or relapse. This can only be measured in the fifth and sixth months of TB treatment. Our study focused on the evaluation of the impact and usefulness of the technology. The study measured treatment adherence rates as they could be assessed at any time during the treatment period (Kochi 2001; WHO, 2012).

Another limitation was that the application was developed on an Android platform, which requires the use of Android smartphones only. The study findings showed that the majority of study participants had mobile phones (93%) but not necessarily Android phones. However, Android phones are widely available in developing countries, including Zanzibar, Tanzania and South Africa.

The motivation to use the Android platform was that, in 2016, Android had 86.8% of the operating system market share, making it one of the most used mobile operating systems globally (IDC, 2016). The price of Android phones is rapidly declining, which makes it very close to the price of feature phones that are largely available in Africa and other developing countries. These findings therefore have provided useful insight that can be used if the application is integrated into other platforms (such as a cross platform application).

Lastly, the size of the research population was small, compared to the entire TB population. This is due to limited resources such as mobile phones. More patients may have participated if mobile phones were widely dispersed in the study. The conclusions are drawn based on data collected in two countries - Zanzibar, Tanzania and South Africa - where in each country its residents share similar languages and ethnic cultures. These findings may not be directly applicable to other countries, however, the reader will be able to take the information provided in this work and use it to help develop their own graphics and to help solve problems specific to their own settings.

8.7 Validation of the Framework for the GBR Application Development

The GBR application development has been validated via the theory of Visual Aids for Communication in Chapter 4. The framework helped to design the GBR system for supporting TB patients' treatment adherence. A further approach to validate the framework is to implement it within a large population of mixed ancestry of races and in a long period of time such as six months – the timeline of TB treatment. This is because in order to attain the precise outcome of TB treatment. In this approach, graphic applications should be adapted to suit the public health management system wherein TB exists.

An investigation is needed to assess the applicability of the framework before its deployment, particularly in the areas where people share different cultural background. For instance, although, this study did not find cultural differences when the participants interpret the graphics, some of them responded that eating with a spoon, Figure 5.7 (a healthy meal graphic), is not part of their values. If the framework is successfully deployed in the mixed-race population where languages and cultural differences exist, it could be deployed to other countries outside Zanzibar, Tanzania and Cape Town, South Africa.

8.8 Directions for Future Work

The system developed in this study is probably the first prototype that addresses the use of mobile GBRs for supporting TB treatment for patients of all literacy levels. Future work could improve the system in the following ways: by increasing the complexity of the system such as developing a device, modality, and context theory.

This can enable users to interact with a system with multiple modes. Another aspect would be to develop a GBR system for other mobile platforms apart from Android, and to create generic applications and builders for reminder systems.

TB treatment is complex and based on the results of this study, multi-interaction systems (not just reminder responses) and a specification language for constrained representation may offer flexible response to the disease. This can allow for multiple communications between the user and system/server, and could address some of the patients that require intensive support. For example, if a patient does not respond to the system at a certain time, another reminder could be sent to the patient to remind him/her again about treatment adherence. If there is still no response, the patient then can be contacted through live communication such as a phone call for further follow-up. Patients also, at any time, could interact with a system by asking any questions related to the treatment of the disease and thus would receive an appropriate answer as quickly as possible.

Graphic animation as a reminder modality suggested by participants may also offer additional support and should be investigated (Section 7.3.2). This may increase the potential of the application, and could effectively encourage more patients to comply with the treatment.

Future studies should consider extending the experimental side of the study to a longer period of at least six months alongside the first line of the TB treatment. This would provide a deeper insight into the longitudinal success of the application.

Finally, future work could investigate the impact of the GBRs on people with different cultural backgrounds and who speak different languages in different nationalities. It also could investigate a comparison of the GBR system in rich regions versus poor developing regions.

It is hoped that the results of this study will place graphics and other forms of visual communication into the broader picture of TB treatment programmes in order to support the most vulnerable in our societies.

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APPENDICES

Appendix A: Studies showing the conceptual similarities and differences to the current study

Study	Condition/ Disease	Conceptual similarities and differences to this study
Da Costa et al., 2010	HIV	▪ This study described how the reminder system called "clinic manager (web)" to support patients to remember appointments was designed. ▪ The automated SMS reminder is scheduled to be sent 24 hours before the appointment. ▪ The similarity of this study and ours is that patients' treatment outcome is measured by self-reporting and pill count success.
Dowshen, 2012	HIV	▪ This work is similar to ours on reminding patients to take pills. ▪ The study also contained a feature that asks the patient to respond after has taken the medication. ▪ SMS was used as a mobile reminder intervention.
Vervloet et al., 2012	Diabetes	▪ The study introduced Real Time Medication Monitoring (RTMM) system that only reminds the patient when he forgets to take the medicines. The system works as follows: if a dispenser is opened no SMS reminder is sent, but if not opened in time, the patient received an SMS reminder.
Mbuagbaw et al., 2011	HIV/AIDS	▪ This study assessed the treatment adherence rates. Participants were divided into 1:1 allocation ratio between usual care and mobile phone reminder. ▪ Intervention group participants received weekly motivational SMSs encouraging them to follow treatment regime. ▪ The messages were sent in English and French. ▪ The study outcome measured a self-report, pharmacy refill and clinical data, such as body mass index, opportunistic infections and quality of life.

