Determining the potential of wearable technologies within the disease landscape of sub-Saharan Africa

by
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In loving memory of my father
Godfrey Kudakwashe Chisi
1964 - 2016

Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work; that I am the sole author thereof (save to the extent explicitly otherwise stated); that reproduction and publication thereof by Stellenbosch University will not infringe any third-party rights; and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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Abstract

Sub-Saharan Africa's (SSA) disease landscape is heavily burden with communicable and non-communicable diseases. Recently, the policy-makers' decision-making process in the region has been influenced by the sustainable development goals (SDGs) that aim at reducing the mortality rates from communicable and non-communicable diseases. Therefore, efforts are being made to introduce more health interventions that can reduce the prevalence of diseases in a cost-effective way.

Recently, health technologies have advanced to mHealth solutions that focus on self-management and person-centred care. mHealth systems are dependent on mobile technology namely mobile phones and smart phones. The expansion of mobile technology into the market has brought about the development of wearable devices. Wearable devices are mobile electronics that can be worn extensively on the body as an accessory or embedded in clothing. These devices make it possible to collect, record and analyse data from the user in a faster and more accurate manner. The main challenge in the region currently is devising a strategy that integrates wearable technology into SSA health system.

The aim of this study is to develop an approach that can be used to determine the potential of wearable technology in SSA based on the disease landscape. The disease landscape will be analysed using the data from the World Health Organization database for the year 2015. The data collected will then be used to select the diseases that heavily burden the region in terms of daily-adjusted life years (DALYs) and fatality. On the other hand a structured review will be used to determine the wearable technology and

its key enabling technologies. The physiological signs are used to cross-reference the wearable sensors to the selected diseases in this study. A 2-step prioritisation exercise is then used to determine the wearable sensors and diseases that are impactful and should receive priority in the region. The stakeholder perspective analysis will be used to determine the entities involved in the application and their anticipated perception and reception of wearable technology in healthcare.

After the prioritisation exercise, the findings indicated that the wearable sensors that will most likely have potential in SSA are photoplethysmography (PPG) sensor, thermistor, pulse oximeter and biosensors, based on the various application areas during disease management. The conditions that require continuous monitoring are ischaemic heart diseases, stroke and premature birth complications and will most likely be impacted by the introduction of wearable technology through reduction of DALYs. From the stakeholder perspective analysis, it was gathered that patients and medical facilities will most likely be resistant to the introduction of wearable technology. The main reasons for the resistance identified were the costs associated with the introduction of wearable technology and the confidential of their medical records.

Based on these findings, further research can be conducted to develop wearable devices that are tailor-made for the unique SSA disease landscape.

Opsomming

Sub-Sahara-Afrika (SSA) se mediese landskap is swaar belas met oordraagbare en nie-oordraagbare siektes. Onlangs was die beleidsmakers se besluitnemingsproses in die streek beïnvloed deur die volhoubare ontwikkelingsdoelwitte wat daarop gemik is om sterftesyfers van oordraagbare en nie-oordraagbare siektes te verminder. Daar word beoog om meer gesondheids intervensies in te stel wat die voorkoms van siektes op 'n koste-effektiewe manier te verminder.

Onlangs het gesondheidstegnologieë gevorder na mHealth-oplossings wat op selfbestuur en persoongesentreerde sorg fokus. mHealth-stelsels is afhanklik van mobiele tegnologie, naamlik selfone en slimfone. Die uitbreiding van mobiele tegnologie in die mark het die ontwikkeling van draagbare toestelle aangebring. Draagbare toestelle is mobiele elektronika wat omvattend op die liggaam gedra kan word as 'n bykomstigheid of in klere ingebed kan word. Hierdie toestelle maak dit moontlik om inligting te versamel en analiseer van die gebruiker op 'n vinniger en meer akkurate manier. Draagbare toestelle word hoofsaaklik vervaardig om nie-oordraagbare siektes aan te spreek wat in gevolg die mees ontwikkelde lande swaar belas. In literatuur is daar tans geen studie wat die potensieel van draagbare tegnologie in die SSA, wat gefokus is massiewe siektes in in die gebied, bereken nie.

Die doel van hierdie studie is om 'n benadering te ontwikkel wat gebruik kan word om die potensiaal van draagbare tegnologie in SSA te kan bepaal. Met behulp van die World Health Organisation (WHO) se databases vanaf 2015 sal die landskap se siektes ontleed word. Die versamelde data sal dan gebruik word om die siektes te selekteer wat 'n swaar las is in die streek in terme van daaglike aangepaste lewensjare (DALYs) en noodlottigheid. Aan

die ander kant sal 'n gestruktureerde oorsig gebruik word om die draagbare tegnologie en die sleutelbemagtige tegnologieë waat met dit gepaard gaan te bepaal.

Die fisiologiese tekens word gebruik om die draagbare sensors na die geselekteerde siektes in hierdie studie te verwys. 'n Twee-stap-prioriteitsoefening word dan gebruik om die draagbare sensors en siektes wat ‘n hoë impak het, te bepaal sodat dit geprioritiseer word in die streek. Die perspektief-analise van belanghebbendes sal gebruik word om die betrokke entiteite by die toepassing en hul verwagte persepsie en ontvangs van draagbare tegnologie in gesondheidsorg te bepaal.

Na die prioriteitsoefening het die resultate aangedui dat die draagbare sensors wat waarskynlik die grootste potensiaal in die SSA sal hê, gebaseer op verskeie toepassings areas gedurende siektebestuur. is: ‘n Fotoplethysmografie (PPG) sensor, termistor, polsoksimeter en biosensors. Toestande wat deurlopende monitering benodig , is iskemiese hartsiektes, beroertes en prematuur geboorte komplikasies en sal waarskynlik beïnvloed word deur die bekendstelling van draagbare tegnologie deur die vermindering van DALYs. Uit die perspektief-analise van belanghebbendes was dit ontdek dat mediese fakulteite en pasiënte heelwaarskynlik weerstand sal bied teen die bekendstelling van draagbare tegnologie. Die hoofredes vir die geïdentifiseerde weerstand was die koste verbonde aan die bekendstelling van draagbare tegnologie en die vertroulikheid van mediese rekords.

Op grond van hierdie bevindinge, kan verdere navorsing gedoen word om draagbare toestelle te ontwikkel wat op maat gemaak is vir die unieke SSA-siekte-landskap.

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NOMENCLATURE

Acronyms

BAN	Body area network
BLE	Bluetooth Low Energy
BSN	Body sensor network
CDs	Communicable diseases
CEA	Cost-effectiveness analysis
DALYs	Daily-adjusted life years
ECG	Electrocardiogram
EEG	Electroencephalogram
EMG	Electromyogram
GBD	Global Burden of Disease
GPRS	General packet radio service
GPS	Global positioning system
GSM	Global system for mobile communications

HIV/AIDS	Human immunodeficiency virus or Acquired immunodeficiency syndrome
ICT	Information and communication technology
MDGs	Millennium Development Goals
NCDs	Non-communicable diseases
PAN	Personal area network
PPG	Photoplethysmography
SDGs	Sustainable developmental goals
SME	Subject matter expert
SSA	sub-Saharan Africa
TB	Tuberculosis
TRL	Technology readiness levels
UMTS	Universal mobile telecommunications system
WHO	World Health Organization
WiMAX	Worldwide interoperability for microwave access
WLAN	Wireless local area network
YLD	Years lived with disability
YLL	Years of life lost

Roman Symbols

A	Annual costs
a	Age
C	Population level costs of intervention
H	Proportion of incidence cases seking medical attention

I	Absolute annual number of incident cases
j	Intervention
r	Real discount rate
s	Sex
T	Life expectancy
t	Time
U	Unit cost of health intervention

CHAPTER 1

INTRODUCTION

The purpose of this research inquiry is to determine the potential of wearable technology for application to the sub-Saharan Africa (SSA) disease landscape. This chapter serves as an introduction providing: (i) the background of the project; (ii) the problem statement along with research aim and objectives; (iii) the research design and methodology; and finally (iv) the report's structure.

1.1 Background

In 2000, the Millennium Development Goals (MDGs) were derived during the United Nations' Millennium Summit (United Nation General Assembly, 2000). These goals were developed in order to improve the living conditions of poor people and to reduce poverty. Of the eight goals that were derived four focused on the improvement of health by 2015. These four goals included (United Nation General Assembly, 2000):

- MDG 1: eradicate extreme hunger and poverty;
- MDG 4: reduce child mortality;
- MDG 5: improve maternal health; and
- MDG 6: combat Human Immunodeficiency Virus or Acquired Immunodeficiency Syndrome (HIV/AIDS), malaria, tuberculosis (TB) and other major diseases.

These goals have managed to reshape healthcare decision-making in developed and developing countries. SSA has managed to achieve remarkable gains in achieving the MDGs, including reducing child and maternal deaths and the prevalence of HIV/AIDS. Specifically, child and maternal mortality were both reduced by approximately 54 percent from 2000 to 2015, respectively. Furthermore, AIDS related deaths have decreased from 1.8 million people in 2005 to 1.1 million people in 2013, as well and the cases of newly infected people halved from 2005 to 2013 (World Health Organization (WHO), 2016). Despite these achievements, women have continued to die during pregnancy or from childbirth-related complications (United Nations, 2015).

As a result, there was a need to create a people-centred development agenda. The process was conducted through a series of global consultations between civil society organisations, citizens, scientists, academics and the private sectors around the world. They were all actively engaged in the process to develop Sustainable Developmental Goals (SDGs) . The SDGs include 17 goals and 169 targets (United Nations, 2016).

The third SDG focuses on "ensuring healthy lives and promoting well-being for all at all ages" (United Nations, 2016). This goal has been considered to have a wider range compared to MDGs that were limited to child and maternal mortality as well as communicable diseases. The targets that were set for the third SDG expand on the MDGs by adding non-communicable diseases (NCDs) and other aspects such as:

1. Reduce the global maternal mortality ratio to below 70 per 100 000.
2. Reduce neonatal mortality to below 12 per 1 000 and under five mortality ratio to 25 per 1 000.
3. End the pandemics of AIDS, tuberculosis, malaria, and neglected tropical diseases and combat hepatitis, water-borne diseases and other communicable diseases.
4. Reduce by one-third premature mortality from NCDs.
5. Strengthen the prevention and treatment of substance abuse.
6. Halve the number of global deaths and injuries from road traffic accidents by 2020.

7. Ensure universal access to sexual and reproductive health-care services.
8. Achieve universal health coverage.
9. Reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination.

MDGs helped in mobilising the international community, leaders, politicians, civil society and sectoral ministries as well as departments to focus on achieving these time-bound and measurable goals. In turn, SDGs not only act as a continuation of the MDGs but will also aim at improving global health with the additional targets (Kumar *et al.*, 2016).

Consequently, SDGs and MDGs have played a vital role in the development of new health interventions to help improve health. Health interventions can be classified into two broad categories, namely (Lukowicz *et al.*, 2004):

(i) preventive interventions: those that prevent disease from occurring and reduce the incidence(new cases) of diseases; and

(ii) therapeutic interventions: those that treat, mitigate, or postpone the effects of disease, once it is under-way and thus reduce the case fatality rate or reduce disability or morbidity associated with a disease.

In real life situations, some health interventions can be classified as both preventive and therapeutic interventions.

For example, preventive interventions that are currently being used to prevent the spread of diseases include: vaccines, nutritional interventions, maternal and neonatal interventions, education and behavioural change and drugs for the prevention of disease. On the other hand, therapeutic interventions that are currently being applied in SSA include: treatment of infectious disease, surgical and radical treatment, diagnostics to guide therapy and control of chronic diseases. SSA faces the challenge of developing new technologies that can aid in eradicating the major diseases including non-communicable diseases.

The World Health Assembly has set a target of a 25 percent reduction of preventable deaths from NCDs by 2025 through the use of person-centred care with improved outreach and self-management to effectively manage risk factors and multi-morbidity (Atun *et al.*, 2013). The use of advanced technology is one way that has been suggested to achieve this goal. The advanced technologies that focus on person-centred care and self management are classified under mHealth. mHealth is a health domain that focuses on mobile and sophisticated technologies such as sensors, mobile phones, smart phones and miniaturised electronics (Lukowicz *et al.*, 2004).

Some of the roles of mHealth in public health include:

- promotion of patient-centred care at lower cost delivered in the patient's natural environment;
- enhanced efficiency in clinical decision-making;
- increased effectiveness of chronic disease management; and
- increased awareness by the user, in turn promotion of healthy lifestyle and self-care.

An important aspect of this research is the investigation of the opportunities to leverage the work that has already been done in the development of wearable technology by considering whether existing solutions can, for example, be applied in an impactful way in SSA with some minor adjustments (either to the wearable device itself or to the condition which the device targets). Therefore, innovators in Sub-Saharan Africa must develop solutions that can add value for the region's disease landscape while also considering resource availability and the intended users of wearable technology.

1.2 Research problem statement

In SSA, the disease landscape is mainly dominated by infectious diseases but non-communicable diseases are also on the rise. Due to the nature of the available funds, the majority of the current health interventions that are being introduced in SSA aim at reducing the spread of infectious diseases. One of the main funding agencies in

Africa is The Global Fund which supports projects concerned with AIDS, tuberculosis and malaria (De Maeseneer *et al.*, 2008). However, SDGs have a target that aims at reducing the premature mortality from NCDs. Therefore, there is a growing need amongst national health departments to start developing new health interventions, aimed at reducing NCDs, that are accessible and affordable to the whole population. This research seeks at determining the potential of wearable technology in the SSA disease landscape.

1.2.1 Research aim and objectives

The aim of this research is to investigate the potential application of wearable technology to prominent diseases in the SSA region and to make recommendations on such applications that should be prioritised for further development. The research objectives are as follows:

(i) Review the SSA disease landscape with the goal of summarising significant current and anticipated future health challenges and identifying the prioritised set of diseases that will be considered during the remainder of the research.

(ii) Review the wearable technology landscape in an effort to generate a comprehensive overview of commercially available technologies and technologies that are in advanced stages of development and are expected to become commercially available in the medium term.

(iii) Identify opportunities for the application of the wearable technologies identified in (ii) to the prioritised healthcare challenges identified in (i).

(iv) Define criteria for prioritising the development of wearable technology for application to specific healthcare challenges.

(v) Apply the criteria defined in (iv) to the range of opportunities identified in (iii) so as to recommend a short list of wearable technology applications to be prioritised for further development.

1.2.2 Research scope

The research's main purpose will be utilised to identify the wearable devices that can be utilised in SSA within the short to medium term. The goal is to use the information so that biomedical engineers can design wearable devices that will be impactful to the SSA health systems when addressing the unique healthcare challenges in SSA. The infrastructure associated with the introduction of wearable technology will only be looked at from the availability of wearable sensors. The other key enabling technologies associated with information and communication technologies (ICTs) as well data analysis will not be looked at in detail as this is out of the scope of this study.

With the time constraint the disease landscape will be studied as a region not at country level. All the countries are affected by the same kind of diseases what will differ is the prevalence and incidence rates.

1.2.3 Research design and methodology

This study comprises qualitative research conducted to document the current SSA disease landscape and the metrics (such as disease severity and disability-adjusted life years (DALYs)) that can be used to determine disease impact either on an individual or population level. The quantitative data for the diseases was collected from the WHO databases and the latest data is from the year 2015.

A structured review is conducted to determine the characteristics of the wearable technology so as to have a comprehensive overview of the wearable technology landscape. The study comprises information about the characteristics of wearable devices that have been developed and are currently commercially available. The information about the wearable devices was gathered from manufacturer's websites and research articles. The wearable devices were then assessed to determine the technology maturity of each device using the technology readiness levels (TRL) assessment scale coupled with the S-Curve.

To determine the opportunities for applications in SSA structured interviews with subject matter experts (SMEs) were conducted to determine the physiological signs and the intended user(s). The data from the interviews was utilised to cross-reference the wearable sensors to diseases and determine the shareholders that will utilise the technology.

In order to prioritise the wearable sensors a set of criteria was defined through the use of previous studies that were conducted in SSA. Heat maps were utilised to identify the wearable sensors that have the highest priority in SSA for the diseases considered for this study. In this study the stakeholder analysis was performed through a qualitative analysis of literature. Figure 1.1 provides the schematic representation of the research methodology followed.

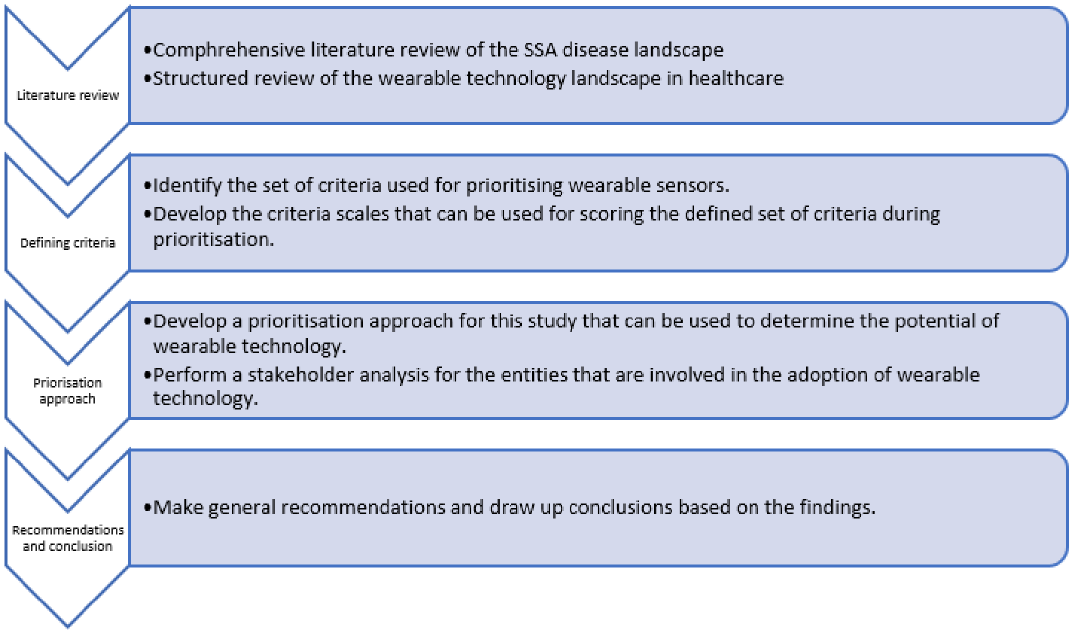

Figure 1.1: Schematic representation of the research methodology

1.3 Structure of the report

This study is arranged in a such a manner that guides the reader through the research process, beginning with a comprehensive overview of the SSA disease landscape and the wearable technology landscape. Then conduct a prioritisation approach in order to identify the wearable sensors and diseases that require priority. Finally make recommendations based on the findings.

Chapter 2 provides a comprehensive overview of the SSA disease landscape by determining the impact of diseases on a population and at individual patient level. In this chapter the disease burden estimates used were the disability-adjusted life years (DALYs) metric and the age-specific deaths for the year 2015.

Chapter 3 gives a comprehensive overview of the current wearable technology landscape by (i) broadly describing wearable technology; (ii) providing the different factors that play vital roles in the usability, functionality and adoptability of wearable devices; and (iii) describing technology maturity of the wearable devices.

Chapter 4 seeks to determine the opportunities between the identified wearable technology and healthcare challenges. This chapter gives a background of the interview process carried out in research and provides a motivation as to why structured interviews were conducted for this part of the study. The summary of the feedback from the interviews as well the cross-reference between the wearable sensors and the diseases.

Chapter 5 defines the selected set of criteria for prioritisation of diseases and wearable sensor technology through literature review. The criteria were categorised under core criteria such as economics, knowledge of need and intervention outcomes. The availability of data will be discussed in detail and the defined set of criteria will be short-listed. The methods to determine the composite score during priority-setting will be discussed as well.

Chapter 6 summarises the findings and discusses the results of the prioritised wearable sensors. In addition to the prioritisation approach, a stakeholder analysis was performed in order to determine the expected reception of the technology and influence of the identified stakeholders on the adoption of wearable technology. Chapter 7 is the final chapter of the study, containing conclusions drawn from the study and proffering recommendations.

1.4 Conclusion

This chapter introduces the research problem briefly, providing the rationale of the study along with the research methodology and the structure of the report. In the following chapter, the current SSA disease landscape is described in more detail by introducing methods of quantifying disease burden, communicable diseases and non communicable diseases. The current disease landscape in SSA is also described and explained using data from World Health Organisation (WHO) databases.