Okuboyejo, Omoregbe & Mbarika, 2012	HIV/AIDS	▪ The process of developing mobile "MedAlert" was very important to our study. The system aimed to reminds patient to comply with treatment using SMS. ▪ The system also contained a feature in which a patient is asked to reply to indicate whether he has taken pills or not.
Puccio et al., 2006	HIV	▪ This study aimed to support young adults between the ages of 16 and 24 to adhere with HIV medication. ▪ The participants were given free mobile phones plus 250 free local airtime minutes and free night and weekend calls.
Sidney et al., 2012	HIV	▪ SMSs sent to participants to remind them about adherence to ARV were captured by Online Web-based interface. ▪ The similarity of this study to the current study is that participants were asked to respond if they had taken drugs. However, this was not used as compliance measurement, but was used to make the reminder interactive.
Curioso et al., 2005	HIV/AIDS	▪ This study described how an SMS reminder system was developed for encouraging patients to take their tablets. ▪ It also concerned with message privacy and confidentiality by using code words, i.e. "remember, it is the time of your life", etc.
Lester et al., 2010	HIV	▪ This study assessed whether cell phone communication improved drug adherence between health workers and patients starting ARV. ▪ Patients from three HIV clinics in Kenya were assessed and randomly assigned 1:1 between SMS intervention and standard care. ▪ Patients self-reported ARV adherence. The researchers also analysed randomisation and laboratory assays by masking treatment allocation

		among those three HIV clinics. However, health worker and study participants could not be masked.
Hanauer et al., 2009	Diabetes	▪ CARDS is a Web-based module that automatically generated electronic messages (via either SMS or email) to patients encourage BG monitoring. ▪ The interesting part in this study is that once a user has submitted the BG value, the feedback was recorded in the database to track the patients' progressions; this was the same as in the current study in which patient feedback was recorded in the database.

Appendix B1: Ethical letter from the University of Cape Town

Faculty of Science
University of Cape Town
RONDEBOSCH 7701
South Africa

E-mail: richard.hill@uct.ac.za
Telephone: + 27 21 650 2786
Fax: + 27 21 650 3456

27 August 2013

Mr Haji Haji
Department of Computer Science
University of Cape Town

Dear Mr Haji

Investigating Mobile Image-based Applications to Support Compliance in Tuberculosis Treatment in Rural Africa

I am pleased to inform you that the Faculty of Science Research Ethics Committee has approved the above-named application for research ethics clearance, subject to the conditions listed below. You are required to:

- implement the measures described in your application to ensure that the process of your research is ethically sound, and
- uphold ethical principles throughout all stages of the research, responding appropriately to unanticipated issues: please contact me if you need advice on ethical issues that arise.

Your approval code is: FSREC 011 – 2013

Yours sincerely

Signed by candidate

Dr Richard C Hill
Chair: Faculty of Science Research Ethics Committee

Appendix B2: Ethical letters from the Ministry of Health of Zanzibar

SERIKALI YA MAPINDUZI - ZANZIBAR
ZANZIBAR REVOLUTIONARY GOVERNMENT
WIZARA YA AFYA
MINISTRY OF HEALTH

ETHICAL CLEARANCE LETTER

PROTOCOL NUMBER: ST /0002/JULY/013 **DATE: 10 JULY,2013**

HAJI ALI HAJI
PHD RESEARCH ST

PROTOCOL TITLE: Investigating Mobile Image – based Applications to Support Compliance in Tuberculosis Treatment in Rural Africa.

RE: ETHICAL CLEARANCE FOR CONDUCTING MEDICAL RESEARCH IN ZANZIBAR.

This is to certify that the research protocol entitled **"Investigating Mobile Image – based Applications to Support Compliance in Tuberculosis Treatment in Rural Africa."** was received and reviewed by the Zanzibar Medical Research and Ethics Committee on July, 2013.

We would like to inform you that the decision of the committee to this protocol was **"Approved"**. The permission to undertake data collection is for one year beginning from the date of this letter.

The principal investigator must ensure that the progress report is made available to the Ministry of Health and the Zanzibar Medical Research and Ethics Committee.

Any change made to the protocol needs to be submitted to the committee for approval prior to its implementation.

Thanks in advance,

DR. MSAFIRI MARUANI
SECRETARY
ZAMREC
ZANZIBAR.

SERIKALI YA MAPINDUZI - ZANZIBAR
ZANZIBAR REVOLUTIONARY GOVERNMENT
WIZARA YA AFYA
MINISTRY OF HEALTH

BARAZA LA UTAFITI, WAU
TEL: 310.80/90
FAX: +255 54 32561
TELEGRAM: HEALTHMIN

MOH RESEARCH COUNCIL
P.O. Box 236
ZANZIBAR

ETHICAL CLEARANCE LETTER

PROTOCOL NUMBER: ST /0002/JULY/014 **DATE: 15 JULY,2014**

HAJI ALI HAJI
PHD RESEARCH ST

PROTOCOL TITLE: **Investigating Mobile Image – based Applications to Support Compliance in Tuberculosis Treatment in Rural Africa.**

RE: ETHICAL CLEARANCE FOR CONDUCTING MEDICAL RESEARCH IN ZANZIBAR.

This is to certify that the AMMENDED research proposal entitled "**Investigating Mobile Image – based Applications to Support Compliance in Tuberculosis Treatment in Rural Africa.**" was received and reviewed by the Zanzibar Medical Research and Ethics Committee on July, 2014.

We would like to inform you that the decision of the committee to this protocol was "**Approved**". The permission to undertake data collection is for one year beginning from the date of this letter.

The principal investigators have to provide progress report after six months and final report to the Ministry of Health and the Zanzibar Medical Research and Ethics committee ZAMREC.

Seek permission to publish from ZAMREC.

Any change made to the protocol need to be submitted to the committee for approval prior to its implementation

Thanks in advance,

DR. MSAFIRI MARIJANI
SECRETARY
ZAMREC
ZANZIBAR.

Appendix B3: The consent form

CONSENT FORM

Title of Project: Investigating Mobile Image-based Applications to Support Compliance in Tuberculosis Treatment in Africa

Name, Position and Contact Address of Researcher:
Haji Ali
Investigator
ICT for Development Research School
Department of Computer Science
University of Cape Town
hhaji@cs.uct.ac.za

		Please Tick Box
1.	I confirm that I have understood the purpose of the above study as explained by the researcher.	☐
2.	I understand that my participation is **voluntary** and that I am free to **withdraw** at any time, without giving reason.	☐
3.	I agree to take part in the above study.	☐
4.	I agree to the interview / focus group / consultation being **audio** recorded.	☐
5.	I agree to the interview / questionnaire / focus group / consultation being **image/video** recorded.	☐
6.	I agree to the use of anonymised quotes in publications.	☐
7.	I agree to the use of my anonymised feedback as part of the results of the study.	☐

| --- | --- | --- |
Name of Participant	Date	Signature
Name of Researcher	Date	Signature

Appendix B4: The texts of audio messages in Kiswahili and their translation in English

Reminder name	Figure	Audio in Kiswahili	English Translation
Appointment reminder	5.3	Habari! Huu ni mfumo wa TB, unakumbushwa siku yako ya kwenda clinic imeshafika	Hi! This is the TB reminder system, you are reminded that your day to go to the clinic is approaching
Consultation reminder	5.4	Habari! Huu ni mfumo wa TB, unakumbushwa kumuona daktari kwa ushauri wakati wowote	Hi! This is the TB reminder system, you are reminded to see a doctor for consultation
Take pill reminder	5.5	Habari! Huu ni mfumo wa TB, unakumbushwa muda wa kunywa dawa zako umeshafika	Hi! This is the TB reminder system, you are reminded that the time to take your medication is approaching
Submit sputum reminder	5.6	Habari! Huu ni mfumo wa TB, unakumbushwa wakati wa kupeleka makohozi yako hospital kwa uangalizi umeshafika	Hi! This is the TB reminder system, you are reminded that the time to submit a smear sputum for checking is approaching
Take a glass of milk reminder	5.7	Habari! Huu ni mfumo wa TB, unakumbushwa kunywa maziwa mara kwa mara kadri inavyowezekana	Hi! This is the TB reminder system, you are reminded to take a glass of milk often, as possible
Eat healthy meal reminder	5.8	Habari! Huu ni mfumo wa TB, unakumbushwa kula mboga mboga mara kwa mara kadri inavyowezekana	Hi! This is the TB reminder system, you are reminded to eat vegetables as much as possible
Proper manner to cough reminder	5.9	Habari! Huu ni mfumo wa TB, unakumbushwa kwa afya nzuri, wakati wote unapokohoa tafadhali funika mdomo wako kwa kitambaa	Hi! This is the TB reminder system, you are reminded that for health purposes, the proper way to cough is to cover your mouth
Do not cough in this manner reminder	5.10	Habari yako! Huu ni mfumo wa TB, unakumbushwa kwa afya nzuri, wakati wote unapokohoa usikohoe kama hivi	Hi! This is the TB reminder system, you are reminded that for health purposes, all time when you cough don't cough in this manner
Collect medication	5.11	Habari! Huu ni mfumo wa TB, unakumbushwa kwenda	Hi! This is the TB reminder system, you are reminded to

reminder		kuchukua dawa zako za siku zinazofuata	collect your medication for the upcoming days
See a doctor when you feel bad reminder	5.12	Habari! Huu ni mfumo wa TB, unakumbushwa wakati wote unapojisikia maumivu si ya kawaida tafadhali muone daktari kwa ushauri zaidi	Hi! This is the TB reminder system, you are reminded that anytime when you feel sick please see a doctor as soon as possible for consultation