CHAPTER 2

SUB-SAHARAN AFRICA DISEASE LANDSCAPE

This chapter comprises background information of the health status of the different WHO regions and highlights the uniqueness of the SSA disease landscape, for instance by considering the quantification of disease burden by looking at communicable diseases and non-communicable diseases. The quantification methods that were considered were mortality rates and disability-adjusted life years (DALYs) as well as the cost-effectiveness concept. Then, Section 2.2 analyses the current SSA diseases based on the latest data from the World Health Organization (WHO) databases for the year 2015.

2.1 Background

In the last two decades, the global health landscape has transformed. This is evidenced by the improvements of the following health indicators namely the global life expectancy, world population and child mortality. The global life expectancy has increased from 66.4 in 2000 to 71.5 in 2015 (World Health Organization (WHO), 2017), and in many places the older population is growing. The number of people in the world has increased from 6.1 billion in 2000 to 7.4 billion in 2016 mainly because of improved healthcare (Worldometers, 2017). Child mortality has decreased from approximately

12.8 million in 1990 to 6.2 million in 2015 due to improved healthcare (The World Bank, 2016).

Globally, the leading causes of death and disability have shifted from communicable diseases (CDs) (also known as infectious diseases) in children to non-communicable diseases (NCDs)[1] in adults. Of 56.4 million global deaths in estimated 2015, 70 percent of these resulted from NCDs. On the contrary, in SSA communicable diseases are still dominant contributing to approximately 60 percent of the total deaths in the region (World Health Organization, 2016*b*).

Appendix A provides the details of the top leading causes of mortality in all the different regions in the world. As shown in Appendix A, East Asia and Pacific (Table A.1), Europe and Central Asia (Table A.2), Latin America and Caribbean (Table A.3), Middle East and North Africa (Table A.4), North America (Table A.5) and South Asia (Table A.6) are mainly dominated by non-communicable diseases.

The non-communicable diseases that dominate these regions include stroke, ischaemic heart disease, chronic obstructive pulmonary disease, Alzheimer's disease, lung cancer and diabetes. In contrast, SSA (refer to Table 2.3) is mainly dominated by infectious diseases such as HIV/AIDS, lower respiratory infections [2] and diarrhoeal diseases. SSA has a unique disease landscape compared to the other regions and therefore requires different health interventions that will specifically target its unique healthcare challenges.

Previous studies have been performed in order to have a comprehensive overview of the global disease landscape. The most popular study was the Global Burden of Disease (GBD) study (Murray and Lopez, 1996). The first Global Burden of Disease (GBD) study, was carried out by Chris Murray at Harvard University and Alan Lopez at the World Health Organization (WHO), in collaboration with a global network of over 100 scientists (Murray and Lopez, 1996). This study provided comprehensive,

[1]Non-communicable disease is a medical condition or disease that is by definition non-infectious and non-transmissible among people (Dalal *et al.*, 2011)

[2]Lower respiratory infections which affect the airways and lungs. These infections include: bronchitis, pneumonia and influenza. (NHS Choices, 2015; Simoes *et al.*, 2006)

valid, reliable and comparable information of maximum relevance to decision-making concerning the global disease landscape (Mathers *et al.*, 2007).

This study assessed the burden of disease consistently across diseases, risk factors and regions. Also this provided information on the distribution and determinants of health-related states or events (including diseases) that affect a population (Friis, 2009; World Health Organization, 2016*a*).

The GBD study estimated mortality, incidence, prevalence and disability weights for over 130 diseases by age, sex and world region (Murray and Lopez, 1996). The study introduced a new metric, the disability-adjusted life years (DALYs), which summarised the loss of health due to mortality and morbidity combined. Because of this metric the GBD study has faced some criticism (Anand and Hanson, 1997; Barendregt, 2003; Oliver, 2005; Williams, 1999). Particularly, because of the social choices around age-weights and severity scores for disabilities and relatively little information around the large uncertainty in the basic descriptive epidemiology [1], especially in developing countries (Mathers *et al.*, 2007). In order to get an understanding of how these weights are applied in the DALY metric, Section 2.1.1 will provide a more detailed explanation.

The GBD approach has been widely adopted by countries and health development agencies as the standard for health accounting (Murray, 1994). Below is a list of the countries that have previously adopted the study (Mathers *et al.*, 2007):

- Mexico
- Mauritius
- The Netherlands
- Australia
- Brazil
- Malaysia
- Turkey
- South Africa
- Zimbabwe
- Thailand
- United States
- Canada

The GBD study has improved over the years because of the improved availability of data. In the 1990 GBD study, the main source of data was the WHO database but in

[1] Descriptive epidemiology provides a way of organising and analysing data in order to understand variations in disease frequency geographically and over time, and how disease (or health) varies among people based on a host of personal characteristics (person, place, and time) (Evans *et al.*, 2005).

recent years information has been gathered from national disease registers, epidemiological studies, health surveys and health facility data(Kassebaum *et al.*, 2016; Murray, 1994, 2015*b*; Murray and Lopez, 1996). Therefore, more reliable information has become readily available to assist in making more informed estimates for the disability weights used in the DALY metric (Mathers *et al.*, 2007).

On the other hand, the World Bank's Development Report, 'Investing in Health', introduced a framework for planning and allocation of resources for healthcare (World Bank, 1993). This framework was designed to identify the diseases with the highest burden using the GBD study. In this framework, the burden of disease was merged with the cost-effectiveness of healthcare interventions. This was used to provide an idea of the lowest possible cost that could reduce the disease burden most for resource allocation and prioritisation (Murray *et al.*, 1994).

2.1.1 Quantifying disease burden using DALYs

The DALY metric was first introduced in the 1990 GBD study to enable conditioned and country-based comparison of disease burden and facilitate healthcare decision-making (Murray, 1994). The DALY metric is used to measure the burden of diseases in a population. The metric is also used to determine the health gap between an ideal health situation where everyone lives to an old age and the actual population health. Furthermore, DALYs provide an indication of the loss of a patients healthy years through living with an illness and years that are lost due to premature death compared with the ideal life expectancy (Barendregt, 2003; Oliver, 2005; Williams, 1999). The DALY metric is calculated by adding the years lived with disability (YLD) and years of life lost because of premature death (YLL) (Barendregt, 2003; Donev *et al.*).

2.1.1.1 Years lived with disability (YLD)

Diseases cause not only deaths but also varying time periods with morbidity and disability. The time period in years that is lived in states of poor health or disability due to each disease is another dimension of the DALY measure (Donev *et al.*; Murray, 1994). Disability is measured by considering the length in years and in severity by using a measure called YLD.

YLD is based on the incidence of a particular disease and disability weight in a given time period. The disability weight provides information on the severity of disease using a scale of zero to one for each disabling condition (also known as disabling sequelae). These weights were determined by a panel of health experts with the knowledge about disease conditions. Most diseases or conditions possess different disability sequelae (Mathers *et al.*, 2007).

To illustrate how the disability weights are applied, see Table 2.1, which shows how malaria has different disability sequelae. For each disability sequelae corresponding values of YLDs are provided. The disabling conditions for malaria include: episodes, anaemia and neurological sequelae. According to the information in the table, the highest disability weight of malaria is experienced when there are episodes of chills, fever and sweating. At this point the patient will be hospitalised (Murray and Lopez, 1996).

Anaemia in malaria is the lowest sequelae because this occurs when the patient has repeated attacks of malaria. Malaria causes the depletion of red blood cells and a decrease in red blood cell production, resulting in anaemia. This condition can be mild or severe depending on the sufferer of malaria (Phillips and Pasvol, 1992). The YLD metric is then derived from multiplying the disability weight with the average duration the person suffers from the disability from each disease.

The neurological sequelae are a common cause of cerebral malaria. The clinical hallmark of cerebral malaria is the presence of coma. Most survivors of cerebral malaria make a full recovery. However, neurological sequelae such as hemiplegia, speech problems, cortical blindness and epilepsy occur in 3 to 31 percent where the affected person has to live with disabilities (Oluwayemi *et al.*, 2013).

Table 2.1: GBD cause categories, disabling sequelae and average disability weights for Malaria (Reproduced from: Mathers *et al.* (2007))

Cause	Case Definition	Disability Weight	
		Average	Range
Malaria	**Infectious disease caused by protozoa of the genus Plasmodium**	**0,191**	**0,172-0,211**
Episodes	Attacks of chills, fever and sweating because of Plasmodium infection	0,471	0,443-0,471
Anaemia	Defined using WHO criteria for mild to very severe anaemia	0,012	0,012-0,013
Neurological sequelae	Include hemiplegia, aphasia, ataxia and cortical blindness	0,35	0.33-0.36

2.1.1.2 Years of life lost (YLL)

YLL metric takes into account the number of deaths at a certain age multiplied by a global standard life expectancy which is a function of that age. In this estimate the different age groups are given different values based on the human capital capabilities, usually referred to as age weights. A number of studies suggest that the years lived by a young adult have more value compared to those of a young child or an older person (Boutayeb, 2006; Murray and Lopez, 1996). This is where the age weight faces criticism because of how unethical it is to place a value on human life (Anand and Hanson, 1997).

The age weights are obtained from a scale where the value of a year lost rises steeply from zero at birth to a maximum at 25 years of age and then decreases progressively at older ages. From Figure 2.1 it is clear that the relative value of a life year for children under 10 and people more older than about 55 years of age is less than 1. Therefore, when priority-setting, interventions targeting these age groups receive less priority (Donev *et al.*).

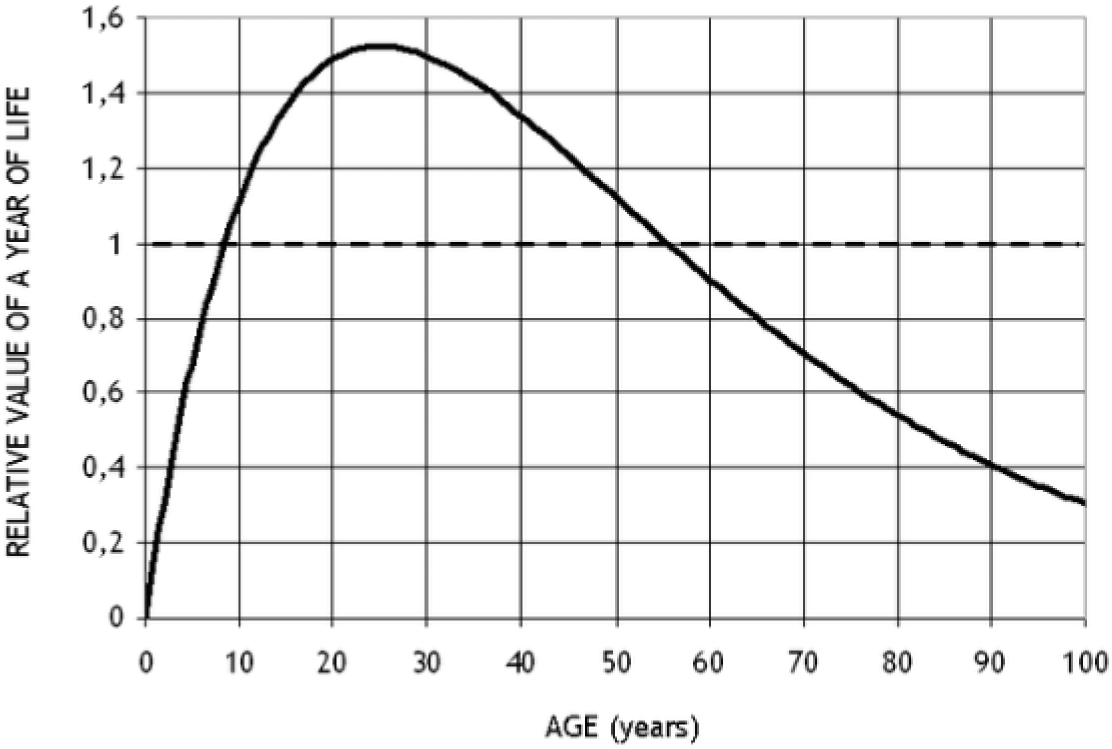

Figure 2.1: Relative values of a year of life. (Reproduced from: The World Bank (1993))

The reasons why DALYs are widely used for the epidemiological studies in developing countries are as follows (Murray and Lopez, 1996):

- Aid in the setting of health services priorities;
- Aid in identifying disadvantaged groups and targeting of health interventions; and
- Provide a comparable measure of output for intervention, programme and sector evaluation and planning.

This metric will be used in this study to indicate the SSA disease burden because of its capability in showing mortality and morbidity.

2.1.2 Cost-effectiveness analysis

Cost-effectiveness analysis (CEA) has been used as a tool used to evaluate the health-care system to provide an economic perspective when addressing resource allocation issues especially in areas with limited resources. The advantage of CEA is that it makes it possible to compare different health interventions in terms of relative cost and health gains (such as DALYs) (Hutubessy *et al.*, 2003). This section aims at providing the methodology used to calculate cost-effectiveness in healthcare based on the study performed by Hansen and Chapman (2008).

2.1.2.1 Costs used for the cost-effectiveness analysis

The costing process can comprise the identification, measurement and valuation of resources required to provide a health service. When performing an economic evaluation the costs considered can be categorised into direct cost and indirect costs. The direct costs that are usually accounted for when performing CEA include (Paganini *et al.*, 2018):

1. medical services such as consultations with a general practitioner or nurses;
2. hospital costs associated with in-patients and out-patients;
3. medication costs associated with the drugs taken during the duration of the illness
4. intervention cost refers to the cost to them at which national intervention agencies are obliged to purchase any amount of a commodity, regardless of the level of market prices; and
5. travel costs that are incurred during treatment.

When costing in healthcare, indirect cost refers to the productivity loss that is faced as a result of absenteeism at work caused by either illness, presenteeism or premature death (Luppa *et al.*, 2007). In the case of a technology-based intervention, the costs associated with integrating the technology in the health system can be considered as well. When the above costs are calculated they provide a unit cost for an individual health intervention (Hansen and Chapman, 2008).

Regarding the total cost of an intervention at population level this can be calculated using the unit cost for an individual health intervention (Hansen and Chapman, 2008). The number of treatments for each disease was determined by incidence and the health seeking behaviour of the population. The incidence of diseases can be drawn from the WHO databases which provide age and gender (sex) specific incident rates for the population (World Health Organization (WHO), 2016). In order to get the proportions of cases by diseases likely to seek treatment, this can be determined from consulting healthcare providers or by using the 80 percent assumption used in most studies. Therefore, the total number of treatments by age and sex can be estimated for each disease under consideration.

Equation 2.1.1 shows how the total costs of a treatment health intervention is multiplied by the unit cost for an individual intervention (Hansen and Chapman, 2008):

$$C^j = U^j \sum_a \sum_s I^j_{as} H^j_{as} \tag{2.1.1}$$

where C^j is the population level costs of intervention j, U^j indicates the unit costs of treatment health intervention j. In addition,I_{as} is the absolute, annual number of incident cases of a health problem (which may be treated by intervention j) in population group of age a and sex s, while H^j_{as} is the proportion of incident cases seeking medical attention in the same population group.

On the other hand, for chronic conditions a different formula is used to estimate the total cost of an intervention at a population level. In these cases, the specific cost figures estimated for a given length of time were recalculated to match the life expectancies at various ages at the beginning of the diseases as indicated in Equation 2.1.2 below (Hansen and Chapman, 2008):

$$C^j = U^j \sum_a \sum_s I^j_{as} H^j_{as} \sum_{t=1}^{T(as)} [(1+r)^{-(t-1)} A^j_t] \tag{2.1.2}$$

where A^j_t is the annual costs at time t for health intervention j for a chronic condition while *T(as)* indicates the life expectancy of an individual belonging to population group of age a and sex s. Future costs are discounted using a real discount rate r of three percent (Hansen and Chapman, 2008).

Regarding preventive interventions the incurred costs are regarded at district and provincial health offices and typically also at the level of health providers such as health centres and hospitals. Then, cost of components for preventive interventions followed the general form (see Equation 2.1.3) (Hansen and Chapman, 2008):

$$C^j = D^j + P^j + U^j \sum_a \sum_s M_{as}^j N_{as}^j \tag{2.1.3}$$

where D^j and P^j represent the overall costs related to preventive intervention j at the district and the particular district's share of the provincial office, respectively. In addition, U^j denotes the unit costs of preventive activities at health centres and hospital outpatient departments. Finally, M_{as}^j is the absolute number of individuals in population group of age a and sex s targeted for intervention j and N_{as}^j denoting the percentage actually covered (Hansen and Chapman, 2008).

2.1.2.2 Estimation of effectiveness of interventions at population level

Effectiveness is based on real-world experience and gives a better idea of whether the technology would work or has worked in the past. If data on effectiveness of a health intervention is unavailable efficacy can be considered because evidence of the latter is more readily available through systematic reviews, randomized trials, etc. (Mathew, 2017). Effectiveness of health interventions in a real-world setting depends on a wide range of factors such as efficacy of individual drugs, diagnostic accuracy, appropriateness of the treatment prescribed and patient compliance.

Mathematically the effectiveness is the reduction in the burden of disease (known as DALYs averted) as a result of intervention. Following the GBD methodology, the burden of disease for an individual of sex s dying prematurely at age a, $BOD_a s$, and with life expectancy *T(as)* (or suffering from a disease episode starting at age a with length *T(as)*) could be calculated from the formula (Hansen and Chapman, 2008):

$$BOD_{as} = \int_{t=a}^{a+T(as)} WKte^{-\beta t} e^{-r(t-a)} dt \tag{2.1.4}$$

where W is a quality adjustment factor (disability weight) representing different levels of health. The component $Kte^{-\beta t}$ is an age weighting curve of an inverted u-shape so that the relative value of life years in young adulthood is higher than at other ages while $e^{-r(t-a)}$ is the discount factor using discount rate r is three percent. Life expectancies *T(as)* therefore depend on both age and sex. The benefit in terms of DALYs gained from a successful intervention j for a person of age a and sex s is calculated in the following way (Hansen and Chapman, 2008):

$$\Delta BOD_{as}^{j} = BOD_{as} - BOD_{as}^{j} \tag{2.1.5}$$

where ΔBOD_{as}^{j} is the burden of disease after a successful intervention.

The benefits at population level in terms of DALYs averted of a specific curative health intervention j were subsequently calculated as (Hansen and Chapman, 2008):

$$DALYs^{j} = E^{j}B^{j}F^{j}G^{j}\sum_{a}\sum_{s} I_{as}^{j}H_{as}^{j}\Delta BOD_{as}^{j} \tag{2.1.6}$$

whereE^{j}, B^{j}, F^{j} and G^{j} are efficacy of the drug prescribed, diagnostic accuracy, correct treatment and patient compliance respectively for curative intervention j measured as percentages. Expressed in words, this equation estimates the number of individuals cured through treatment j by excluding ineffective services from the total number of individuals seeking treatment and translating the resulting health benefits into DALYs averted.

The number of DALYs averted at population level for a given preventive intervention j was calculated as:

$$DALYs^{j} = E^{j}R^{j}\sum_{a}\sum_{s} I_{as}^{j}\Delta BOD_{as}^{j} \tag{2.1.7}$$

where E^{j} is the efficacy of the intervention under ideal circumstances and R^{j} is any necessary downward adjustment j (less than perfect coverage) of efficacy while I_{as}^{j} is the incidence of disease in different age and sex groups.

2.1.2.3 Calculation of cost-effectiveness ratios

Having estimated the total costs and effectiveness of various health interventions, the cost-effectiveness ratio for intervention j, CER^j, was found as:

$$CER^j = \frac{C^j}{DALYs^j} \tag{2.1.8}$$

where costs were estimated using equation 2.1.1, 2.1.2 or 2.1.3 and effects were estimated using 2.1.6 or 2.1.7.

2.1.3 Communicable diseases

Communicable diseases are illnesses that arise as a result of specific infectious agents that are transmitted from an infected human, animal or inanimate reservoir to susceptible host. An illness results from the presence and growth of pathogenic biological agents in an individual host organism (Mboera *et al.*, 2014). Communicable disease are infectious or contagious diseases, parasitic diseases, infections transmitted by a vector (the zoonoses) and all the transmissible diseases. A brief explanation of zoonoses is provided in Section 2.1.3.2.