Appendix B5: Phase I – Respondents' demographic information

Characteristics	Respondent Distribution	N=29 (%)
Gender	Male	12 (41)
	Female	17 (59)
Respondent groups	Health worker	15 (52)
	Patient	13 (45)
	Patient's supporter	1 (3)
Patient types	Home-based care	9 (69)
	In-patient	4 (31)
Health worker occupations	Regional TB coordinator	1 (7)
	Pharmacist	1 (7)
	Data manager	1 (7)
	Clinical officer	2 (13)
	Health officer	3 (20)
	Community health workers	5 (33)
	Nurses	2 (13)
Age	< 20	4 (14)
	20-29	10 (34)
	30-39	9 (31)
	>= 40	6 (21)
Employed	Yes	21 (72)
	No	8 (28)
Literacy level	Literate	26 (90)
	Illiterate	3 (10)
Residential status	Urban	19 (66)
	Rural	10 (34)
Mobile phone ownership	Owns	27 (93)
	Does not own	2 (7)

Appendix B6: The interview of phase I

Semi-structured Interview for User Requirements

The purpose of this survey is to find:-

- Challenges faced by TB healthcare workers and patients during treatment regimen
- Reminder interventions that could be used to support patient to treatment adherence

The interview questions:

The followings are the pre-structured interview questions. Others questions are automatically added during the interview sessions.

Healthcare workers interview questions

- How many categories of TB patients/treatments are there?
- What are the differences between them?
- What kind of challenges do you face during the treatment process?
- Do you think the use of a mobile reminder system can be useful to support TB treatment?
- What time do you think mobile phone can be used to remind patient to their treatment regimen?
- What kind of reminder messages do you think/suggest could be used to support patients to their treatment adherence?
- What is your opinion concerning the use of mobile graphic-based reminder systems to support TB treatment?

Patients/patient supporters interview questions

- What kind of challenges do you face during treatment process?
- Do you think the use of mobile reminder system can be useful to support TB treatment?
- What time do you think mobile phone can be used to reminder you/your supporter to treatment regimen?
- What kind of reminder messages do you think/suggest could be used to support you/your supporter to treatment adherence?
- What is your opinion concerning the use of mobile graphic-based reminder systems to support TB treatment?

Thank you very much for your participation.

Note: This survey also collected participants' demographic information including gender, age, education level, occupation, residential status (such as rural and urban), and mobile phone ownership.

Appendix B7: Phase II - Respondents' demographic information

Characteristics	Respondent distribution	N=34 (%)
Gender	Male	18 (53)
	Female	16 (47)
Respondent groups	Patients	11 (32)
	Health workers	4 (12)
	Researchers	16 (47)
	Students	3 (9)
Site participants	Zanzibar	17 (50)
	Cape Town	17 (50)
Patient type	Home-based care	7 (64)
	Inpatient	4 (36)
Age group	18-27	7 (21)
	28-37	12 (35)
	38-47	9 (26)
	>=48	6 (18)
Literacy level	Literate	29 (85)
	Illiterate	5 (15)
Nationality	Zanzibar	17 (50)
	South Africa	5 (14)
	Tanzania	2 (6)
	Nigeria	2 (6)
	Kenya	2 (6)
	Uganda	2 (6)
	Ghana	1 (3)
	Gambia	1 (3)
	Zambia	1 (3)
	Zimbabwe	1 (3)

Appendix B8: Phase III – Participants' demographic information

Characteristics	Respondent distribution	N=38 (%)
Gender	Male	13 (34)
	Female	25 (66)
User group	Patients	27 (71)
	Health workers	11 (29)
Age group	18-25	8 (21)
	26-35	13 (34)
	36-45	10 (26)
	>=46	7 (19)
Literacy level	Literate	35 (92)
	Illiterate	3 (8)
Residence status	Urban	23 (61)
	Rural	15 (39)
Mobile phone ownership	Have mobile phone	36 (95)
	Don't have a mobile phone	2 (5)
	Mobile owned by the patient	25 (93)
	Mobile not owned by the patient	2 (7)
	Mobile owned by a health worker	11 (100)

Appendix B9: The questionnaire of Phase III

Questionnaires for User Evaluations

The purpose of this questionnaire is to evaluate a user experience of the TB reminder application. You are asked to participate in this survey as a part of the study. Your cooperation and time to fill up this questionnaire is highly appreciated.