Communicable diseases can be either in the endemic or epidemic form (Van den Berg and Viljoen, 1999) . An endemic is constantly present in a geographical area or population group (Webber, 2016). An example of an endemic disease is malaria, an infectious disease that is constantly present in tropical regions because of the conducive condition for the mosquito life cycle. An epidemic is the introduction of a new infection or the presence of an illness in excess of normal expectancy(Webber, 2016). In some instances, this can be seasonal such as with influenza. In other instances, this results when the number of susceptible people is sufficient for a new epidemic to take place, for example measles.

2.1.3.1 Mode of transmission

Webber (2016) suggested that the best way to know about diseases is being able to group them based on their modes of transmission. In many instances, some diseases may share the same mode of transmission therefore can be treated in the same way. The agents that transmit the communicable diseases can be organisms (such as virus, prion, bacteria, rickettsia, protozoa, helminth, fungus or arthropods), or a physical or chemical agent (toxin or poison). Communicable diseases are transmitted through the three ways listed below (Ayim, 2011):

- direct contact transmission;
- mechanical transmission; and
- biological transmission.

Direct contract transmission is the instantaneous transfer of the infectious agent from a reservoir to a susceptible host by direct contact or droplet spread. Direct contact can either occur with an infected animal, human or plants through touching, kissing, skin contact, and sexual intercourse (Ayim, 2011; Van den Berg and Viljoen, 1999; Webber, 2016). Vibrio cholerae bacterium is transmitted through water contaminated by a person infected with cholera.

Droplet spread of infectious agents entails aerosols, coughing, sneezing or even talking to a contaminated person. Typically, TB is spread when an infected person coughs, sneezes or spits *Mycobacterium tuberculosis.* The *Mycobacterium* is released into the air and breathed in by an unaffected human (Ayim, 2011).

Mechanical and biological transmission is aided by a vector. In brief, a vector is an organism that carries an infection by transferring pathogens from one host to another. Mechanical transmission occurs when the agent does not multiply or undergo any physiological changes in the vector. For example flies pick up micro-organisms from human or animal excretions and deposit them on food (World Health Organization, 2005).

In contrast to mechanical transmission, biological transmission occurs when the agent multiplies or undergoes part of its life cycle inside a vector before transmission to a susceptible host (Ayim, 2011). For instance, malaria is transmitted to a susceptible host by a female Anopheles mosquito. The process is explained in more detail in Section 2.2.2.1. Understanding the transmission of a communicable disease allows the development of effective preventive measures. The Centre for Disease Control used this strategy to control the malaria, Ebola and HIV epidemics (Toole, 1997).

2.1.3.2 Factors that cause communicable diseases

In reality, most of the infectious diseases that are being passed on originate from animals; these are zoonotic in nature. A number of publications suggest that between 65 and 80 percent of CDs are transmitted from animals (Jones *et al.*, 2008; Mboera *et al.*, 2014). The zoonoses that have posed health threats in sub-Saharan Africa are avian influenza, bovine tuberculosis, rabies, Ebola, anthrax, plague and bovine brucellosis (Toole, 1997).

The spread of CDs is influenced by other factors such as socio-economic, ecological factors and environmental factors. These factors are discussed below:

Socio-economic factors: In order for an infection to prevail socio-economic factors play a vital role. The factors that can be considered are: education, resources and economics as well as communities and movements (Webber, 2016).

Education can be used to stop the spread of infections. Education plays a vital role in preventing the spread of some diseases because people will be knowledgeable and aware of the best practices for better living conditions. Education is a complex process which involves teaching people and making sure the people understand how to modify their lives. Webber (2016) suggested that it is not only the tropical climates that contributes to much of the spread of infectious disease but this is added to by poverty and lack of education. In developed countries communicable diseases have been eradicated because of the improvement in health education (European Centre for Disease Prevention and Control (ECDC), 2014). As education improved people began to understand the need for good water and proper sanitation, personal hygiene and cleanliness (Van den Berg and Viljoen, 1999).

The lack of resources leads to poverty, which reduces the ability to combat disease. In this context, resources refer to everything that people have to carry out for their livelihood. Resources are required to enable the preventive, palliative and curative methods or raise the standards that have come to be demanded by education. Diseases are best prevented by education on how to overcome them, but resources are required to achieve this (Webber, 2016).

Some of the essential resources that are needed for a better livelihood are:

- Food is required to build up body processes and prevent malnutrition;
- Clean and safe water supply; and
- Housing in good conditions.

Resources, education and disease are linked directly. The type of houses that a community occupies plays an essential role in the type of diseases they are exposed to. In South America, the Reduviidae bugs that transmit Chagas' disease live in the mud walls of houses, so replacing these with more permanent materials can prevent the disease (Beard *et al.*, 2002).

Recently, the attraction to cites has resulted in large demographic changes. In the past, the majority of the population lived in rural areas but now urban areas have become the commonest place of residence in tropical countries (Dalal *et al.*, 2011; Mayosi *et al.*, 2009). Because of urbanisation (unplanned and under-planned urbanisation) and migration to urban areas for employment, people settle in slums where they have poor living conditions. The water sources provided in such communities make them susceptible to diarrhoeal diseases(Webber, 2016).

Recently, issues have arisen as a result of globalisation and dietary changes, leading to the emergence of fast food chains in developing countries. Fast food poses a health risk and contributes to the emergence of non-communicable diseases (Pang and Guindon, 2004).

Ecological changes and environmental factors : Ecological changes and environmental factors usually occur when people are exposed to vectors that they were not in contact with but were already in existence such as zoonotic or arthropod-borne infections (Morse, 1995). Global warming has led to an increase in the global temperature resulting in climatic changes. Climate change has brought about increase in tropical cyclones making the affected populations susceptible to diseases (Ayim, 2011; Van den Berg and Viljoen, 1999; World Health Organization, 2005). These diseases include diarrhoeal diseases and leptospirosis which thrive in watery environments.

The increase in the average temperature has also led to the spread of infectious diseases such as malaria. In most cases, these high temperatures are favourable for mosquitoes to thrive in and multiply especially in tropical areas in SSA (Kirigia and Barry, 2008). Recently, the southern part of Africa has been experiencing more droughts because of climate change (Ko *et al.*, 2016). This has resulted in the scarcity of food in some areas leading to malnutrition. Malnutrition usually affects children under the age of five by making their immune system weaker and susceptible to diseases such as lower respiratory infections, kwashiorkor and marasmus (Webber, 2016).

These are the other environmental factors that can contribute to the spread of infectious disease (Webber, 2016):

(i) agricultural activities that attract rodents that are associated with the spread of the plague;

(ii) deforestation and reforestation may cause the spread Lyme disease; and

(iii) dams can lead to the spread of malaria by providing breeding places for mosquitoes.

It is estimated that 40 percent of the disease burden in SSA is environmentally determined (Barrat *et al.*, 2014). As a result, complex health problems such as CDs are difficult to solve without an understanding of these factors.

2.1.4 Non-communicable diseases

A non-communicable disease is a medical condition or disease that is by definition non-infectious and non-transmissible among people (Dalal *et al.*, 2011). The main types of NCDs are cardiovascular diseases [1], chronic lung diseases, cancer and diabetes. Most NCDs are linked and strongly associated with four preventable risk factors namely: i) tobacco use, ii) physical inactivity, iii) unhealthy diet and iv) the harmful use of

[1]Cardiovascular diseases include Rheumatic heart disease, Ischaemic heart disease, Stroke, Hypertensive heart disease and Cardiomyopathy and myocarditis

alcohol. These behavioural risk factors lead to four key physiological changes listed below (World Health Organization, 2010):

(i) high blood pressure;

(ii) overweight or obesity;

(iii) hyperglycaemia (high blood sugar levels); and

(iv) hyperlipidaemia (excess fat level)

According to the World Health Organization (WHO) (2014*a*), tobacco is not only the most prominent cause of cancer but also cardiovascular diseases and chronic respiratory disease. It has been estimated that in the twentieth century 100 million people died worldwide from tobacco-associated diseases (Boutayeb, 2006). Despite the risk associated with smoking, there are 1.2 billion smokers in the world and 80 percent live in developing countries. The number of smokers in developing countries increases by 3.4 percent per annum (World Health Organization (WHO), 2014*a*). It is estimated that 6 million deaths recorded in 2015 recorded were linked to smoking and 10 percent of those were from passive smoking (Kassebaum *et al.*, 2016).

Obesity and dietary habits represent potential risk factors for cardiovascular diseases, type 2 diabetes, and some types of cancers, especially in the absence of physical activity. Approximately 3.2 million deaths are linked to physical inactivity every year (World Health Organization, 2010). Recent studies reported by the World Health Organization (2016*b*) suggest that the intake of fruit and vegetables is recommended and helps reduce the risk of coronary disease, stroke and high blood pressure. However, in developing countries the Western diet is taking over, leading to the reduction in the consumption of fruit and vegetables (Bourne *et al.*, 2002; World Health Organization (WHO), 2014*a*).

Alcohol consumption is a risk factor associated with 2 million deaths in the world ever year (World Health Organization (WHO), 2014*a*). It is mainly associated with liver disease and oesophageal cancer. The increase in alcohol consumption in developing countries will contribute other hazards caused by violence and road accidents to the burden of disease (Crampin *et al.*, 2016). Table 2.2 gives a summary of the main risk factors and their associated diseases.

Table 2.2: Diseases that are linked to the four main risk factors

Risk Factors	**Diseases Linked to Risk Factors**	**Comments**
Tobacco	oral cancer, hypertension, heart diseases, lung cancer, chronic respiratory disease, cardiovascular diseases and also communicable diseases such as tuberculosis and lower respiratory infections	6 million deaths and of this 10 percent from second hand smoking. There are different forms of smoking smokeless (unburnt forms) and smoking. (Stevens, 2009)
Insufficient physical activity	ischaemic heart disease, diabetes, breast and colon cancer, stroke, hypertension, and depression	3.2 million deaths reported annually (World Health Organization, 2010). People who are not sufficiently active have a high 20 - 30 percent increased risk of all cause mortality. Automation of work is taking away the physical aspect. (Crampin *et al.*, 2016)
Harmful use of alcohol	cancers , cardiovascular diseases, liver cirrhosis, ischaemic heart disease, cerebrovascular disease	2.3 million deaths annually (World Health Organization (WHO), 2014*a*)
Unhealthy diet	gastrointestinal cancer, ischaemic heart disease, stroke	insufficient intake of fruits and vegetables (Cordain *et al.*, 2005)

2.2 Disease landscape in sub-Saharan Africa

The SSA disease landscape can best be described as double-burdened because of the prevalence of CDs and NCDs. Over the past decade, there has been a gradual increase of the mortality and morbidity caused by NCDs in SSA, unlike in the past where the disease landscape was dominated by infectious diseases (Boutayeb, 2006). The challenge that faces SSA health systems is the limited resources which forces them to prioritise communicable disease more than NCDs. As a result most of the resources are allocated to controlling the spread of infectious diseases and epidemics (Anyangwe and Mtonga, 2007). In this section the disease landscape will be determined by considering the burden of disease.

2.2.1 Top causes of death in SSA for the year 2015

Of the 9.5 million deaths in SSA in 2015, more than half (55 percent) were due to the top 10 causes (see Table 2.3). Lower respiratory infections, HIV/AIDS and diarrhoeal diseases are the region's biggest killers, accounting for a combined 2.5 million deaths in 2015. These diseases have remained the leading causes of death for the past 15 years.

Stroke claimed 459 thousand lives in 2015, while ischaemic heart disease caused 453 thousand deaths. Tuberculosis killed 446 thousand in 2015. Deaths due to malaria recorded in 2015 were 409 thousand deaths. Pre-term birth complications caused 355 thousand deaths and birth asphyxia and birth trauma claimed 338 thousand babies lives. Road injuries claimed 273 thousand in 2015. These diseases affect different age groups in the population. This gives an idea of the target group when coming up with interventions for different age groups.

In SSA, children under five have the highest mortality from communicable diseases such as lower respiratory infections, malaria and diarrhoeal diseases. About 70 percent of these conditions could be treated with access to simple, affordable interventions. Over half of all under-five child deaths occur partly due to poor or delayed seeking of treatment, leaving children in developing countries 10 times more likely to die than children in developed countries (Lloyd and de Witt, 2013; Palmer and Gershbein, 2012).

Between the ages of 5 to 14 years mortality is due to severe malnutrition, HIV/AIDS, diarrhoeal diseases, meningitis and acute lower respiratory infections. In literature the majority of these diseases affect children that live in rural areas because of the poor health care services and socio-economic factors (Dedefo *et al.*, 2016).

Among young adults in SSA fatality results mainly from these communicable diseases, namely HIV/AIDS, diarrhoeal diseases, lower respiratory diseases, meningitis, tuberculosis and malaria. The females in this age group are susceptible to maternal deaths. The top causes of maternal mortality include: pathogenic causes, obstetric haemorrhage, puerperal sepsis, pregnancy induced hypertension, obstructed labour, ruptured uterus and complication from unsafe abortions(Rogo *et al.*, 2006). A study in Eritrea found that 16 percent of maternal deaths occurred during pregnancy, 48 percent of those during childbirth, and 36 percent post-partum (Ghebrehiwot, 2004). Non-communicable diseases that affect the population in this age group are: ischaemic heart disease and liver cirrhosis. These NCDs are as a result of risk factors such as unhealthy diet, harmful use of alcohol and smoking (World Health Organization (WHO), 2014*a*).

From the age of 30 to 49 years more people die from NCDs than the people below 30. The top NCDs that cause fatality include: liver, breast and cervical cancer, diabetes and stroke. The same diseases affect the elderly population. According to WHO, the life expectancy of sub-Saharan Africa has risen from 50.6 to 60.0 (World Health Organization (WHO), 2017). This indicates that the demographics in SSA are shifting and the elderly population is increasing. However, the elderly are mainly affected by conditions such as: cancer, diabetes, ischaemic heart disease, stroke and chronic obstructive pulmonary disease, all of which are chronic conditions (World Health Organization (WHO), 2016).

Table 2.3: Top 10 Causes of Death and disease burden in Sub-Saharan Africa 2015 (Adapted from: World Health Organization (WHO) (2016))

Rank	**Causes of death**	**Deaths thousands (000)**	**Diseases**	**DALYs (000s)**
1	Lower respiratory infections	1 040	Lower respiratory infections	64 750
2	HIV/AIDS	765	HIV/AIDS	45 870
3	Diarrhoeal diseases	671	Diarrhoeal disease	44 483
4	Stroke	459	Malaria	35 615
5	Ischaemic heart disease	453	Preterm birth complications	31 798
6	Tuberculosis	446	Birth asphyxia and birth trauma	30 367
7	Malaria	409	Congenital anomalies	19 846

Continued on next page

Table 2.3 – *Continued from previous page*

Rank	Causes of death	Deaths thousands (000)	Cause	DALYs (000s)
8	Preterm birth complications	355	Tuberculosis	18 543
9	Birth asphyxia and birth trauma	338	Road injury	16 463
10	Road injury	273	Neonatal sepsis and infections	15 984

2.2.1.1 Cause-specific DALYs in 2015

The total DALYs in SSA recorded in 2015 were 629 million. The top ten causes (in Table 2.3) accounted for 51 percent of the total DALYs in the region. Lower respiratory infections, HIV/AIDS and diarrhoeal diseases cause the highest disease burden in the region, accounting for 25 percent of the total DALYs.

Pre-term birth complications, birth asphyxia and congenital anomalies all combined accounted for 98 million DALYs in children under the age of five. The child mortality is believed to have been reduced by cost effective interventions such as resuscitation of the new born baby, breastfeeding, kangaroo mother care [1] and prevention of hypothermia in resource limited settings (Darmstadt *et al.*, 2004). Congenital anomalies refer to structural defects, chromosomal anomalies, inborn errors of metabolism and hereditary disease present at birth (Lloyd and de Witt, 2013). Congenital anomalies can contribute to long-term disabilities that is why it causes three percent DALYs.

The morbidity due to malaria accounted for 36 million DALYs and tuberculosis 19 million DALYs. The survivors from a stroke are usually paralysed, have trouble speaking or understanding speech and trouble seeing(Mayo Clinic).

The neonatal (babies that are 0 - 28 days old) DALYs accounted for about 82 million DALYs in the year 2015 and this gradually increased to 145 million for children under the age of five. The number of deaths for the population between the ages of 5

[1] Kangaroo mother care is a method of care for pre-term infants. The method involves infants being carried, usually by the mother, with skin-to-skin contact especially for low-birth-weight and pre-term infants (World Health Organization (WHO) and Dept. of Reproductive Health and Research, 2017)

to 14 years steeply decreases to about 45 million DALYs. Then there is a ten percent decrease of the DALYs rates in the 15- to 29-year age group to 40 million DALYs. The DALYs rate increases slightly for the young adult population between 30 to 49 years of age to about 50 million DALYs. Finally, for the elderly population above 50 the DALYs dropped to 7.7 million.

Babies under the age of 28 days are burdened by neonatal conditions such as preterm birth complications, birth asphyxia and birth trauma, neonatal sepsis and infections. Children under the age of five have disabilities resulting from diarrhoeal diseases, malaria, lower respiratory infections, childhood cluster diseases (such as whooping cough, diphtheria, measles and tetanus) and protein energy malnutrition (World Health Organization (WHO), 2016). These children under the age of five have the highest DALYs from the communicable diseases.

The population between the ages of 15 to 49 is affected by a different set of communicable diseases such as tuberculosis, HIV/AIDS, lower respiratory infections and diarrhoeal diseases. In this age group the females are burdened because of maternal conditions. The elderly population is susceptible to the conditions that affect the adult population except for the disabilities caused by maternal complications (World Health Organization (WHO), 2016).

For non-communicable diseases the trend shows a gradual increase from 0 to 49 years and then a decrease from then on. In the neonatal stage non-communicable diseases have the lowest DALYs (7.6 million DALYs) recorded in 2015. Then the DALYs increase slightly to 20 million DALYs for children under the age of five.The DALYs recorded for children aged between 5 and 14 years they levels off at 20 million DALYs. The NCDs reach a peak (37 million DALYs) for the ages between 30 to 49 years. Then from the ages of 50 to over 70 the disease burden levels off at about 22 million DALYs.

The neonatal disabilities from NCDs are as a result of congenital anomalies. For children under the age of five in addition to congenital anomalies there is sickle cell anaemia, epilepsy and skin diseases. The children aged from 5 to 14 years are affected by the same NCDs as the children under the age of five. The changes in the

NCDs affecting the population between the age of 15 to 29 years include: sickle cell anaemia, depressive disorder, alcohol use disorders, drug use disorders, anxiety disorders, epilepsy, ischaemic heart disease, asthma, kidney diseases and cirrhosis of the liver. Most of these are chronic conditions that affect the daily livelihood of the people. The major concern in SSA is the fact that non-communicable diseases affect the active age group (15 to 29) which affects the economy. The NCDs have started to take over the SSA disease landscape because of the unhealthy diet, smoking, physical inactivity and alcohol abuse (World Health Organization (WHO), 2016). Furthermore, SSA health systems lack the policies that can be used to prevent the prevalence of NCDs (World Health Organization, 2010).

For elderly people, the burdens they are ridden with include: prostate, breast and cervical cancer, hearing loss, ischaemic heart disease, chronic obstructive pulmonary disease, diabetes, Alzheimer disease and other dementias, and stroke. Most of the elderly population are burdened by chronic conditions. These chronic conditions need constant monitoring and treatments are extremely expensive. Such costs can force families into catastrophic spending and impoverishment (World Health Organization, 2010).

From the data presented in Table 2.3 SSA is still heavily burdened by communicable diseases. This explains why the health systems focus mainly on CDs at the expense of NCDs.

2.2.2 Disease physiological signs

In this section the top 10 diseases will be briefly described to get an understanding of each diseases and how they can be monitored through physiological signs.

Lower respiratory infections are common for causing disease burden in infants especially pneumonia. Rodriguez *et al.* (2015) made a severity score for the parameters that can be used to clinically assess lower respiratory infections. The parameters that were considered for the monitoring of lower respiratory infections were respiratory rate, heart rate and oxygen saturation. Furthermore, the GP-Update suggested more physiological signs such as temperature, respiratory rate and blood pressure (GP-Update

Red Whale, 2016).

HIV infection harms the immune system by destroying the white blood cells that fight against infections. This leaves the body vulnerable to contracting serious infections and certain cancers. HIV infection advances in three significant stages:

- During the initial stage the signs of HIV infection that may be evident are swollen glands and flu-like symptoms which eventually disappear after two to four weeks.
- Then Stage 2 may last for 10 years or so, with no more apparent symptoms.
- Lastly Stage 3 is when the immune system is severely damaged that it can no longer fight off serious infections and diseases, also known as "opportunistic infections".

The three stages are then followed by AIDS. However not everyone with HIV develops AIDS. Currently the only way to diagnose HIV infection is through a blood test. The disease can be monitored by checking the level of the CD4 count in the blood. The infected person takes antiretrovriral medication after being tested positive.

Diarrhoeal diseases are characterised by loose and watery stools that occur more frequently than usual. The severity of the disease varies from the frequency of defecation of the loose stool. According to Crombie *et al.* (2013), the physiological signs that can be utilised to assess diarrhoea include temperature, body fluid levels, electrolyte composition, blood pressure, heart rate and heart electrical activity (especially in the case of tachycardia [1]).

[1]Tachycardia is a condition when the heart beats too fast leading to the failure of proper blood circulation to all parts of the body. (GP-Update Red Whale, 2016)

Stroke is an acute condition that affects people that are hypertensive. There is need to monitor these patients continuously to prevent the occurrence of a stroke. The recommended vital signs that can be used to monitor high risk patients are blood pressure, body temperature, blood oxygen saturation, and blood glucose levels (Wong and Read, 2008). After the stroke heart electrical activity, blood pressure, body temperature, pulse oximetry, blood glucose and brain activity can be monitored to improve the patient's health during treatment and rehabilitation (Moheet and Katzan).

Ischaemic heart diseases are monitored using the heart rate, respiratory rate, blood pressure, oxygen saturation, heart electrical activity, heart sounds and urine composition. At the moment there are devices that can be used to change the lifestyle of a patient at high risk by monitoring the activities and sleep quality (Ministry of Health and Quality of Life, 2000; National Heart Lung and Blood Institute, 2017).

Tuberculosis is an communicable disease caused by *Mycobacterium tuberculosis*. For tuberculosis the vital signs that can be monitored are the heart rate, blood pressure, temperature and respiratory rate (International Union Against Tuberculosis and Lung Disease). In some instances the cough frequency in the first three months of contraction of the disease can be used to screen TB patients (Bregani *et al.*, 2013). The sputum is analysed to detect the presence of tuberculosis when the patient shows some of the signs and symptoms.

Malaria results from being bitten by an infected Anopheles mosquito. The infected Anopheles carries a *Plasmodium* parasite which is released into the bloodstream. These parasites infect the red blood cells and begin to multiply and cause the red blood cells to burst open. There are different forms of malaria such as:

- swelling of the blood vessels of the brain, or cerebral malaria;
- accumulation of fluid in the lungs that causes breathing problems or pulmonary oedema;

- organ failure of the kidneys, liver or spleen;
- anaemia due to the destruction of red blood cells; and
- low blood sugar.

Malaria is diagnosed through a blood test and can only be prevented by not allowing the intrusion of the malaria parasite into the body. The signs and symptoms of malaria are non-specific, therefore a proper diagnosis has to be carried to confirm the results.

Congenital anomalies are known as "birth defects." These are defined as structural or functional anomalies that occur during the intrauterine life and can be identified prenatally, at birth or sometimes may only be detected later in infancy. These conditions can be caused by genetic factors, environmental factors and infections. This condition can be corrected through paediatric surgery and early treatment can be administered to children with functional problems such as recessive blood disorders, sickle cell disorders and reduced function of the thyroid.

Pre-term birth complications arise from immature organ systems that are not yet prepared to support life in the external environment. These complications can lead to the risk of contracting acute neonatal illnesses which are dependent on the length of the gestation period and reflect the fragility and immaturity of the brain, lungs, immune system, kidneys, skin, eyes and gastrointestinal system (Behrman and Butler, 2007). Infants born prematurely ('preemies") have the highest likelihood of dying during the first 28 days (neonatal) and infancy (first year). Therefore, the mortality rate increases proportionally with decreasing gestation age or birth weight. Preemies in the intensive care unit require that their respiratory rate, blood pressure, heart rate, brain activity, temperature, haemoglobin levels and blood sugar levels be monitored continuously as well as after they are discharged from hospital (Hofmeyr *et al.*, 2014).

Birth asphyxia is a condition arises when a baby is deprived of oxygen before, during or just after birth. This condition can be caused by the following complications during birth (World Health Organization):

- mother's blood possessing insufficient oxygen levels;
- placenta separating from the uterus too soon;
- long delivery process;
- high or low blood pressure in the mother; and
- baby's blood cells cannot carry enough oxygen.

These conditions can be assessed or monitored by taking note of the following physiological signs: temperature, heart rate, capillary refill time (perfusion), colour, oxygen saturation, respiration rate, brain activity, haemoglobin levels and blood glucose levels (World Health Organization). It is important that the heart rate, heart electrical activity and the oxygen saturation of the pregnant woman are monitored before giving birth to prevent and detect complications that can cause pre-term birth complications (Mahmudul, 2013).

Neonatal sepsis is a blood infection. This infection can be caused by bacteria such as *Escherichia coli*, *Listeria* and some strains of streptococcus (Lee, 2016). The infection can be characterised by body temperature changes, breathing problems, diarrhoea, low blood sugar, slow or fast heart rate and yellow skin, as well as the whites of the eyes (jaundice). The physiological signs that can be measured to assess neonatal sepsis are heart rate variability, respiratory rate and oxygen saturation (Griffin *et al.*, 2007).

In order to get more understanding, the leading causes of mortality and morbidity are described in detail in Appendix A Table A.7. This table provides information on the causes, signs or symptoms, preventive measures and treatments of a disease.

2.2.3 Other challenges that affect health in SSA

SSA has widespread poverty, marginalisation and displacement. Poverty and health form a vicious cycle which can be broken by encouraging economic development through improving healthcare (Kengne *et al.*, 2013). Furthermore, the environmental factors and degradation are not sufficiently addressed even though they influence the transmission of most infectious diseases as stated in Section 2.1.1. The region also faces shortfalls in agriculture, low literacy, on going conflicts and lack of safe water, adequate sanitation, electrification and infrastructure. All of these are drivers of the SSA disease burden (Akintola *et al.*, 2015).

The health interventions that are developed often do not match the scale of the problem. The other challenge that most people are facing in SSA is insufficient empowerment to improve their health and inadequate involvement by the health departments in their respective countries. According to Anyangwe and Mtonga (2007) the improvement of health systems plays an important role in improving the health of sub-Saharan Africa. There is also an issue with equity of health services where the people who are heavily burdened by diseases do not have access to them.

In SSA the extent of extreme poverty has been reduced from 57 percent in 1990 to 43 percent in 2012 (Kengne and Mayosi, 2014). However, the reduction of poverty and the development of countries leads to a shift from primary infections such as diarrhoea and pneumonia to non-communicable such as cardiovascular diseases and cancers (Bourne *et al.*, 2002). This shift results from:

i Improvements in medical care, which mean that children can not easily die from preventable and curable diseases such as diarrhoea.

ii The ageing population, because NCDs affect older adults at the highest rates. (Demographic transition)

iii Public health interventions such as vaccinations and the provision of clean water and sanitation, which reduce the incidence of infectious diseases, as stated by Stevens (2009).

Non-communicable diseases in SSA are on the rise in rural communities and are also affecting poor people living in urban settings, resulting in an increase in chronic disease care (World Health Organization, 2010). As stated by Bourne *et al.* (2002) the reason why South Africa is facing a transition from CDs to NCDs is because of the shifts in dietary intake. In urban settings the fat intake by people has increased from 16.4 to 26.2 percent of total energy whereas carbohydrate intake has decreased from 69.3 to 61.7 percent in the past 50 years (Cordain *et al.*, 2005). This has resulted in having a population that is at high risk of suffering from non-communicable diseases.

Kengne and Mayosi (2014) stated that the transition from communicable to non-communicable diseases in SSA is increasing at a faster rate than it did in high-income countries.This rapid transition poses challenges to the health systems in the region as they struggle to adapt at a sufficient pace to provide the resources required for chronic care, typically associated with NCDs. The transition has been evidenced by the increase of deaths from diabetes, chronic kidney disease and cancer especially of the prostate and cervix, and by the increasing proportion of disability-adjusted life years (DALYs) attributed to neuropsychiatric disorders such as anxiety, neurotic complaints and mood disorders (Mayosi *et al.*, 2009).

Studies have shown that non-communicable diseases accounted for 14 percent of the total deaths in SSA. The mortality rate of the adults under 60 was 29 percent compared to 13 percent in high-income countries (Unwin *et al.*, 2001). Data estimates have proven that the probability of death from NCDs prevalence is higher in SSA than in developed countries (Mayosi *et al.*, 2009; Unwin *et al.*, 2001). This has raised alarms in SSA and from 2009 approximately 89 percent of SSA countries are paying attention to NCDs by setting divisions in Ministries of Health that focus on action plans and functional programs (Kengne and Mayosi, 2014). In 2014, WHO performed surveys and found that only about 26 percent of the countries had a functional programme or an action plan (World Health Organization (WHO), 2014*a*).

It is of importance that policies be implemented to encourage better lifestyle and to control the rapid increase of NCDs, despite the fact that most SSA countries do not prioritise this (Hughes *et al.*, 2012). In 2007, \$21.8 billion was allocated by the

Global Fund for assistance in health and only three percent of that was dedicated to NCDs (Nugent and Feigl, 2010). Monitoring of NCDs should be encouraged because it was observed that these diseases have a negative impact on health systems because of increasing demand and escalating health care costs.Therefore, SSA countries need to improve their surveillance and monitoring of NCDs by implementation of population-wide interventions.

2.2.4 Selected diseases for this study

The diseases that will be used for the rest of the study where found to be the diseases that heavily burden (50 percent of the total DALYs in the region) and cause the highest mortality in SSA (55 percent of the total deaths in the region). The list of the diseases that will be considered further for this study are:

1. Lower respiratory infections
2. HIV/AIDS
3. Diarrhoeal diseases
4. Stroke
5. Ischaemic heart disease
6. Tuberculosis
7. Malaria
8. Congenital anomalies
9. Pre-term birth complications
10. Birth asphyxia and other infections
11. Neonatal sepsis

2.3 Conclusion: Sub-Sahara Africa Disease Landscape

This chapter broadly explored the DALY metric, the cost-effectiveness of health interventions, communicable diseases and non-communicable diseases. It also provided an overview of the SSA disease landscape based on the data recorded by the World Health Organisation for 2015. In Chapter 2 the top 10 causes of death and disease burden (in terms of DALY), according to the World Health Organization (WHO) (2016), were discussed in detail to give an idea of how they affect the SSA population. This information will be used to identify the diseases that should be prioritised and can benefit from new health intervention such as wearable technology.

CHAPTER 3

WEARABLE TECHNOLOGY LANDSCAPE

This chapter aims at providing the necessary knowledge and background pertaining to the status quo of the wearable technology landscape in healthcare. The overview of the wearable technology landscape includes the characteristics of the devices and the application areas. The technology maturity of the wearable devices will be assessed in detail. A portion of the research contained in this chapter was presented at the International Association for the Management of Technology's annual conference held in Vienna, Austria, in May 2017.

3.1 Background

Wearable technology (wearables) can be broadly defined as mobile electronic devices that can be worn extensively as an accessory or embedded in the user's clothing (Lam Po Tang, 2007; Mahoney and Mahoney, 2010; McCann and Bryson, 2009; Sultan, 2015). Stedmon (2016) provides the following description of wearable devices:

> *(...) this technology aims to bring computing power closer to the user so that, ultimately, they form one and the same system: physically and functionally. However, these are more than just portable computing systems,*

they offer the potential for fully integrated interfaces which aim to synthesise the user and task, through seamless interface technology, to new levels of operational capability.

The concept of wearable technology aims to bring computer power closer to the user with the intention of forming one and the same system, physically and functionally (Stedmon, 2016).

Claude Shannon and Edward Thorp at Massachusetts Institute of Technology (MIT) developed the first wearable computer in June 1961. This device predicted where the ball would end up on the roulette wheel (Thorp, 1998). Since this breakthrough, wearable devices have become more advanced and usable because of the development of mobile devices, sensor technology, battery technology as well as microelectronics. As a result, the increase of adoption as well as compliance of the user to wearable devices has led to the development of more devices. The devices that have been developed over the years include Mann's wearcam (Mann, 1997), Philips-Levi's industrial clothing design ICD + Jacket (Sheriff, 2000), smart tattoos (Heo and Takeuchi, 2013), Google Glass (Iltifat, 2014) and Pebble (Pebble, 2016).

Over the past decade, mobile technology has become a popular communication platform and it is expected to become even more so in the future. This is according to research conducted by the Connected Life Initiative sponsored by Groupe Speciale Mobile Association (GSMA). The Initiative established that in 2011, there were 6 billion mobile devices in use and estimated that by 2020, this figure will have increased to 12 billion (Connected Life Initiative, 2013). This increase in mobile devices usage has played an important role in the development of wearable devices (Patel *et al.*, 2012). Bass *et al.* (1997) predicted that with the decreasing size and increasing power of most of the modern computer components, it was a matter of time before computers could be worn on the body.

The miniaturisation of sensors and electronic circuits based on the use of microelectronics has also played a key role in the development of wearable systems. In the past, one of the hurdles of adopting sensing technology, especially for wearable applications, has been the size of the sensors and front-end electronics that were obstructive for long-term monitoring applications (Patel *et al.*, 2012). Recently in the field of micro-electronics, researchers have developed miniature circuits entailing sensing capability, front-end amplification, micro controller functions and radio transmission thereby making wearable devices non-invasive (Patel *et al.*, 2012).

3.1.1 Wearable technology characteristics

Despite the development of different wearable devices for different purposes, ranging from industrial to personal applications, they all share some common characteristics that allow for easy differentiation from other mobile devices. Rhodes (1997) proposed the following list of the main characteristics that wearable devices typically possess:

- Sensors – miniaturised computers and transmission embedded on objects that can be worn on the body. Sensors can be used for measuring temperature, heart rate, and blood glucose level.
- Continuous operation – constant interaction with the human recording, collecting and analysing data.
- Portable – easy to carry around and rechargeable batteries that allow several hours or more of operation without access to an external charger or power source
- Hands-free use – include the use of head-up displays, direct voice output and gesture recognition
- Proactive – the ability to convey data to its user even when it is not being actively used. The tasks that wearables usually perform are collection, recording and analysing.

The characteristics can be used by engineers to develop a design philosophy of wearables Stedmon (2016). The main distinguishable feature of wearable devices is that they are also designed to be usable at any time with the minimum amount of invasion of the user's primary task (Rhodes, 1997).

In this study these characteristics will be used as a guide to identify wearable devices that have been developed specifically for healthcare applications.

3.1.2 Types of wearable devices

A misconception is that wearable technology refers exclusively to wrist worn devices. The International Data Corporation (2016) reported that 78.1 million wearable device units were shipped in 2015 and that of those, 50.4 million units were smart watches. In reality, wearable technology comes in many forms that can be broadly classified as either portable or implantable devices as shown in 3.1 (Mann, 2014; Tehrani and Andrew, 2014).

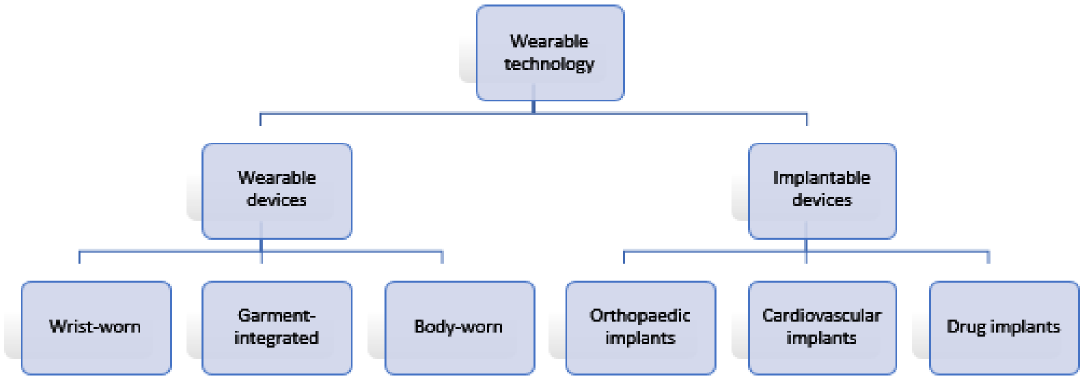

Figure 3.1: Types of wearable devices

These two categories of wearable devices will be discussed briefly in Section 3.1.2.1 and 3.1.2.2:

3.1.2.1 Portable devices

Portable devices are hand-held and can easily be carried around. These portable devices can be further classified into three classes as shown in Figure 1: wrist-worn, garment-integrated and body-worn (Patel *et al.*, 2010) .

Wrist-worn devices available on the market include wristbands, smart watches and jewellery. Some of the brands that are currently available for consumers include Fitbit, Apple, Jawbone, Pebble, Samsung and Sony.

Garment-integrated devices are embedded into a garment and are designed for constant wear. They only function when worn on the body (Barfield and Baird, 1998).

These devices are smart garments that incorporate textile based sensing and smart garment design (Dunne *et al.*, 2005). Currently, the garments that are available on the market include AiQ Smart Clothing (AiQ, 2016) and Athos Gear (Athos, 2017).

Body-worn devices are also designed to be constantly worn, but not in the form of traditional clothing. Instead they are strapped on or otherwise affixed to the body. Examples of the devices that have been developed include the BodyMedia SenseWear armband (Bodine and Gemperle, 2003).

3.1.2.2 Implantable devices

Implantable devices are devices used to replace or act as a fraction or the whole of the biological structure. Implantable devices have been developed for various applications such as orthopaedics, pacemakers, cardiovascular stents, defibrillators, neural prosthetics and drug delivery systems (Regar *et al.*, 2001). Implantable devices are further classified into cardiovascular implants, orthopaedic implants and drug implants (Khan *et al.*, 2014).

Cardiovascular implants are devices used for the treatment of heart diseases. These implants are divided into three further categories that are pacemakers, cardiac stents and related stents as well as structural cardiac implants (Khan *et al.*, 2014). Pacing devices are used for cardiac resynchronisation therapy. They also used as cardioverter-defibrillators. A cardiac stent is a small, expandable tube that treats narrowed arteries in the body and is inserted into the artery through an angioplasty procedure (Beckerman, 2016). Structural cardiac implants incorporate technological advances in heart valves, ventricular assist devices and implantable monitors (Khan *et al.*, 2014).

Orthopaedic implants are defined as medical devices used to replace or provide fixation of bone or to replace articulating surfaces of a joint (Rouhi and Amani, 2013). This category incorporates procedures such as knee replacements, hip replacements and spinal implants (Khan *et al.*, 2014).

Drug implants are utilised for drug delivery. These drug implants allow site specific drug administration where the drug is needed the most (Arps, 2013). Examples include histreline implants for palliative treatment of prostate cancer and uterine fibroids (Hirsch *et al.*, 2005).

3.2 Methodology: identifying wearable technology devices

In order to investigate the current wearable technology landscape a review was conducted that was limited to devices that are currently on the market and underdevelopment. On completion of the review, information regarding the various wearable devices, based on the prominent categories from the structured review, was gathered by means of internet sources such as web-pages and articles. The devices that were investigated in detail are listed in Table B.7.

In this study, 62 wearable devices have been reviewed from internet sources excluding journals Appendix B Table B.7. The aim of this study is to review devices that are currently commercially available and at the latter stages of development. The detailed information on these devices is provided on the product's company web pages. All the devices that were reviewed were portable devices as described in Section 3.1.2.1. The key enabling technologies of the wearables devices were identified and the applications.

3.3 Methodology: Identify wearable technology characteristics

Because of the different wearable devices that are being produced they possess a wide range of characteristics. In order to achieve the second research objective in Section 1.2.1 a structured literature review was performed in order to determine the different features or characteristics that can be used to describe the wearable technology landscape.

A structured search of the electronic database, Scopus, was conducted to identify the relevant articles in the wearable technology landscape. The search terms used were related to the characteristics or features of wearable technology in healthcare. These were the search terms used: (health* AND technolog* AND wearable AND characteristic*) OR (health* AND technolog* AND wearable AND feature*)). The relevant articles searched dated from 2006 to 2017 with no language restriction. Manual searches were conducted on references to obtain additional relevant studies.