Please complete the questionnaires by filling the gaps and tick an appropriate in the spaces below, based on the observation of what you get and what you see from your reminder application. Your task is to indicate the strength of your observation, with each statement utilizing a scale in which 1=Strong disagree; 2=Disagree; 3=Neutral; 4=Agree; 5=Strong agree.

General Questions:

Your professional ……Institution
…..…….

How long have you been using the reminder app?
……

		Strong disagree	**Disagree**	**Neutral**	**Agree**	**Strong agree**
		1	**2**	**3**	**4**	**5**
1.	I found the graphics illustrated the intended purpose.	○	○	○	○	○
2.	I found the application provide clear and understandable voices.	○	○	○	○	○
3.	I found the reminder notifications triggered properly.	○	○	○	○	○
4.	I found the application is relevant to the purpose and user needs.	○	○	○	○	○
5.	I thought the application was easy to use.	○	○	○	○	○
6.	I think anyone could able to use the application.	○	○	○	○	○
7.	I found the application provide quick response when a confirmation feedback button pressed.	○	○	○	○	○
8.	I didn’t notice any inconsistencies as I use the application.	○	○	○	○	○

General comments:

Do you have any other comments or suggestions regarding the application?

……
……
……
……
……
……
……
……
……
……
……

Thank you very much for your participation.

Your response is essential for improving the TB reminder application.

Note: This survey also collected participants' demographic information including gender, age, education level, occupation, residential status (such as rural and urban), and mobile phone ownership.

Appendix B10: The interview of Phase III

Semi-structured Interview for User Evaluations

The purpose of this interview is to evaluate a usability of the TB reminder application. You are asked to participate in this survey as a part of the study. Your cooperation and time for participating in this interview is highly appreciated.

Interview questions:

1.	How long have you been using the reminder application?
2.	How do you found the application?
3.	Do you think the graphics illustrate the intended purpose?
4.	Do you think the application was provide clear and understandable voices?
5.	Do you found the reminder notifications triggered properly?
6.	Do you think the application is relevant to the purpose and your needs?
7.	Do you found the application was easy to use?
8.	Does the application provide quick response when a button pressed?
9.	Did you notice any inconsistencies as you use the application?

General Comments:

Do you have any other comments or suggestions regarding the application?

……
……
……
……
……
……
……
……

Thank you very much for your participation.

Note: This survey also collected participants' demographic information including gender, age, education level, occupation, residential status (such as rural and urban), and mobile phone ownership.

Appendix B11: Table showing participants' demographic information for first and second experiments

		First Experiment	Second Experiment	Total
Characteristics	**Respondent distribution**	**N=29 (%)**	**N=30 (%)**	**N=59 (%)**
Gender	Male	16 (55)	13 (43)	29 (49)
	Female	13 (45)	17 (57)	30 (51)
Treatment type	Intensive	11 (38)	12 (40)	23 (39)
	Continuation	18 (62)	18 (60)	36 (61)
Age group	18-27	6 (21)	6 (20)	12 (20)
	28-37	5 (17)	8 (27)	13 (22)
	38-47	10 (34)	6 (20)	16 (27)
	>=48	8 (28)	10 (33)	18 (31)
Literacy level	Literate	17 (59)	19 (63)	36 (61)
	Illiterate	12 (41)	11 (37)	23 (39)
Residence status	Urban	19 (66)	18 (60)	37 (63)
	Rural	10 (34)	12 (40)	22 (37)
Occupation	Employed	5 (17)	9 (30)	14 (24)
	Unemployed	9 (31)	7 (23)	16 (27)
	Self-employed	11 (38)	11 (37)	22 (37)
	Students	4 (14)	3 (10)	7 (12)

Appendix C1: Sample codes for implementation of components of the application

Appendix C1.1: Variables stored in the database server

```
…….
    List<NameValuePair> nameValuePairs = new ArrayList<NameValuePair>(4);
        nameValuePairs.add(new BasicNameValuePair("userID", userID));
    nameValuePairs.add(new BasicNameValuePair("reminderType", reminderType));
    nameValuePairs.add(new BasicNameValuePair("responseDate", responseDate));
    nameValuePairs.add(new BasicNameValuePair("responseTime", responseTime));
          httppost.setEntity(new UrlEncodedFormEntity(nameValuePairs));
…….
```

Appendix C1.2: Sample xml code for broadcast receiver

```
…
<receiver android:process=":remote"android:name="TakepillReminder"></receiver>
…
```

Appendix C1.3: Sample code of graphic reminder message

```
…
                ImageView image =new ImageView(this);
                    image.setImageResource(R.drawable.Takepill);
                               setContentView(image);
…
```

Appendix C1.4: Sample code for activating application when the phone is rebooted

```
…
            public void onReceive(Context context, Intent intent) {
                if (intent.getAction().equals(Intent.ACTION_BOOT_COMPLETED)){
                     Intent i = new Intent(context, ReminderSystem.class);
                    i.addFlags(Intent.FLAG_ACTIVITY_NEW_TASK)
                          context.startActivity(i);
                                }
                                }
…
```

Appendix C1.5: Xml code for reactivating android application

```
…
<uses-permission android:name="android.permission.RECEIVE_BOOT_COMPLETED"/>

       <receiver  android:name=".BootCompletedIntentReceiver">
                                <intent-filter>
         <action android:name = "android.intent.action.BOOT_COMPLETED"/>
                               </intent-filter>
                                  </receiver>
…
```

Appendix C1.6: Code for the implementation of automatic data synchronization

```
                                                                    ……..……
//check Internet connection
  if(CheckInternet(getApplicationContext())){
  dialog = ProgressDialog.show(Feedback.this, "",
                          "Sending Feedback...", true);
               new Thread(new Runnable() {
              public void run() {
              send();        // call send call and send data to Database server
             }
           }).start();
      }
                 else{
//if no Internet connection
       Toast.makeText(Feedback.this,"No Internet connection, your    feedback will be forwarded once a
       connection is available!",    Toast.LENGTH_LONG).show();
            savedata();      //call savedata class and save data to SQLite database
            onBackPressed();
       }
      }
     });


//Method to check Internet connection either wifi or mobile data
 public boolean CheckInternet(Context context)  {
  ConnectivityManager connec = (ConnectivityManager)
context.getSystemService(Context.CONNECTIVITY_SERVICE);
android.net.NetworkInfo wifi = connec.getNetworkInfo(ConnectivityManager.TYPE_WIFI);
android.net.NetworkInfo mobile = connec.getNetworkInfo(ConnectivityManager.TYPE_MOBILE);
      if (wifi.isConnected() || mobile.isConnected())   {
                return true;
              }
  return false;
    }
                                                                    ……..…..
```

Appendix C1.7: Code for the implementation of periodic check of the phone clock

```
                                                                    …….
//Periodic correct the phone clock
  r = new Runnable()  {
  int x = 1;

public void run()  {
                switch(x) {
                 case 1:
 Settings.System.putInt(getContentResolver(), Settings.System.AUTO_TIME, 1);
                      break;
               }
          x=1;
handler.postDelayed(this, 1800000);          //interval synch time is every 30min
               }
       };
handler.postDelayed(r, 60000);        //This is initial time, 1 min
               }
                                                                    …….
```

Appendix C2: Verbatim feedback from respondents

Participant X1
General comments: Do you have any other comments or suggestions regarding the application? Mfumo huu ni mzuri sana, ni maraya nyu ya kwanza kuusikia na kuona. na elhemu utawasaidia sana wagonjwa kufuata utaratibu wa matibabu kama wana vyaelekezwa. **Thank you very much for your participation.**
English translation: This system is very good. It is my first time to hear and see this. I think this system will be helpful in supporting patients to comply with treatment as prescribed.

Participant X2

General comments:

Do you have any other comments or suggestions regarding the application?

Maoni yangu ni kwamba hii mfumo wa ukumbusho wa picha kwa njia ya simu ni mzuri sana sana na utawasaidia sana wagonjwa kufuata ipasavyo utaratibu wa matibabu, wagonjwa wengi wanasema wanasahau kwenda dawa kwa wakati na kuja kliniki kama wakipewa hii wataweza mfumo hii utawasaidia sasi utawasaidia sana wao na hata sisi madaktari kazi kwa kuwa fikisha utaratibu hii wa matibabu.

Thank you very much for your participation.

English translation:

I think this mobile graphic-based reminder system is very good. I hope this will support patients to adhere to treatment. Currently majority of patients complain about forgetfulness for a time of taking medication and clinic appointments. If this system will be implemented, I'm sure it will support them and us, as healthcare workers to achieve our goals.

Participant X3

General comments:

Do you have any other comments or suggestions regarding the application?

Hili ni wazo la utumiaji wa picha kama ukumbusho kwa njia ya simu ni mzuri sana na utatusaidia kweli kufuata utaratibu wa matibabu kama tulivyo elekezwa.

Thank you very much for your participation.

English translation:

This idea of using picture (graphic) through mobile phone as reminder system is very good and I'm sure this will support us (patients) to treatment adherence.

Participant X4

General comments:

Do you have any other comments or suggestions regarding the application?

Mfumo huu wa utambusho kwa kutumia picha ni mzuri sana kuliko maandishi, kwani kila mtu ataweza kupahamu maudhui kwa urahisi na ufasaha katika picha hususan kwa wale wasiojuwa kusoma na kuandika.

Thank you very much for your participation.

English translation:

This mobile graphic-based reminder system is very effective compared with text-based systems, because everyone can easily and clearly understand content in images and this could help support patients especially those who are unable to read and write.

Participant X5

General comments:

Do you have any other comments or suggestions regarding the application?

NAUNGA MKONO MFUMO HUU KWA ASILIMIA MIA MOJA. NI MFUMO MZURI SANA.