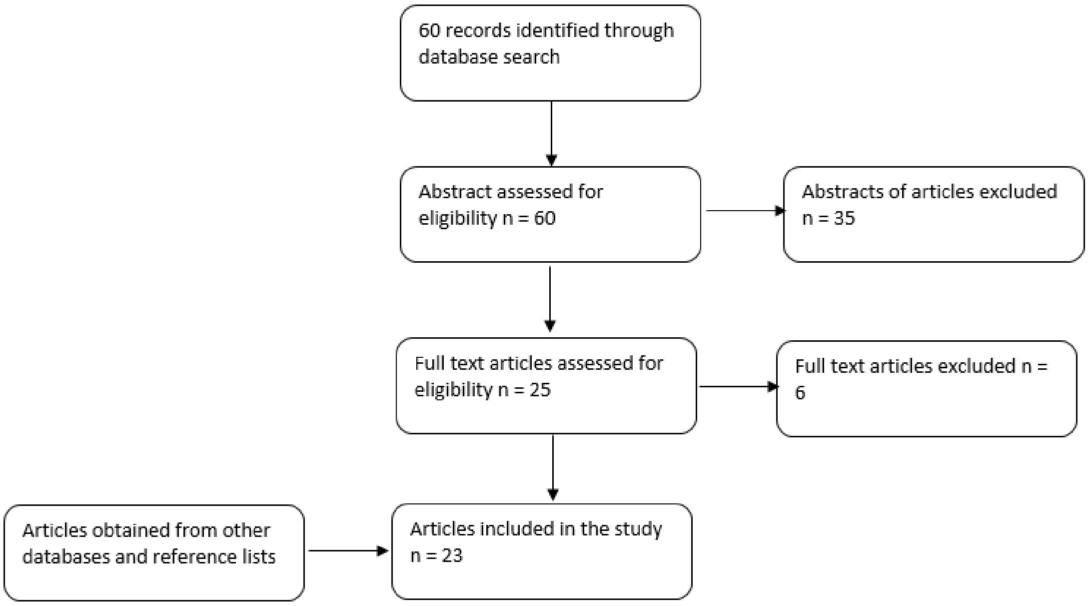

Figure 3.2: Schematic representation of the systematic review process

The first stage for checking the results of a search includes assessing the titles, abstracts and keywords to determine whether each article meets the pre-determined eligibility criteria. The pre-determined eligibility criteria included studies that considered:: i) characteristics of wearable devices, ii) applications of wearable devices and iii) technologies incorporated in wearable devices. Table B.1 in Appendix B gives the studies that were reviewed and motivates the reasons for inclusion or exclusion. When the screening process was completed, the full text of the selected citations considered for the review were further assessed . The information gathered from the relevant articles are presented in Table B.2, Table B.3, Table B.4, Table B.5 and Table B.6.

From the search terms 60 of the most cited articles were reviewed. After that, their abstracts were assessed in order to determine which articles were relevant for the study. From this exercise 25 articles were identified. As indicated in Figure 3.2 the full texts of the 25 articles that were selected were reviewed for eligibility. Six of the articles were excluded because:

(i) articles unavailable;

(ii) repeated articles;

(iii) articles not in English; and

(iv) not relevant to the study.

After reviewing the 19 articles, four additional articles were extracted from the reference lists of all the included studies. From the 23 articles the prominent characteristics or features that were identified were grouped together to form categories such as: i) sensing technology, ii) information and communication technology, and iii) healthcare services.

3.4 Key enabling technologies

The success of wearable technology relies entirely on several key enabling technologies. Without these technologies, it would be impossible to achieve the usability, connectivity and capabilities required for applications such as remote monitoring of chronic conditions. Based on the structured review described in Section 3.3 the key enabling technologies that are used in wearable systems typically include:

(i)z Sensing technology, and

(ii)z Information and Communication Technology

3.4.1 Sensing technology

From the findings of the structured review, the sensing technologies were subdivided into i) hardware description, ii) physiological signals or vital signs and iii) diseases and conditions monitored by wearable devices. These categories indicate the sensors and their relevance in wearable technology.

Sensors are usually embedded in clothing or worn as an accessory on the body (Lukowicz *et al.*, 2004). They measure physiological signs such as: blood pressure, body or skin temperature, respiration rate, oxygen saturation, heart rate, blood glucose levels and body motion. These vital signs are used to determine the health status of a patient and can be further analysed to identify the disease or condition affecting a patient.

Wearable technology allows sensors that will be positioned on the user for prolonged periods. Wearables consist of multiple miniaturised, smart, non-invasive and self-powered sensor devices that can be attached, or even implanted into, humans to monitor their physiological, body motion and behavioural parameters (Alam and Hamida, 2014; Banos *et al.*, 2014; Khattak *et al.*, 2011; Pantelopoulos and Bourbakis, 2010; Tao *et al.*, 2012).

3.4.1.1 Sensor hardware

Micro-Electro-Mechanical Systems (MEMS) technology has enabled the development of miniaturised inertial sensors that have been used in motor activity and other health status monitoring systems. By using batch fabrication techniques, significant reduction in the size and cost of sensors has been achieved (Patel *et al.*, 2012). Microelectronics has also been relied upon to integrate other components, such as microprocessors and radio communication circuits, into a single integrated circuit thus resulting in System-on-Chip implementations(Brand, 2006). A system-on-chip is "*a microchip with all the necessary electronic circuits and parts for a given system, such as a wearable device, on a single integrated circuit*"(Flynn and Luk, 2011).

Micro-controller boards are used in wearable systems for data collection and are usually based on wired transmission of biosignals from the sensors to the processing board (Pantelopoulos and Bourbakis, 2010). In order for sensors to work effectively, microcontrollers should incorporate the following vital capabilities (Niewolny, 2013):

(i) Low-power operation – this is essential because it allows the extension of battery life and keeps the device footprint small. Wearable devices should be able to operate maintenance-free for long periods of time. Some devices are being designed with the intention of having battery-free operation by means of energy harvesting methods (through body heat or motion) through the utilisation of ultra-low-power DC-DC converters. Low power operation can be achieved by improvements in battery technology, power scavenging techniques and low-power transceivers (Pantelopoulos and Bourbakis, 2010).

(ii) Integrated precision-analogue capabilities – these make it possible for sensors to achieve high accuracy at low costs.

(iii) Graphical user interfaces (GUIs) – GUIs improve the usability by allowing display devices to convey vast amounts of information in clear detail and give easy access to information.

From the structured review, the sensors in Table B.2 were summarised in Table 3.1 with their respective measurable.

Table 3.1: Sensors and their respective measurable

Type of Sensor	**Measurable**	**Description of measured data**
Skin or chest electrodes	Electrocardiogram (ECG)	Electrical activity of the heart
Arm cuff-based monitor or Blood pressure sensor	Blood pressure	Focuses on the force exerted by circulating blood on the walls of blood vessels, especially the arteries.
Temperature probe or skin patch or skin temperature sensor or thermistors	Body or skin temperature	A measure of the body's capability to generate and release heat
Piezoelectric or piezoresistive sensor or pressure sensor or Respiratory meter	Respiration rate	Number of movements indicative of inspiration and expiration per unit time
Pulse oximeter	Oxygen saturation	Indicates the oxygenation or the amount of oxygen that is being 'carried' in a patient's blood.
Pulse oximeter or skin electrodes	Heart rate	Frequency of the cardiac cycle
Galvanic skin response or Skin electrical conductivity, Thermal conductivity sensor	Perspiration or skin conductivity	Electrical conductance of the skin is associated with the activity of the sweat glands
Phonocardiograph	Heart sounds	A record of heart sounds, produced by a microphone (stethoscope) properly placed on the chest.
Strip-base glucose meters	Blood glucose	Measurement of the amount of glucose in blood.

Continued on next page

Table 3.1 – *Continued from previous page*

Type of Sensor	**Measurable**	**Description of measured data**
Enzyme electrodes	Blood glucose	Use of glucose oxidase immobilised on a gel to measure the concentration of glucose in biological solutions and in the tissues in vitro
Skin electrodes	Electromyogram (EMG)	Electrical activity of the skeletal muscles
Scalp placed electrodes	Electroencephalogram (EEG)	Measurement of electrical spontaneous brain activity and other potentials
Accelerometer	Body Movements	Measurement of acceleration along its sensitive axis
Gyroscope	Angular velocity	Measure of the radial motion
Magnetoresistive	Static and dynamic magnetic fields	Measurement of motion and posture of the human segment in gait analysis by measuring gait analysis
Flexible goniometer	Angular measurement of the human joint	Measurement of the range of motion in the range of motion in bending the arm at the elbow, bending the knee, bending at the waist.
Piezoelectric sensors	Force	Based on the piezoelectric effect which generates electric charge when stressed
Electric field sensor	Electric conductivity	Proximity sensing that allows robots and computers to detect, evaluate and work with objects in their vicinity
Force sensors or force sensitive resistors	Force	Based on the variation of conductivity of the sensor itself.
Capacitative sensors	Body pressure	Measured by the changes in capacitance in the function of the applied force

Figure 3.3 illustrates different types of sensors that are found in wearable devices. Sixteen different sensors were identified during the investigation. From the results, there are four dominant sensors that are being used in wearable technology for healthcare:

- Accelerometers (used in 18 of the 62 reviewed devices). Accelerometers are popular because they measure and assess physical activity in tracking devices (Yang and Hsu, 2010). Tracking devices are the most popular wearable devices that have been developed to date (Crawford *et al.*, 2015). Accelerometers can also be used to detect the user's respiratory and snoring characteristics that can be utilised to diagnose sleep apnoea (Kawada *et al.*, 2008);

- Electrocardiographs electrodes (used in 15 of the 62 reviewed devices).ECG electrodes records electrical signals generated by the heart and can be used to diagnose heart attacks, ischaemia and abnormalities to the user's heart (Maric *et al.*, 2009) ;

- Photoplethysmography (PPG) (used in 12 of the 62 reviewed devices).PPG sensors allow the user to measure their heart rate in real time using optical sensing technology (Ozana *et al.*, 2015). Usually, PPGs are found wrist worn fitness trackers (FitBit, 2017; Jawbone, 2017); and

- Thermometers (used in 8 of the 62 reviewed devices). The thermometer is used to measure the skin temperature of the user. Skin temperature fluctuations can be used to determine the health status of the user. For example, an increase of one or more degrees Celsius above the normal temperature could indicate the presence of infectious diseases (Görges *et al.*, 2017).

Other sensors that have been utilised in wearable technology include global positioning system (GPS), respirometers, EEG (used to evaluate electrical activity in the brain and diagnose conditions such as seizures, stroke and dementia), biosensors, glucometers, pressure sensors as well as pedometers. The analysis also revealed that most wearable devices have multiple sensors. They therefore, have the ability to record, collect and analyse multiple vital signs.

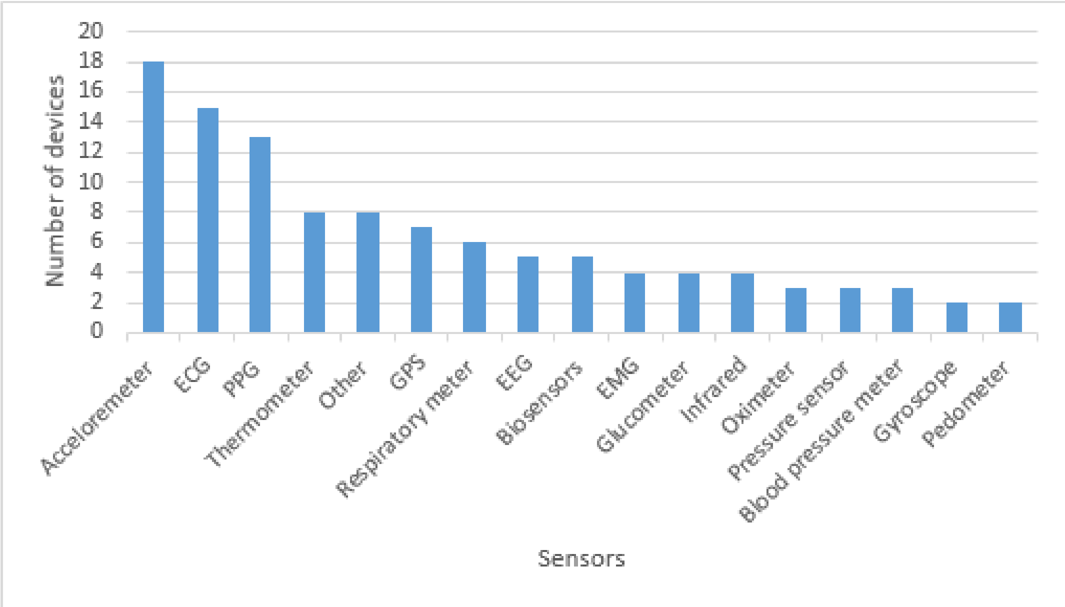

Figure 3.3: Sensors utilised in the 62 wearable devices included in this review

3.4.1.2 Wearable devices measurable

The measurement of these vital biosignals, leads to a collection of real-time gathered physiological parameters which give an overall indication of the user's health condition at any given time. The data collected by wearable devices is important because it can be used to determine the health status of the user. The data that can be collected by wearable devices can be subdivided into: physiological data, behavioural data and body motion data (Alam and Hamida, 2014; Banos *et al.*, 2014; Patel *et al.*, 2012).

Physiological data: According to the British Department of Health, the term physiological measurement reflects on services that can be used to assess the function of major organ systems (Department of Health, 2007). In wearable technology, physiological data that can be assessed includes: blood pressure, heart rate, oxygen saturation, glucose levels, electrocardiogram, skin or body temperature and respiration rate. Some of the physiological data that are collected by wearable devices are listed in Table 3.1.

The devices that can collect physiological data can be designed to enable easy integration into the clinical work-flows of healthcare professionals. The data monitored is usually focused on clinical parameters related to a patient's clinical condition regarding chronic diseases such as cardiovascular diseases and diabetes making remote monitoring possible.

Behavioural data: The data collected from wearable devices include information about an individual's activity, type of activity, walking or climbing stairs and patterns of activity. The activity data can be used for early detection and better understanding of patient conditions such as motor problems in Parkinson disease (Butala *et al.*, 2012; Patel *et al.*, 2010; Salarian *et al.*, 2007), patients with bipolar disorder (Naslund *et al.*, 2015), posture and gait problems (Pappas *et al.*, 2004; Shull *et al.*, 2014) in the elderly population that can be used to assess risk for falls and activity of the daily living assessment using related indicators.

The devices that are available at the moment provide valuable information regarding the individual's behaviour and when linked to the GPS and self-reporting tools on the wearables. They can help detect and alert early detection of some risks (Patel *et al.*, 2012). Some of the devices that are being developed can be used for tracking patients with dementia and include an emergency button in case of a fall detection (Mahoney and Mahoney, 2010).

Recently, the technologies developed can detect psychological stress and poor sleep quality of a person may serve as indicators for predicting the onset of mental health problems such as depression and/or anxiety (Swan, 2012).

Body motion data: Body motion data can be used to study human locomotion (Tao *et al.*, 2012). Locomotion is the study of the variety of movements or methods that animals use to move from one place to another. Because of advances in technology, the measuring of human movement has been made possible using wearable devices. The data that is collected by wearable devices include (Alam and Hamida, 2014):

(i) body posture and orientation;

(ii) activity;

(iii) fall;

(iv) mobility;

(v) acceleration; and

(vi) limb movement.

These measurements can be used for gait analysis (Shull *et al.*, 2014; Tao *et al.*, 2012), early fall detection (Patel *et al.*, 2012; Tolkiehn *et al.*, 2011*b*; Zhang and Sawchuk, 2012) and early disease diagnosis (Shull *et al.*, 2014).

As shown in Figure 3.4 the main vital signs that are measured by the 62 wearable devices are heart rate (22 devices), skin temperature (10 devices), motion (10 devices) and breathing rate (8 devices). These physiological signs can be used by clinicians to determine the complications that a user could have developed during long-term monitoring (Lukowicz *et al.*, 2004). Cardiovascular diseases are some of the complications that can be monitored using the heart rate and heart electrical activity wearables.

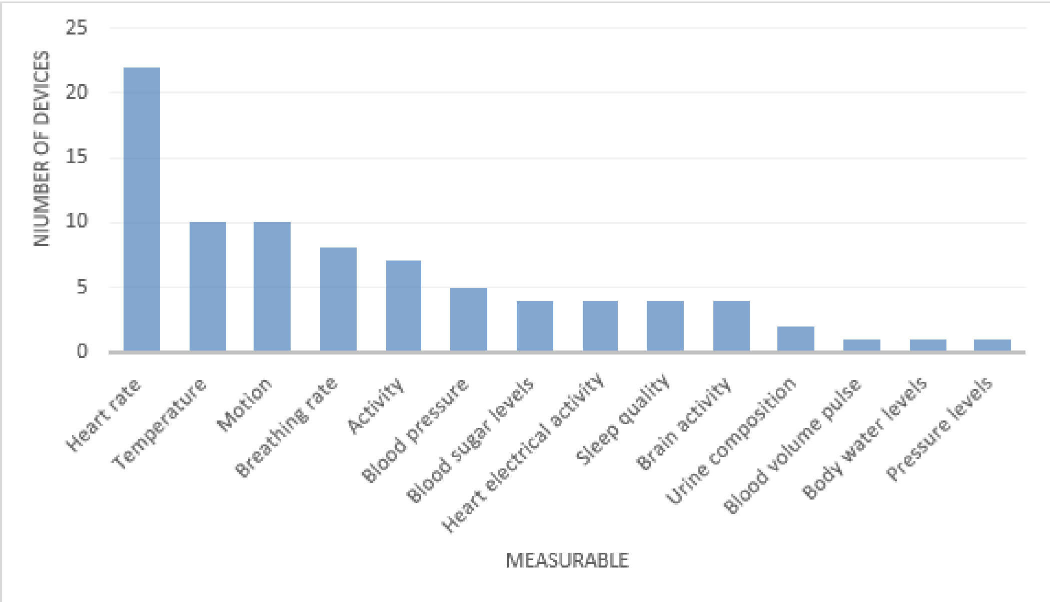

Figure 3.4: The different measurable measured by the 62 wearable devices included in this study

3.4.1.3 Disease or condition monitored by wearables

Currently, there are various diseases that can be monitored, diagnosed or treated using wearable devices. With the assistance of multi-physiological signs, mentioned previously, different diseases can be managed. These include:

- Cardiovascular disease is a heart disease that can be diagnosed using wearable devices that can remotely monitor and analyse ECG patterns (Grange *et al.*, 2009; Maric *et al.*, 2009). The diseases that are classified under cardiovascular diseases include: angina, atherosclerosis, cardiac dysrhythmia, congestive heart failure, coronary artery disease, heart attack and tachycardia (Chan *et al.*, 2012).

- Diabetes mellitus is a disorder of glucose metabolism. Patients suffering from this condition require continuous blood glucose level monitoring and correct administration of insulin to prevent hypoglycaemic complications (Hettige and Cooper, 2017). A device can be designed to manage and monitor glucose levels and the infusion of insulin (Gomez *et al.*, 2008).

- Respiratory diseases include diseases such as dyspnoea, sleep apnoea syndrome, chronic obstructive pulmonary disease and asthma can be monitored for early detection of symptoms or administration of treatments (Okubo *et al.*, 2009). ADAMM is a wearable device used for asthma symptom detection by monitoring the cough, respiration rate, wheeze and heart rate (Health Care Originals, 2016).

Parkinson's disease, renal diseases and stress are amongst other conditions that can be monitored by wearable devices. Monitoring of diseases using wearable devices improves healthcare in a cost-efficient manner and gives patients easy access to clinicians.

Figure 3.5 illustrates the different diseases that are monitored by the devices that were reviewed in this study. The most prominent diseases or conditions that are monitored by wearable devices are cardiovascular diseases. There are 29 wearable devices which are used to monitor cardiovascular diseases. Metabolic syndromes (monitored using 12 wearable devices) are a risk factor for cardiovascular diseases and diabetes. Diabetes and infectious diseases are each monitored by 7 wearable devices.

Most of the devices that are currently on the market are used to either prevent, treat or diagnose chronic conditions such as cardiovascular diseases, metabolic syndrome, diabetes, chronic pain, muscle disorder as well as respiratory conditions such as asthma (Fafoutis *et al.*, 2016). This observation is also supported by the results of this review, displayed in Figure 3.5.