Thank you very much for your participation.

English translation:

I agree with this system. It is very excellent idea

Participant X6

General comments:

Do you have any other comments or suggestions regarding the application?

Huu mfumo nimeupenda sana, umenisaidia sana kwa kweli kama kukumbuka kama muda wa kunywa dawa na kwenda hospitali kwa wakati na pia kufuata desturi za matibabu kama kukohoa kwa njia inayostahili na kula mboga mboga mara kwa mara kwa ajili ya kuitenga afya.

Thank you very much for your participation.

English translation:

I like this system very much. It helped me a lot. The system supported me to remember the time of taking medication and clinic appointments. It also helped to adhere to treatment' ethics such as cough in a proper manner and eat healthy.

Participant X7

General comments:

Do you have any other comments or suggestions regarding the application?

Hii System nimeipenda sana. Picha zote zina fahamika Vizuri sana, kwa kweli sina zaidi isipokuwa naomba isiishie hapa, iendelee ili ipate kutusaidia.

Thank you very much for your participation.

English translation:

I like this system. All graphics were clearly understood. My suggestion is that this system would be sustainable.

Appendix D1: The reviewed TB documentations and publications

Study	Publication name
Public documentations	
TZNational TB, 2011	"Tanzania National TB Programme Annual Report 2011"
ZTLP, 2011	"Zanzibar TB Programme Annual report"
SANAC, 2012	"South African National AIDS Council: National strategic plan on HIV, STIs and TB, 2012-2016"
SANational TB, 2014	"South Africa National Tuberculosis Management Guidelines 2014"
CTPlan, 2014	"The city of Cape Town: city health HIV and TB plan 2014/2015"
Other publications	
Mamboya, 2009	"Improving case detection of TB in rural area in Zanzibar through advocacy, communication and social mobilization"
Kritzinger et al., 2009	"No decrease in annual risk of tuberculosis infection in endemic area in Cape Town, South Africa"
Wilkinson & Wu, 2010	"Prevalence of latent mycobacterium tuberculosis infection in adolescents and young adults in Cape Town, South Africa"
Wood et al., 2011	"Tuberculosis control has failed in South Africa: time to reappraise strategy"
Churchyard et al., 2014	"Tuberculosis control in South Africa: Successes, challenges and recommendations"

Appendix D2: Data from application event logs

Number of Responses

First experiment				Second experiment			
Participant	Speech	Graphic	Total	Participant	Speech	Graphic	Total
Patient1	73	81	154	Patient1	62	80	142
Patient2	65	79	144	Patient2	50	56	106
Patient3	71	80	151	Patient3	60	72	132
Patient4	67	81	148	Patient4	59	62	121
Patient5	69	79	148	Patient5	39	62	101
Patient6	61	83	144	Patient6	59	65	124
Patient7	74	81	155	Patient7	64	73	137
Patient8	69	84	153	Patient8	43	43	86
Patient9	65	74	139	Patient9	39	62	101
Patient10	68	74	142	Patient10	48	51	99
Patient11	79	68	147	Patient11	54	69	123
Patient12	55	80	135	Patient12	61	71	132
Patient13	65	73	138	Patient13	40	65	105
Patient14	68	76	144	Patient14	52	53	105
Patient15	65	67	132	Patient15	38	51	89
Patient16	68	71	139	Patient16	54	58	112
Patient17	54	76	130	Patient17	43	59	102
				Patient18	45	52	97
				Patient19	49	41	90
				Patient20	56	57	113
Total	**1136**	**1307**	**2443**	**Total**	**1015**	**1202**	**2217**

Mann-Whitney Test - Number of Responses

Ranks

	Reminder_Group	N	Mean Rank	Sum of Ranks
Number_Of_Responses First Experiment	Speech	17	10.94	186.00
	Graphic	17	24.06	409.00
	Total	34		

Test Statistics[a]

	Number_Of_Responses
Mann-Whitney U	33.000
Wilcoxon W	186.000
Z	-3.851
Asymp. Sig. (2-tailed)	.00012
Exact Sig. [2*(1-tailed Sig.)]	.000[b]

a. Grouping Variable: Reminder_Group

b. Not corrected for ties.

Ranks

	Reminder_ Group	N	Mean Rank	Sum of Ranks
Number_Of_Responses Second Experiment	Speech	20	15.43	308.50
	Graphic	20	25.58	511.50
	Total	40		

Test Statistics[a]

	Number_Of_Responses
Mann-Whitney U	98.500
Wilcoxon W	308.500
Z	-2.748
Asymp. Sig. (2-tailed)	.006
Exact Sig. [2*(1-tailed Sig.)]	.005[b]

a. Grouping Variable: Reminder_Group

b. Not corrected for ties.

Time of Responses

	First Experiment		Second Experiment	
Reminder Name	Speech	Graphic	Speech	Graphic
Take pill	31	22	30	24
Cough manner	30	22	31	24
Feel unwell	32	22	32	25
Eat healthy meal	27	18	27	18
Clinic appointment	39	27	35	29
Refill pill	46	30	33	28
Drink milk	30	23	37	23

Mann-Whitney Test - Time of Responses

Ranks

	Reminder _Group	N	Mean Rank	Sum of Ranks
Time_Of_Responses First Experiment	Speech	7	10.64	74.50
	Graphic	7	4.36	30.50
	Total	14		

Test Statistics[a]

	Time_Of_Responses
Mann-Whitney U	2.500
Wilcoxon W	30.500
Z	-2.839
Asymp. Sig. (2-tailed)	.005
Exact Sig. [2*(1-tailed Sig.)]	.002[b]

a. Grouping Variable: Reminder_Group

b. Not corrected for ties.

Ranks

	Reminder_Group	N	Mean Rank	Sum of Ranks
Time_Of_Responses Second Experiment	Speech	7	10.71	75.00
	Graphic	7	4.29	30.00
	Total	14		

Test Statistics[a]

	Time_Of_Responses
Mann-Whitney U	2.000
Wilcoxon W	30.000
Z	-2.878
Asymp. Sig. (2-tailed)	.004
Exact Sig. [2*(1-tailed Sig.)]	.002[b]

a. Grouping Variable: Reminder_Group

b. Not corrected for ties.

Appendix D3: Data from treatment adherence rate

A. Table showing Self-Reported adherence (0 for Patient did not improved adherence after trial, 1 or 2 for Patient improved adherence based on the Self-Reported VAS scale – see Chapter 7)

	First experiment				**Second experiment**		
Participant	Control	Speech	Graphic	Participant	Control	Speech	Graphic
Patient1	1	1	1	Patient1	0	1	1
Patient2	1	0	2	Patient2	1	1	1
Patient3	0	1	1	Patient3	1	0	2
Patient4	0	1	1	Patient4	0	1	0
Patient5	1	1	1	Patient5	1	1	1
Patient6	0	0	1	Patient6	1	0	1
Patient7	0	1	1	Patient7	0	0	2
Patient8	0	2	0	Patient8	1	1	1
Patient9	1	0	1	Patient9	0	0	1
Patient10	0	1	1	Patient10	1	1	1
Patient11	1	0	0	Patient11		1	1
Patient12	0	1	1	Patient12		0	1
Patient13		1	1	Patient13		1	1
Patient14		0	2	Patient14		1	1
Patient15		1	1	Patient15		2	0
Patient16		1	1	Patient16		1	1
Patient17		0	1	Patient17		1	1
				Patient18		0	2
				Patient19		1	1
				Patient20		1	1

B. Table showing Pill Count adherence

	First experiment			Second experiment		
	Control	Speech	Graphic	Control	Speech	Graphic
Pill dispensed*	1540	1134	1134	1360	1292	1292
Pill not taken	512	107	0	404	137	130

*The following Table C shows how the pill dispensed was obtained/calculated

C. Table showing how the pill dispensed was obtained in each group in all experiments

	First experiment			Second experiment		
	Control	Speech	Graphic	Control	Speech	Graphic
	8p*35d*4t = 1120 + 4p*35d*3t = 420	12p*18d*4t = 864 + 5p*18d*3t = 270	12p*18d*4t = 864 + 5p*18d*3t = 270	10p*34d*4t = 1360	8p*34d*4t = 1088 + 2p*34d*3t = 204	8p*34d*4t = 1088 + 2p*34d*3t = 204
Total	**1540**	**1134**	**1134**	**1360**	**1292**	**1292**

p=patients, d=days of trial, t=tablets/pills per day, - as described earlier adult TB patient is asked to take 3 or 4 tablets daily, depending on his weight

Appendix D4: Some verbatim feedback from respondents

Verbatim feedback from respondents
Respondent [EXPI_3] said: "The reminder system was very helpful. Both my friends and I liked it very much. I usually showed my friends every time when I received the reminder. But, there is one thing I didn't like, a sound contains some words that I would not like to share with other people. You know…! If you are suffering with disease like TB or HIV, it's something like a secret you don't want everyone to know."
Respondent [EXPI_4] said: "I think the graphic system was very good and can be useful in supporting the TB treatment. It was helping me a lot. Before this system, I was frequently forgetting to take my medication – so I think this system would be helpful to remember to take medication and attend clinic appointments."
Respondent [EXPII_3] said: "Compared to speech system, the graphic was very good, I liked it … *(during the interview, she received an image message, then she said)* … look …! This picture is clearly interpreted that I remembered to eat vegetarian" *(she was pointing at the GBRs – it was of a healthy meal).*
Respondent [EXPII_4] said: "I have a hearing problem, I cannot hear well. I always set my phone to vibrate mode, if I do not hear a phone alert I feel the vibration. During the speech system, I missed the content of several reminders, but in GBR system, I understood the content of every image."