Some of the devices that have been included in this review of wearable technology for healthcare applications are not designed to address specific diseases or conditions and have therefore been excluded from Figure 3.5. Examples include devices that have been designed to assist in rehabilitation (2 devices), posture and balance (3 devices), and specialised care for disabled and elderly individuals (6 devices).

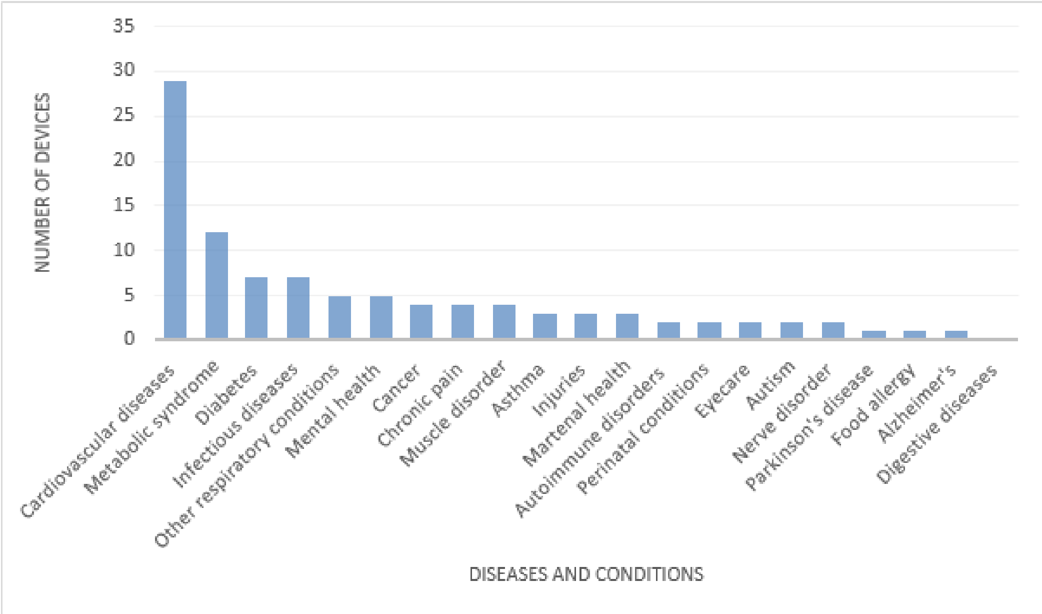

Figure 3.5: Diseases and conditions utilised in the 62 wearable devices included in this study

3.4.2 Information and communication technology (ICT)

The term 'information and communication technology' (ICT) is generally used to refer to all devices, networking components, applications and systems that combined allow people and organisations (for example businesses, non-profit agencies, governments and criminal enterprises) to interact in the digital world. Therefore based on this broad definition, ICT was categorised as shown in Figure 3.6. The different categories were:

1. Data communication
    - Communication Devices
    - Data Transfer including wired and wireless connections
2. Data Handling
    - Storage and computation
    - Data analysis
    - Data encryption and security

The last category includes the healthcare services provided by manufacturers of wearable devices through the stages of care and intended user.

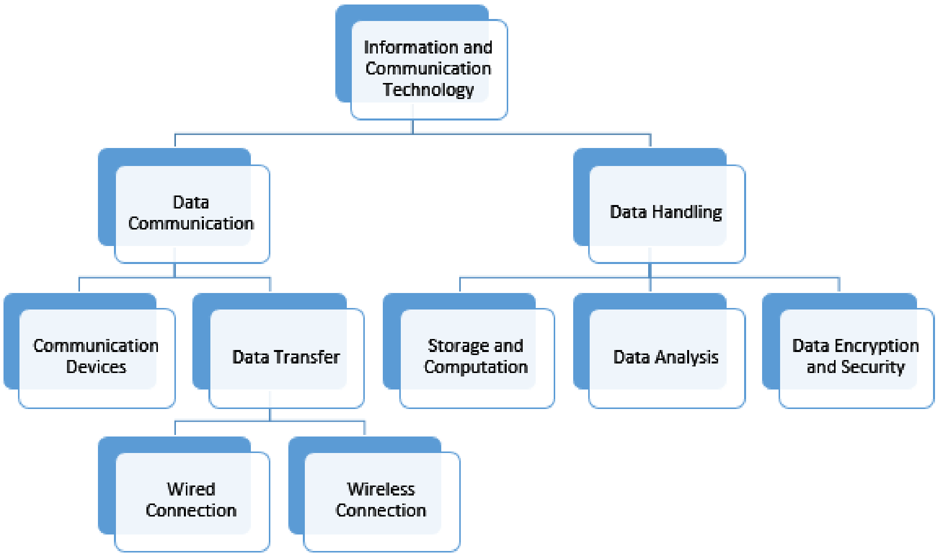

Figure 3.6: Schematic representation of information and communication technology

Communication hardware and software in wearable technology play a vital role in relaying data collected by sensors to a mobile phone or an access point (Patel *et al.*, 2012).

3.4.2.1 Data communication

This study introduces a brief description of the different communication software and hardware found in wearable technology.

Communication Devices: Khattak *et al.* (2011) suggested that wearable devices are designed in such a way that allows easy communication between them and mobile devices such as PDA, smartphones or tablets. In other instances, the data is directly transferred to laptops or computers as well (Butala *et al.*, 2012). Research (Banos *et al.*, 2014) has shown that these communication devices can typically be used in wearable technology to :

(i) run an application that can be used as a data collector (Hu *et al.*, 2008; Liu and Xiao, 2011);

(ii) support a system for medical diagnosis and health alerts;

(iii) interface with user data inspection;

(iv) act as a gateway to forward the data to a remote storage device for further analysis;

(v) access data processing and analysis capabilities (Butala *et al.*, 2012); and

(vi) transmit using data logging and sending commands (Patel *et al.*, 2012).

Gateways are the information centres that collect sensor data, analyse it and then transfer it to the cloud via wide area network (WAN) technologies (Niewolny, 2013). Gateways can be designed to be applied in clinical or home settings. This is the platform that is mainly utilised by wearable devices that require remote access of patients that require remote monitoring in healthcare (Patel *et al.*, 2010). For example, the data transmitted from sensors can be sent to gateways such as mobile phones or personal computers (PCs).

Figure 3.7 shows the communication devices that are used to relay information from the wearable devices to servers. The gateways that were identified from the investigation were smartphones (used by 39 of the devices), PCs or laptops (used by 18 of the device), monitors (used by 12 of the devices) and smartwatches (used by 3 of the devices). 14 of the devices reviewed incorporated more than one gateway.

The incorporation of smartphones into wearable systems reduces cost because there is no need to develop specific additional devices (Morón *et al.*, 2014). Smartphones are characterised by an integration of all the necessary technologies in an mHealth system. These special capabilities smartphones have powerful processors, large memory capacity, multiple network interfaces such as Bluetooth, Wi-Fi and mobile communication, relatively low cost, etc. (Patrick *et al.*, 2008).

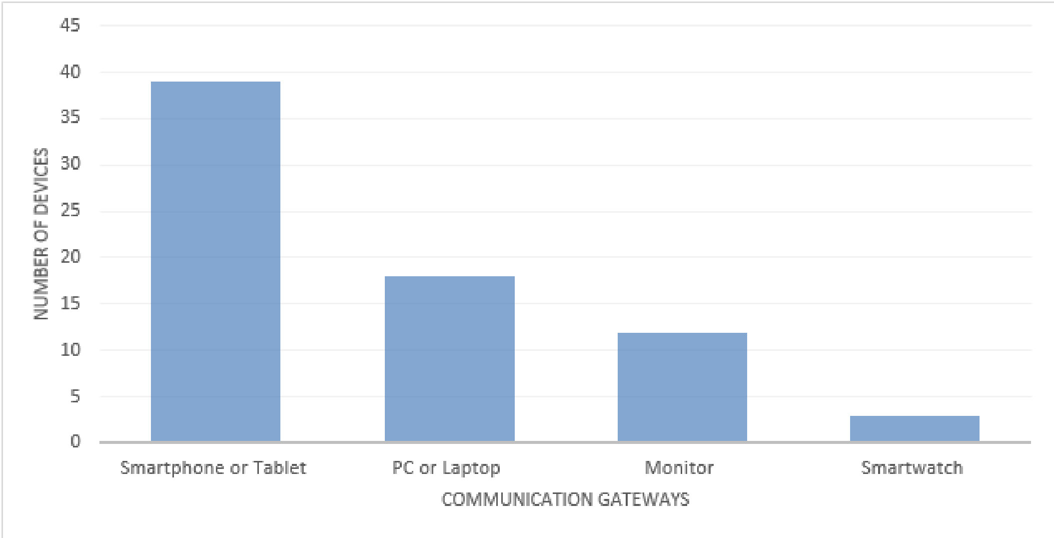

Figure 3.7: Communication devices utilised in the 62 wearable devices included in this study

Data Transfer The transmission of measured data in a wearable system needs to be performed for two different purposes:

(i) for communicating the collected physiological signals from the sensors to the system's central node; and

(ii) for sending the aggregated measurements from the wearable system to a remote medical station or to a physician's smart phone.

In wearable technology, short-range transmission can be handled either by wires or by multiple wireless links such as body area network (BAN) or body sensor network (BSN). Long-range communication between the wearable device and a remote station is made possible by wireless technologies that can serve that goal. Examples are:

(i) Sensor network systems

Because of the development of wireless connections, wired systems are gradually being replaced in sensor technology. The viability of wireless connection in sensor network systems was proved and tested by Chae *et al.* (2012). Two different wireless sensor networks that relay the information collected by the sensor to the device are BAN or BSN and personal area network (PAN). BAN is worn or implanted on the body of the user and this network comprises wearable sensors and a personal digital assistant (PDA) as a wearable device (Chan *et al.*, 2012).

BAN can then connect to a PAN, providing a connection to the other devices the user will have in their immediate environment. The short range connections that are mostly employed in BANs are IEEE 802.15.1(Bluetooth), Bluetooth Low Energy (BLE) and 802.15.4 (Zigbee) (Alam and Hamida, 2014; Pantelopoulos and Bourbakis, 2010). Examples of the other devices the user can typically have are: smartphones, a pocket PC and environment sensors (Pantelopoulos and Bourbakis, 2010).

(ii) Wireless networking

Wireless networking removes the physical restrictions caused by traditional wired solutions such as Ethernet and USB (Nsoesie *et al.*, 2015). Technologies that are currently being used are wireless local area network (WLAN), global system for mobile communications (GSM), universal mobile telecommunications system (UMTS) and worldwide interoperability for microwave access (WiMAX). There are also Broadband cellular networks such as (GSM, General Packet Radio Service (GPRS), 3G or 4G, LTE, etc.). The popular wireless standards include Bluetooth® and Bluetooth Low Energy (BLE) for personal area networks (PAN) and Wi-Fi® and Bluetooth for local area networks (LAN) in clinics or hospitals (Niewolny, 2013; Patel *et al.*, 2012). Use is also made of mobile network GSM and GPS for wireless networking (Niewolny, 2013).

Table 3.2: Long range transmission

Transmission Type	**Description**
WLAN	Wireless network communication over short distances using radio or infrared signals instead of traditional network cabling. A WLAN is a type of local area network (LAN).
GSM	Mobile communications

Continued on next page

Table 3.2 – *Continued from previous page*

Transmission Type	Description
GPRS	Packet oriented mobile data service on the 2G and 3G cellular communication system's global system for mobile communications (GSM).
UMTS	A third-generation (3G) broadband, packet-based transmission of text, digitised voice, video, and multimedia at data rates up to 2 megabits per second (Mbps). UMTS offers a consistent set of services to mobile computer and phone users, no matter where they are located in the world.
WiMAX	A wireless industry coalition dedicated to the advancement of IEEE 802.16 standards for broadband wireless access (BWA) networks.
4G or 3G mobile communication	As 'ultra-broadband' access for mobile devices
Long term evolution (LTE)	Wireless broadband technology designed to support roaming Internet access via cell phones and handheld devices.
Wi-Fi	Technology for wireless local area networking with devices based on the IEEE 802.11 standards.

Table 3.3: Short range transmission

Transmission Type	Description
Bluetooth	Wireless technology standard for exchanging data over short distances from fixed and mobile devices, and building personal area networks.
Bluetooth Low Energy	The power version of Bluetooth that was built for the Internet of Things (IoT).
Zigbee	An IEEE 802.15.4-based specification for a suite of high-level communication protocols used to create personal area networks with small, low-power digital radios, such as for home automation, medical device data collection, and other low-power low-bandwidth needs, designed for small-scale projects which need wireless connection.
Infra-red	Is the use of wireless technology in devices or systems that convey data through infrared (IR) radiation. Infrared is electromagnetic energy at a wavelength or wavelengths somewhat longer than those of red light.

Continued on next page

Table 3.3 – *Continued from previous page*

Transmission Type	Description
Medical Implant Communication Service	Low-power, short-range (2 m), high-data-rate, 401–406 MHz (the core band is 402–405 MHz) communication network that has been accepted worldwide for transmitting data to support the diagnostic or therapeutic functions associated with medical implant devices.
Ultra wideband	A radio technology that can use a very low energy level for short-range, high-bandwidth communications over a large portion of the radio spectrum.

Currently, most wearable devices use Bluetooth Low Energy (BLE) which allows the transfer of large amounts of data. One of the limitations of using BLE is the limited range it covers. This is because the device needs to be tethered to a mobile phone at a close range. Some wearable devices, such as Google glass, use Wi-Fi which is easy to access when in a Wi-Fi hotspot. Otherwise, Google glass uses mobile connection when the user is not in a Wi-Fi hotspot (Iltifat, 2014). There are also devices that are designed to operate using BLE and Wi-Fi connections, for instance an Apple iWatch.

Figure 3.8 illustrates the network connections that are used to transfer data from the device to the gateways. The data can be relayed using USB connections, Wi-Fi, mobile connections (GSM), GPS, Ethernet and Bluetooth. As shown in Figure 3.8, most of the wearable devices have wireless connections: 29 wearable devices use Wi-Fi connections, 28 use Bluetooth connection, 10 use mobile connections and seven devices utilise GPS connections.

Devices that use Bluetooth require the receiving device to be in close proximity (approximately 5 to 30 metres). FitBit Charge2 and Jawbone UP are examples of devices that utilise Bluetooth to transfer data from the sensor to a smartphone (Lee *et al.*, 2016; Soultanopoulos *et al.*, 2016). Wi-Fi connections range from 32 to 95 metres and are the preferred choice for remote monitoring systems (Maric *et al.*, 2009; Patel *et al.*, 2012). Therefore, the type of connectivity required is dependent on the application area of the device in healthcare.

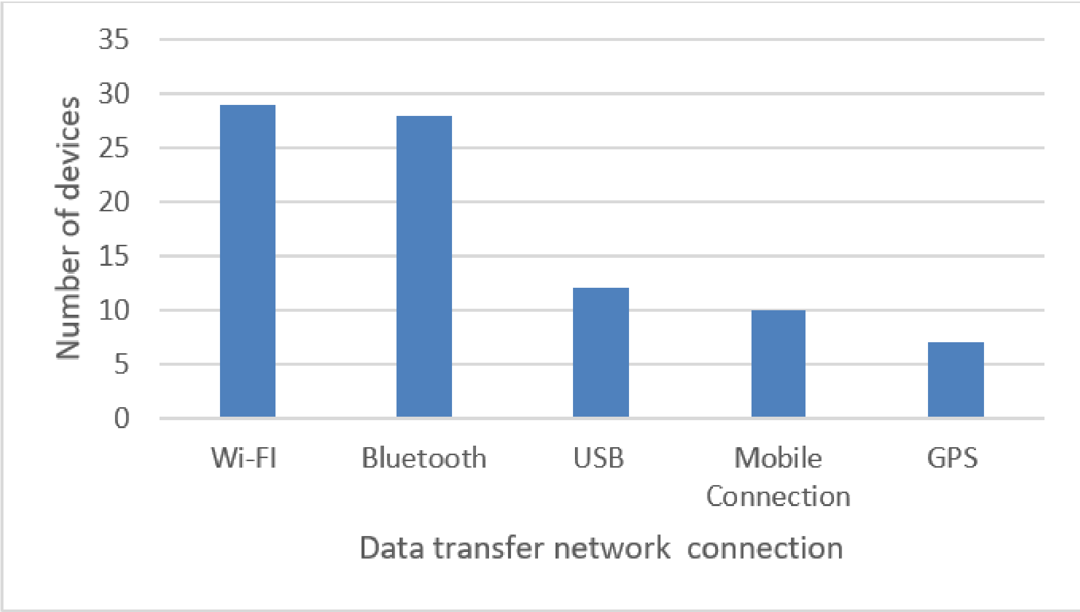

Figure 3.8: Data transfer methods utilised in the 62 wearable devices included in this study

3.4.2.2 Data handling

Storage and computation: The data collected by wearable devices is transferred to several systems such as smartphones, computers and servers or cloud services (de Arriba-Perez *et al.*, 2016). These systems can be divided into two different categories, namely (Pantelopoulos and Bourbakis, 2010):

- Proprietary systems – these can be found as wearable devices, applications for smartphones and computers and servers or cloud services. They are provided and maintained by vendors of wearables to collect users' data to perform analytics and to provide data and analytic results to the users and to authorised third parties (de Arriba-Perez *et al.*, 2016). Proprietary systems usually provide a Representational State Transfer Application Programming Interface (REST API) for data collection. This REST API allows third parties to gain access to users' data collected by a proprietary system (de Arriba-Perez *et al.*, 2016). Examples of devices that have proprietary systems are the Jawbone UP Move and the Microsoft Band.

- Third-party systems – include services, applications (apps) for smartphones and wearables, and computer programs that can be developed as well as maintained by external entities to provide specific functionalities. An example of a device with a third party system is a Galaxy Gear which allows external entities to collect data from the sHealth application (de Arriba-Perez *et al.*, 2016). Third party applications that utilise existing platforms such as Strava which enable the connectivity of people of from different parts of the world and can share their information about their fitness lifestyle (Strava).

The data collected can be transferred and stored on the cloud. Al-Qurishi *et al.* (2015) suggested that the advantage of cloud-based systems is their capability to increase access to healthcare services in rural areas. Furthermore, the user's data can be easily updated in the databases without requiring that the patient install any software on their personal monitoring device. These advantages make the system maintenance quick and cost effective.

In the operation of wearable technology there are different mobile operating systems that they are compatible with. These systems combine the different features a wearable device or a smartphone can possess. The common features in mobile operating systems are cameras, Bluetooth, GPS and Wi-Fi.

The mobile operating systems that are utilised in the wearable devices for healthcare applications are shown in Figure 3.9. The Apple iOS mobile operating system is compatible with 26 of the 62 wearable devices reviewed, Android with 21 of the devices, Windows with 16 of the devices and the OSX operating system with 4 of the devices. Furthermore, 15 of the wearable devices are compatible with both Android and iOS systems.

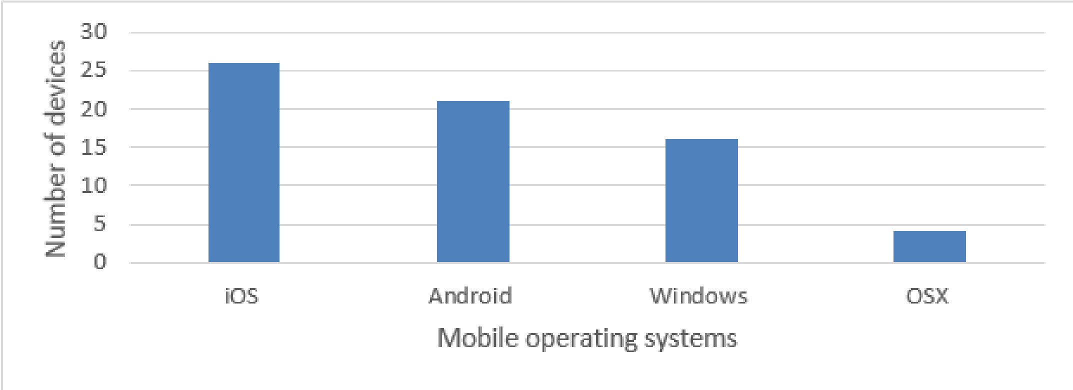

Figure 3.9: Mobile operating systems utilised in the 62 wearable devices included in this study

Data Analysis Techniques: From the structured review a number of data analysis techniques were identified. The techniques that were identified include:

1. nearest neighbour (Chan *et al.*, 2009).
2. signal processing (Chan *et al.*, 2009; Hu *et al.*, 2008; Lukowicz *et al.*, 2004; Patel *et al.*, 2012; Tao *et al.*, 2012).
3. integrated analysis support for making decisions and diagnosis.
4. decision support system (Pantelopoulos and Bourbakis, 2010).
5. extraction and classification techniques (Banos *et al.*, 2014; Egbogah and Fapojuwo, 2011; Hu *et al.*, 2008).
6. image processing (Hu *et al.*, 2008).
7. pattern recognition (Hu *et al.*, 2008; Khattak *et al.*, 2011; Patel *et al.*, 2012; Segerståhl and Oinas-Kukkonen, 2011).

Recently, wearable devices have advanced from simple reasoning readings (such as calculating sleep hours or steps per day) to the higher level of data processing, in order to give much more information that is valuable to end users. In wearable technology, the main application for data analysis is remote monitoring of a patient using techniques such as prediction and anomaly detection. Also in clinical settings, the data mining task focuses on diagnosis (Baig and Gholamhosseini, 2013; Stacey and McGregor, 2007). Data analysis supports real-time decision making that can be useful to the intended user(s) (Patel *et al.*, 2012). An example of a data analysis technique typically used for remote monitoring is data mining (de Arriba-Perez *et al.*, 2016) .

Data mining (also known as knowledge discovery) is the process of discovering interesting knowledge such as patterns, associations, changes, anomalies and significant structures from large amounts of data stored in the database or other information repositories. It is a multi-disciplinary field, borrowing and enhancing ideas from diverse areas such as machine learning, signal and image processing, image understanding[1] and pattern recognition (Han *et al.*, 2012). For example, machine learning can be used to detect soft falls based on pattern recognition (Genoud *et al.*, 2016).

Data encryption and security Wearable technologies are expected to deal with essential private information such as personal healthcare data. These devices can subsequently be connected to global information networks for their access anytime, anywhere.

The security requirements for wearable technology that were gathered from the structured review include (Riazul Islam *et al.*, 2015):

1. Confidentiality – This ensures the inaccessibility of medical information for unauthorised users.

2. Integrity – Ensures that received medical data are not altered in transit by an adversary. In addition to that, the integrity of stored data and content should not be compromised.

3. Authentication – This enables the wearable device to ensure the identity of the user with which it is communicating.

4. Availability – This ensures the survivability of wearable technology services (either local or global/cloud services) to authorised parties when needed even under denial-of-service attacks.

[1] Image understanding is the task-oriented reconstruction and interpretation of a real world scenario by means of images.

5. Data freshness – This ensures that each data set that is collected by a wearable device is recent and makes sure that no adversary replays old messages.

6. Authorisation – This ensures that only authorised nodes can access network services and resources.

7. Fault tolerance – A security scheme should continue to provide respective security services even in the presence of a fault, for instance a software glitch, a device compromise and a device failure.

8. Self-healing – A wearable device in a system may fail or run out of energy. Then remaining or collaborating devices should enable a minimum level of security.

9. Encryption – This ensures the conversion of information or data into a code, especially to prevent unauthorised access (Pantelopoulos and Bourbakis, 2010).

3.5 Wearable technology in healthcare

Over the past several decades, the impact of mHealth systems in improving access to primary, secondary and tertiary healthcare services has been demonstrated (Connected Life Initiative 2013). Its importance is mainly noticed in the management of chronically ill and elderly people who require continuous monitoring of human vital signs (Awad *et al.*, 2017). The South African Department of Health define mHealth as:

> *"Mobile computing, medical sensor and communication technologies used for the delivery of health related services in the support of medical and public health" National Department of Health (2015).*

In 2003 mHealth was first introduced, in response to the expansion of mobile communication technology (Istepanian, 2011). The growth in mobile applications designed to monitor or improve users' health and well-being allowed the expansion in m-health. An important feature of m-health is the person-centred nature and ubiquity enabled by mobile phone technology and connection to the Internet (as a Personal Area Network (PAN)) (Bashshur *et al.*, 2011).

The only health domain that focuses on mobility technology and sophisticated technologies that involve transmission, storage and receipt of voice, still images, data, and video is mHealth (Bashshur *et al.*, 2011). These sophisticated technologies include general packet radio service (GPRS), third- and fourth-generation mobile telecommunications (3G and 4G systems), global positioning system (GPS) and Bluetooth technology (World Health Organization, 2011).

The emergence of advanced technology in mHealth is important for two reasons (Niewolny, 2013):

(i) Advancement in sensor and connectivity technology allows the design of devices that collect, record and analyse data, thereby supporting increased access to healthcare services. This enables the collection of patient data over time that can be used to support preventive care, allow prompt diagnosis of acute complications and promote understanding of how a specific therapy is impacting a patient's relevant parameters.

(ii) The ability of wearable devices to gather data on their own removes the limitations of human-entered data by automatically obtaining the data the doctors need, at the time and in the format they need it. This reduces the risk of error. The reduction of error results in increased efficiency, reduced costs and improved quality in the healthcare industry.

Wearable devices are classified under devices used for mHealth. Wearable technology use in mHealth has expanded; the total revenue is expected to grow from USD 3.2 billion in 2016 to 7.9 billion in 2021 (Mordor Intelligence, 2017). This technology can be applied either for remote monitoring, clinical care or early intervention (Chowles, 2015; Swan, 2012).

Wearable technology systems comprise miniature sensors, wireless communication, wired communication, processing units, multimedia devices, software as well as data analysis as shown in Figure 3.10. As described in the previous section sensors are used to measure physiological signs. The data measured is transferred using wireless and wired connections provided in the section above such as Wi-Fi, Bluetooth, GSM, Ethernet, universal serial bus (USB) and cable wires (de Arriba-Perez *et al.*, 2016).

The data communicated through these methods is transferred to a gateway such as Personal Digital Assistant (PDA) or a microcontroller board. These central nodes turn the data into information that can be displayed on a graphical user interface (GUI) or transmitted as aggregated vital signs to a medical centre. Smart phones, personal computer (PC), laptop and tablet are some of the communication hardware that is used in a wearable system.

In a wearable system, as shown in Figure 3.10, the relayed information is used by either the device user, clinicians or paramedics. The wearable systems designed for the user or clinician vary in complexity. The one designed for the user focuses on personal situations that need attention such as monitoring of physical activities. For instance, the data communicated to the user by a FitBit Charge 2 is the heart rate, step count, calories burned, active minutes or sleep quality (FitBit, 2017), whilst for clinicians, the system is designed to allow them access to data while interacting with a patient, performing a procedure or remote monitoring (Lukowicz *et al.*, 2004). For instance, Google glass can be used to gain access to patient data or direct advice from a remote expert (Iltifat, 2014).

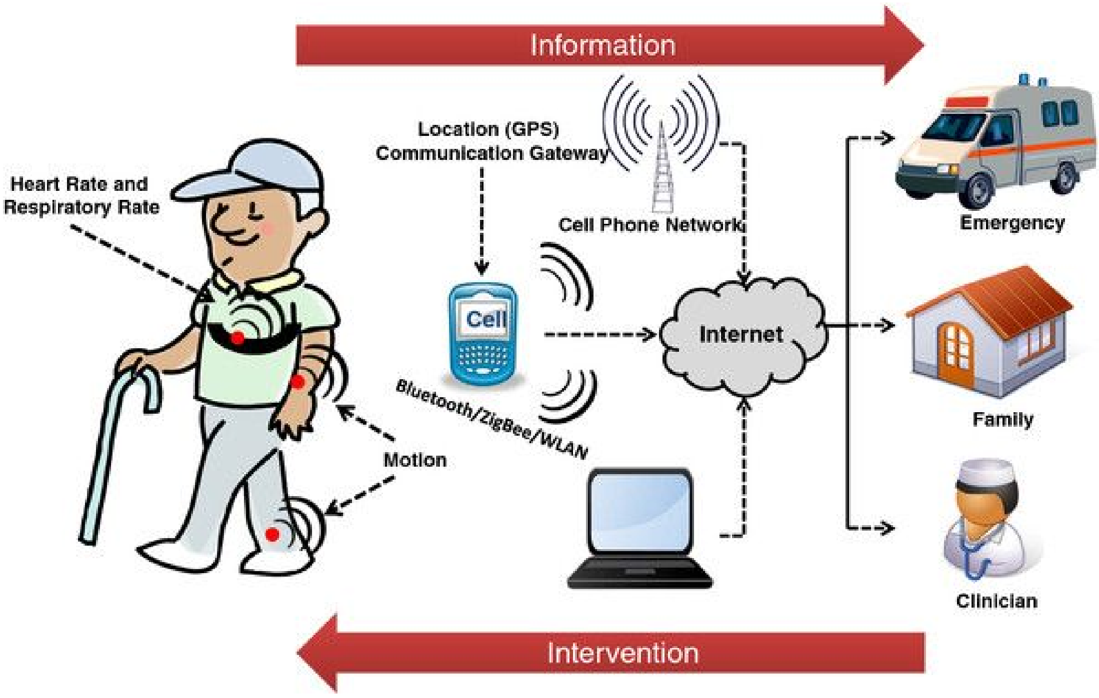

Figure 3.10: Illustration of the wearable system that is utilised in healthcare during remote monitoring or self-management(Source: de Arriba-Perez *et al.* (2016))

Therefore, the wearable system indicates the important aspects that make it functional. It shows the key enabling technologies such as sensors, and communication hardware and software and intended user(s) for the technology.

3.6 Healthcare services in wearable technology

Healthcare services are the most visible functions of the health system, both to the users and the general public. A new form of healthcare service has been introduced by mHealth, allowing people to take charge of their own health and gain easy access to health practitioners. The stages of care that are provided by wearable devices include preventive, wellness care, diagnosis, treatment and restorative or rehabilitative, based on the information gathered from the structured review in Table B.6.

3.6.1 Stages of care

In this section the stages of care are briefly described by providing how they function and how they are applied using wearables.

3.6.1.1 Preventive

Preventive care aims at reducing the risk of developing an illness in individuals and within a community. Wearable devices have played a role in the provision of patient-generated data that improve preventive care strategies (Technology Advice, 2014). For instance, FitBit devices are typically used to track fitness and daily activity level. These tracking devices provide the user with information on their vital signs so that they can prevent chronic conditions by improving their lifestyle (Roderick, 2016). In other instances, wearable devices have been developed for remote monitoring of patients with chronic conditions by clinicians to prevent heart attacks and strokes (Maric *et al.*, 2009; Meystre, 2005).

3.6.1.2 Wellness care

Wellness is an active process of becoming aware of and making choices towards a healthy and fulfilling life. In addition to that, the World Health Organization define wellness as:

> *"... a state of complete physical, mental, and social wellbeing, and not merely the absence of disease or infirmity."*

Healthy people can benefit from wearable technology because of the ability to monitor vital signs, daily activities and well-being (Niewolny, 2013). Currently on the market there are devices designed to bring wellness to people including tracking devices. Tracking devices such as FitBit Charge series (FitBit, 2017) and Jawbone UP series (Jawbone, 2017) are also examples of devices used for wellness purposes.

3.6.1.3 Diagnosis and screening

Diagnosis is the process of determining which disease or condition explains a person's symptoms and signs. Currently, wearable devices are being designed to diagnose movement disorders (Son *et al.*, 2014) and constantly monitor patients that require special attention from clinicians using non-invasive devices. The Monica AN24 (foetal health monitor) is a wearable device used to diagnose muscle and nerve disorder, coronary heart diseases as well as heart failure (Monica Healthcare, 2016). Screening is the checking of the body for cancer before any symptoms show (Centers for Disease Control and Prevention (CDC), 2016). For instance, iSono Health device is a wearable device that can be used for the screening of breast cancer.

3.6.1.4 Treatment of diseases

Treatment is the medical care given to a patient for an illness or injury. Usually chronic diseases need medical care (Yu *et al.*, 2016). Examples of wearable devices that can be used to treat different conditions include the Quell and implantable pills. Quell can be worn on the leg and stimulates the sensory nerves for pain relief (Quell, 2016). Implantable pills are used to dispense drugs into the system when required (Arps, 2013).

3.6.1.5 Rehabilitation

Rehabilitation is designed to restore an individual back to an optimal level of health. This is to reduce the risk of permanent disability related to disease or illness (Patel *et al.*, 2012). Rewalk Personal 6.0 is used for clinical rehabilitation for people that have suffered lower limb injuries.

Therefore, various conditions can be monitored using these healthcare services. Currently, most of these devices are designed to track fitness and daily activity levels. They are aimed at improving people's lifestyle and eradicate cardiovascular diseases.

There are five different healthcare services that are provided by wearable devices. As shown in Figure 3.11, 40 and 39 of the wearable devices that have been included in this review are used for wellness and preventive purposes respectively; 14 of the devices are used for treatment purposes; 7 for diagnosis and screening and 6 for rehabilitation.

As mentioned above, the devices that are used for wellness purposes motivate people to follow a healthy lifestyle. These help prevent the user from developing chronic conditions such as cardiovascular diseases, diabetes and obesity. The devices that are used for treatment usually cater for chronic pain, diabetes as well as muscle disorders. Three of the wearable devices reviewed used for screening mainly focus on breast cancer

(Cyrcadia Health, 2016; iSono Health, 2016). An example of a device that has been designed for rehabilitation purposes, is the Rewalk Personal 6.0, which assists the user to regain their walking abilities.

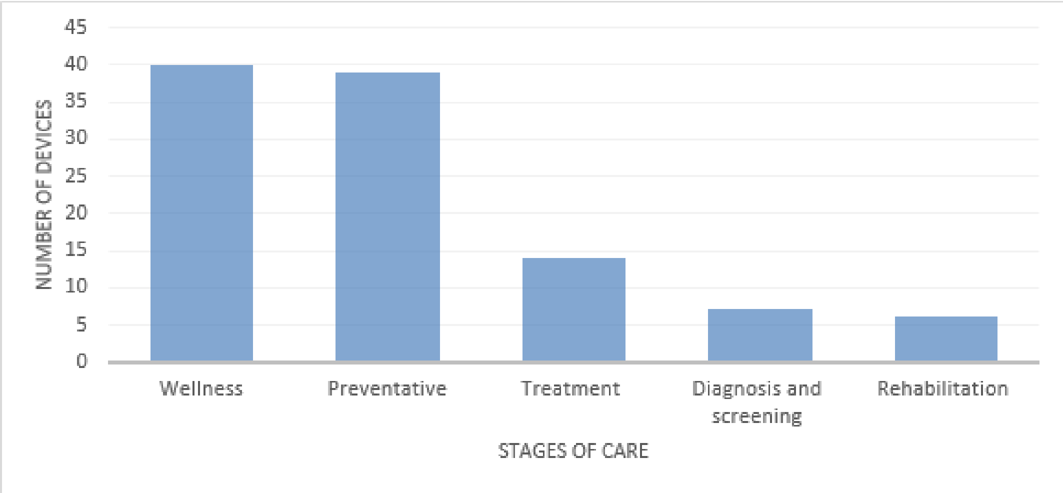

Figure 3.11: Stages of care provided by the 62 wearable devices included in this study

3.6.2 Intended users of the wearable device

Chan *et al.* (2009, 2012); Shull *et al.* (2014) suggested that wearable devices are designed to be utilised by elderly people, people with disabilities, people with chronic conditions and hospital-based health professionals. The intended users are dependent on the care provided. For instance, wearable devices for health and wellness care are designed with the intention that the user or patient acquires information on their vital signs such as heart rate.

Figure 3.12 shows the three different intended users of wearable devices, namely: clinicians, user and paramedics. Figure 10 shows that 49 of the 62 devices are intended for the patient or user, followed by 15 devices for the clinicians. The devices that are intended for the user are usually for self-management, for clinicians for remote monitoring and paramedics for access to medical records in case of emergency. Currently, healthcare's main focus regarding wearable technology is on fitness tracking which gives the user information on vital signs such as heart rate, temperature and motion (Technology Advice, 2014).

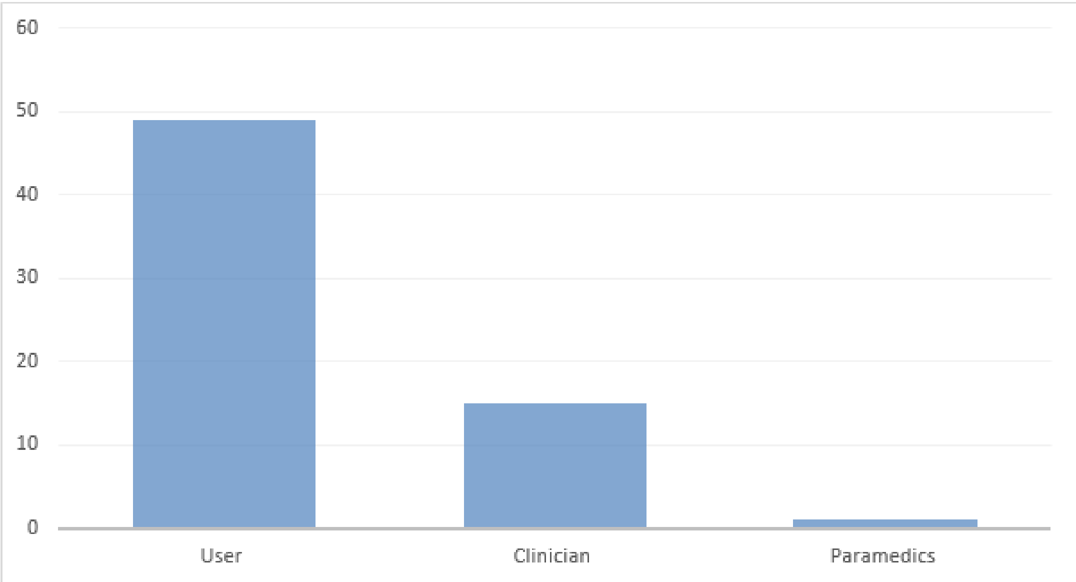

Figure 3.12: Intended user of the 62 wearable devices included in this study

3.7 Technology maturity

In the structured review, Pantelopoulos and Bourbakis (2010) was the only researcher who performed a technology maturity evaluation. He performed the evaluation in order to identify the development level of the devices based on their potential and to provide possible direction for further research in the fields that they show a lack of performance. Based on the nature of this study, technology maturity is considered so as to highlight the development levels and performance of the different devices in healthcare.

Technology maturity explains the growth of technology. Growth means change over time (Nolte, 2008). Nolte (2008) suggests that technology maturity means that the understanding of technology has also improved. As the knowledge of technology expands it makes it easier for the people to apply it to meet their needs. A technology reaches maturity when people know almost everything about it and at that point technology growth depreciates. The depiction of technology maturity can be shown by the s-curve shown in Figure 3.13 (Christensen, 1992).

S-curves show different forms of technology as shown in Figure 3.13:

- New technology is still in the early stages and the rate of progress in performance is slow. This is because of the level of low levels of understanding, control and rate of diffusion (Sahal, 1981).
- Improving technology is within the exponential developmental phase. The exponential phase can be assessed using the universally accepted method of Technology Readiness Level (TRL) scale.
- Mature technology is the stage when technology development ceases. This occurs when all the knowledge about that technology has been exhausted (Nolte, 2008).
- Ageing technology — at this stage technology performance declines because new technologies will be developed that are more efficient and/or cheaper (Nolte, 2008).

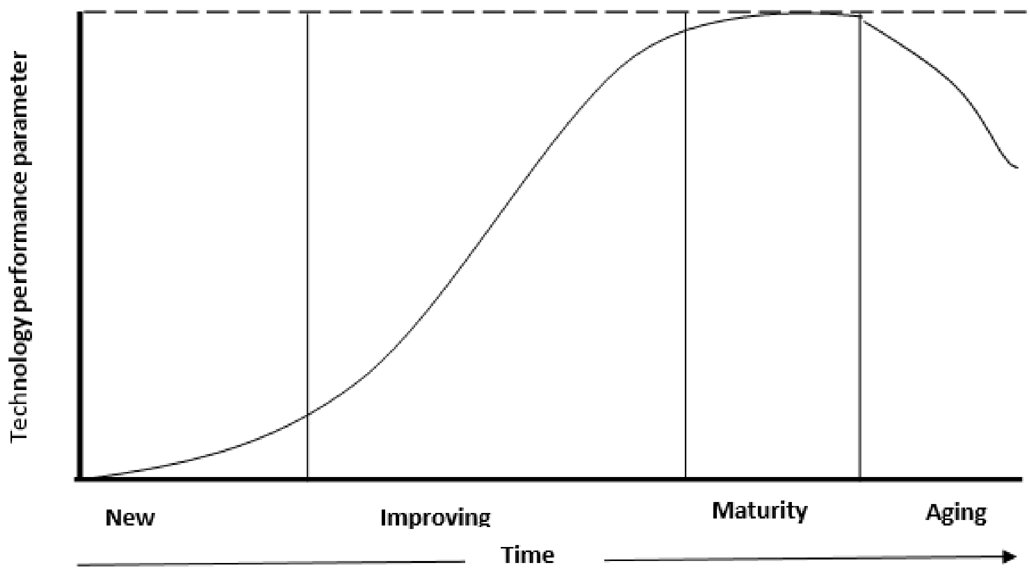

Figure 3.13: Technology maturity: S-Curve (Source: ?)

3.7.1 Maturity characteristics

One of the ways to characterise technology maturity is using dimensionality. Dimensionality considers technology to be measurable using the different dimensions suggested by Nolte (2008). In order to get the full picture of technology maturity involves looking at and measuring technology from all possible viewpoints including:

- Programmatic maturity - used to determine the maturity of a program by focusing on aspects that are programmatic in nature such as the documentation, customer focus and budget
- Developer maturity – this is the consideration of the technology developer. The dimensions for developer maturity are capability, production process and past performance.
- Customer maturity - this considers the compliance of the customers towards a new technology.

However, this paper will focus on technology maturity because this gives insight into the wearable technology landscape. Below are the six dimensions that were developed by Nolte (2008):

i Current state of technology development - This parameter gives an idea of the current state of the technology. This uses the Technology Readiness Level (TRL) scale that was developed by NASA.

ii Amount of development work remaining - This is a difficult indicator to use because it requires an estimation of the amount of technology that still needs to be developed for the device to be fully functional.

iii Difficulty of remaining work – This is a predictive dimension because there is a need to measure the level of difficulty of the remaining work. Therefore, this dimension raises uncertainty.

iv Predicted supportability of final product – Sub-divided into three different measurements; reliability, availability and maintainability. Reliability is the probability that the technology is fit for use at any given time. Availability is the probability that the item will be fit when it is needed. Maintainability considers the ease with which an item can be repaired after it breaks.

v Interoperability with existing systems or products – This measures how compatible systems or components are, especially when they must exchange information or interact with each other.

vi Manufacturing and producibility - This based on whether or not you can manufacture a product that uses a particular technology.

In this research, the main focus will be on the first dimension which can be coupled with the S-Curve and give the picture of the current wearable technologies that are currently available in industry.

3.7.2 Technology readiness levels

Technology readiness levels are a type of measurement system used to assess the maturity level of a particular technology in the improving phase of the S-curve as mentioned in the previous section (Mai, 2015). The National Aeronautics and Space Administration (NASA) initiated the process in the 1980s to inform the development and deployment of new systems for space technology (Mai, 2015). For instance, TRL has been used to assess the technology maturity of advanced nuclear fuels and materials (Carmack *et al.*, 2017).

Each technology is evaluated against the parameters for each technology level and is then rated based on the TRL scale. The scale ranges from TRL 1 (lowest) to TRL 9 (highest) as shown in Table 3.4. When the technology is at TRL 1, scientific research begins and those results can be translated into future research and development. Then, during TRL 2 the invention begins, practical application is identified but is speculative; no experimental proof or detailed analysis is available to support the conjecture.

TRL 3 occurs once there is an active research and design. In this level, both analytical and laboratory studies are required to determine the appropriate context for the technology application. In this level, a proof-of-concept model is constructed. After this, the technology advances to TRL 4 when the proof-of-concept model is ready. In this level multiple component pieces are tested with one another.

TRL 5 is a continuation of TRL 4. A technology that is at level 5 is identified as a 'breadboard technology' and must undergo more rigorous testing than technology that is only at TRL 4. Simulations should be run in environments that are as close to realistic as possible. After this, the technology advances to TRL 6 where it has a fully functional prototype or representation model.

A TRL 7 technology requires that the working model or prototype be demonstrated in a space environment. Then, a TRL 8 technology has been tested and 'flight qualified' and it is ready for implementation into an already existing technology. Finally, when a technology is flight proven during a successful mission it is called TRL 9.

This TRL has not only been applied to measure technology maturity by NASA. For example, Carmack *et al.* (2017) used the TRL to measure the technology maturity of advanced nuclear fuels and developed a framework to follow.

Table 3.4: Technology readiness levels (Adapted from: U.S. Department of Energy (2010))

TRL range	**Definitions**	**Description**
TRL 1	Basic principles observed and reported	Scientific research is beginning and then later translated into future research and development. At this level basic scientific principles are being studied analytically and experimentally.
TRL 2	Concept and/or application formulated	Practical applications are beginning to be invented or identified. Applications are still speculative and there is no proof or detailed analysis to support assumptions.
TRL 3	Concepts demonstrated analytically or experimentally	At this level active research and development is initiated. This includes analytical and laboratory-based studies to physically validate predictions of key elements of the technology. These studies and experiments should constitute 'proof-of-concept' validation of the applications or concepts formulated at TRL 2.

Continued on next page

Table 3.4 – *Continued from previous page*

TRL range	Definitions	Description
TRL 4	Key elements demonstrated in laboratory environment	The key elements must be integrated to establish that the pieces will work together. The validation should be consistent with the requirements of potential applications but is relatively low-fidelity when compared to a final product.
TRL 5	Key elements demonstrated in relevant environments	Key elements increase significantly. These elements are integrated with realistic supporting elements so that the technology can be tested and demonstrated in simulated or actual environments.
TRL 6	Representative of the deliverable demonstrated in relevant environments.	Represents a major step in a technology's demonstrated readiness.
TRL 7	Final development version of the deliverable demonstrated in operational environment	Development version of the deliverable is near or at the planned operational system. This represents a significant beyond TRL 6 and requires the demonstration of an actual development version of the deliverable within the next assembly, and advanced technology demonstrations of integrated systems such as flight testing.
TRL 8	Actual deliverable qualified through test and demonstration	The technology has been proven to work in its final form under expected conditions. This represents the end of true system development.
TRL 9	Operational use of deliverable	Application of the technology in its final form and under mission conditions such as those encountered in operational test and evaluation. This is the end of the last bug fixing aspects of true system development.

Figure 3.14 gives information on the technology maturity of the wearable devices

using the TRL coupled with the S-curve that were reviewed in this study. A total of 57 of the 62 devices reviewed have passed the prototype phase which starts at TRL 6 (Mai, 2015). From the investigation, 15 of the devices are below TRL 8 because they could be in the process of seeking approval from FDA or are undergoing clinical trials.

From the data gathered the technology maturity is determined by the advancement of the technology. The devices that have reached maturity are mostly fitness trackers. The advancement of wearables is as a result of the development of micro-electronics-mechanics systems resulting in advancement of sensors for monitoring physiological signs, recording and transferring reliable data collected.

Most wrist-bands devices that are used for fitness tracking have reached maturity because they have been on the market for less than five years and the understanding of the technology has improved. The developers of these devices keep on upgrading them so that they avoid reaching the ageing phase of technology maturity. For example FitBit has over the years evolved from FitBit Flex (released in 2013) to FitBit Alta 2 (released in March 2017).

The FitBit Flex had sensors such as 3-axis accelerometer and vibration motor. Then the FitBit Alta 2 developed also includes photoplethysmography and 3-axis accelorometers. The company has been working on the improvement of their products through the development of the devices software. According to the CEO of FitBit their products have dominated the wearable technology landscape because of timing. Their device was released at the right time when people were starting to realise the potential of sensors for fitness tracking.

The challenges that are faced in the development of wearable devices are:

- Power consumption
- Data security
- Wearability
- Data integrity

- Sensor technology

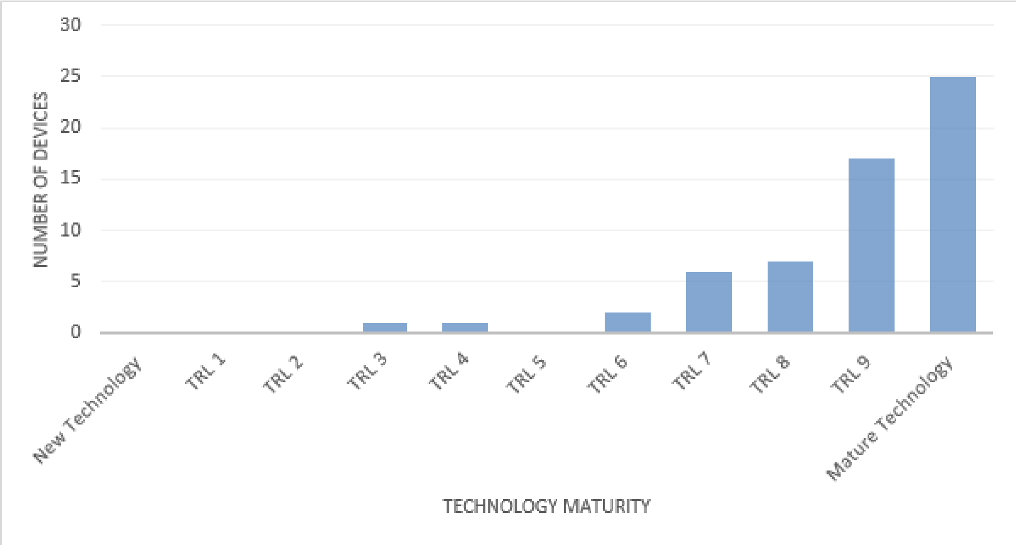

Figure 3.14: Technology maturity of the 62 wearable devices included in this study

The maturity of wearable devices is dependent on the intended users in Section 3.6.2.The stakeholders play a vital role because they are the ones that require their needs to be met by the specific technology. For this technology to be utilised by people, it should first gain acceptance from the intended users. The act of the user to accept and use the device is affected by many factors. In the case of wearable computers, it should be able to perform two functions: first, as a computer and second, as a garment or accessory, and these will both affect users' preferences of the device. The fulfilment of these preferences or requirements will then lead to acceptance.

The acceptance of a technology determines its rate of diffusion. The rate of diffusion also determines the technology maturity. The issues that affect the acceptability of wearable technology are:

- Users are attracted to devices that fulfil their fundamental needs such as monitoring sport activity and regulating body temperature which satisfy physiological needs.

- The acceptance of wearable technology is also affected by social aspects such as personal privacy, social influences[1] and culture[2].
- The other aspect is the physical aspect which relates to the (i) physical comfort and safety, (ii) aesthetics and appearance, and (iii) mobility.
- Demographic characteristics such as gender and age. In terms of the age elderly are not accustomed to technology and experience difficulties with understanding it. Research has shown that men are more receptive to smart shirts compared to women. Then women are less accepting to technologies because they have low a level of interest towards technologies.
- Previous technical experience with technologies affects how people accept technologies.

The other issue with the adoption of wearable devices is the certification and regulations of medical devices. Certification and regulations are based on the classification of the devices which is determined by the level of risk the device poses to the patient. Most non-invasive wearable devices are classified as Class A devices because they have low risk to the user (RSA, 1998). The devices that are invasive such as an OmniPod which is used to monitor and regulate blood glucose levels have needle-like structures that penetrate the skin as such are classified as Class B devices as they pose intermediate threat to the user. Therefore when producing wearable devices the designer should ensure that the devices meet the standards that are required for the medical devices so that the certification process does not take long.

Wearable technology is still going through the development and improvement stages therefore the technologies are still emerging into the healthcare field especially for advanced applications. More research and development still needs to be carried out to

[1]Social influences are based on the human interaction and how people value the opinion and beliefs of the people that surround them. People tend to shy away from wearable technology especially if the society does not favour the technology.

[2]Culture has a significant effect on people's behaviour, beliefs, and decisions. Thus, it is not surprising that culture influences an individual's acceptance and use of wearable technology. In evaluating the acceptance of some features of smart clothing, Duval et al. hypothesised that the high acceptance of artificial intelligence in Japan was affected by the users' religion

improve the efficiency of the wearable devices and ensure that the users do not abandon their devices after a specific period of time. The wearable technology developers have to ensure the data transfer process is efficient and secure in order to protect the privacy of the users and the integrity of the healthcare providers.

Wearable technology developers should also pay close attention to the intended user as the new device will affect their day-to-day lives as they have to carry the device at all times. Therefore, in order for people to accept the device the developers need to ensure that the technology will benefit the users without infringing their daily lives and be user friendly.

3.8 Conclusion: Wearable technology landscape

A better understanding of the current wearable technology landscape can be achieved by investigating the key characteristics that make it functional. In order to achieve the main objective of this paper, it was important to perform a comprehensive review to help identify the important aspects that will give an understanding of the landscape. From the review, the following key aspects were identified: sensors and data collection software, communication software and hardware, data analysis, diseases monitored, intended user(s), physiological signs measured as well as the technology maturity using S-curve and TRL assessment. Past work in literature focused on wearable technology in specific applications such as remote monitoring (Maric *et al.*, 2009; Patel *et al.*, 2010, 2012). The current study focuses on all the wearable devices that are being used in healthcare for other applications such as clinical care and early prevention so as to get a broader picture of the landscape.

This study revealed that the main wearable sensors that are currently found in the wearable technology landscape are accelerometers, ECGs, heart rate monitors and thermometers. These are mainly incorporated in fitness trackers and activity monitors. The data gathered by the sensors is transferred to the servers through a gateway. From the investigation, the most popular gateway in a wearable system is a smartphone. The smartphones that are commonly used in wearable systems are either compatible with android, iOS mobile operating systems or both. Most wearable systems use network connections such as Wi-Fi and Bluetooth to transfer data from the wearable device to the servers.

The most prominent physiological signs that can be measured using wearable devices are heart rate, temperature, motion as well as breathing rate. The main medical conditions that are usually monitored are cardiovascular diseases, metabolic syndrome, diabetes and infectious diseases. These diseases can be monitored using the temperature, heart rate, motion and blood glucose levels. From the investigation, most of the wearable devices are being designed for the user to monitor their own health especially for wellness and preventive purposes.

Technology maturity was determined using the S-curve and TRL scale. Most of the devices are that were reviewed showed that the devices that are on the market are reaching maturity already especially fitness trackers. The devices that are used for advanced healthcare such as Google contact lenses are still at the prototype phase (at TRL 6).

CHAPTER 4

CROSS-REFERENCE THE DISEASES TO THE WEARABLE DEVICES

This chapter contains the results of a qualitative analysis, through interviews, that was conducted in order to collect medical knowledge about prominent diseases that affect the sub-Saharan African region (refer to Section 2.3) from clinical subject matter experts (SMEs). During the interviews, SMEs provided information on the physiological signs that are used to clinically monitor these diseases. They were asked to consider the potential application of wearable technology to each disease and to provide information on the stage(s) of care where the measured data may be useful and also which stakeholders may find such data useful and/or benefit from it. The feedback gathered from the interviewers will be gathered and discussed in detail.

4.1 Interviews with experts

This section focuses on providing the background information of interviews and the different types that are available. Interviewing is a primary way of collecting qualitative data. According to Mouton (2001), the following are the advantages of conducting interviews:

- Flexibility and adaptability.

- The interviewer has control over the responses and can ensure all the questions are answered by the interviewee. The interviewer can provide clarity to the interviewee if there are questions that are misunderstood.
- Anonymity is provided so that the interviewee gives unbiased responses.
- There is a high response rate to face-to-face interviews compared to providing responses via email or telephone interviews.

Mouton (2001) also highlights an important disadvantage of interviews, namely that they are subject to bias.

The three common types of interview techniques used for data collection include: (i) structured; (ii) semi-structured; and (iii) unstructured. These will be described in more detail in the following subsections, before motivating the selection of the most appropriate interview technique for this research in Section 4.1.4..

4.1.1 Structured interviews

Structured interviews often produce quantitative data when conducted correctly (Dicicco-Bloom and Crabtree, 2006). The questions asked during a structured interview are controlled, so is the data elicited by the interviewee. During a structured interview, the interviewer follows a specific set of questions with a predetermined order and a limited number of response categories (Denzin and Lincoln, 2008). Structured interviews play a vital role especially when the interviewer knows much about the topic and creates the questions in a survey-like format with closed-ended questions (Stuckey, 2013). The questions are compiled as a questionnaire that guides the interviewer with pre-coded answers.

4.1.2 Semi-structured interviews

Often the sole data sources for qualitative data research projects are semi-structured interviews. The researcher sets an outline of the predetermined open-ended questions with other questions emerging from the dialogue between the interviewer and interviewee(s) (Stuckey, 2013). The semi-structured interview is flexible and could cover a broader scope than the structured interview approach because the interviewees can give lengthy and vivid details to the questions asked (Dicicco-Bloom and Crabtree, 2006).

4.1.3 Unstructured interviews

Unstructured interviews are informal and are used to explore general areas of interest in depth. In this instance, the interviewer has a general topic in mind, but many of the question are formulated as the interview proceeds, in response to what the interviewee says. These interviews can also be referred to as in-depth interviews. Although no interview can truly be unstructured, some have less guidance than others(Dicicco-Bloom and Crabtree, 2006). Unstructured interviews are usually conducted in explorative and qualitative research to identify important variables in a particular area, to formulate penetrating questions about them, and to generate hypotheses for further investigation (Dicicco-Bloom and Crabtree, 2006).

4.1.4 Conclusion: Selected interview technique

The structured interview approach was chosen for this study because of its ability to control the topics of the interview and to elicit controlled responses. The data collected using this method is (i) reliable, (ii) standardised, and (iii) repeatable. The interview format that was selected was questionnaire-based and interviews were conducted face-to-face.

4.2 Interview process and feedback

The interview process that was followed is set out in this section and the data that was gathered through the interview is also summarised. The section will also go into detail in explaining the relevance of each question posed to the interviewees.

4.2.1 Interview process

The interviewees were subjected to an introduction of the thesis by the interviewer to provide an understanding of the relevance of the interview and how the information they provide will contribute to the study. The interviewees were also afforded the opportunity to recommend changes to the questionnaire guiding the structured interview. This questionnaire had been made available to each interviewee via email prior to the interview. The following changes were made to the questionnaire in line with recommendations by the interviewees:

- Oxygen saturation was added as a physiological sign;
- Congenital anomalies were removed from the list of diseases since they can not be monitored non-invasively; and
- The order of the diseases in the questionnaire was rearranged to group all the conditions that affect neonatal babies together.

The basis for the questionnaire was the prioritised list of diseases identified in Section 2.2.4, and repeated below for the sake of clarity. The same set of questions was asked for each disease. The diseases that were included in the questionnaire were:

- Lower respiratory infections
- HIV/AIDS
- Diarrhoeal diseases
- Stroke
- Ischaemic heart disease
- Tuberculosis
- Malaria
- Preterm birth complications
- Birth asphyxia and other infections
- Neonatal sepsis

Figure 4.1 illustrates a portion of the questionnaire. The questions that were asked for each disease are summarised below; the reasons for including each question in the questionnaire are also provided:

(a) **Choose the physiological signs that can be used to monitor the condition:** In healthcare research, a person's physiological signs can be monitored for precise and accurate data for diagnostic purposes. In order to keep the outputs consistent, a list of physiological signs was presented to the interviewees. The list was based on the physiological signs that were found from the structured review of the wearable technology landscape (in Section 3.3). This approach restricted the physiological signs to those that can be monitored by wearable technology that is either presently commercially available or is in an advanced stage of development. Interviewees were, however, allowed the option of adding additional physiological signs not listed in the structured interview guideline as part of their response.

(b) **Identify the stages of care where the physiological signs identified in (a) would be useful clinical indicators:** The stages of care give an indication of where these physiological signs play a vital role in health systems and can be used to assess the health impact for decision-making. Therefore, this information enables the potential health outcome of the wearable technology to measure these physiological signals to be determined.

(c) **The intended user of the information:** The question was posed to indicate the stakeholders that find the information useful. Intended users were grouped into two categories, the one consists the patients and other care givers or stakeholders that do not necessarily have formal medical training, the other consists of the various medical professionals involved in providing care. This would be relevant information to individuals seeking to develop or adapt wearable technologies for these applications.

a) Choose the physiological signs:

☐Heart Rate
☐Temperature
☐Motion
☐Breathing Rate
☐Activity
☐Oxygen saturation
☐Blood pressure
☐Blood sugar levels
☐Heart electrical activity
☐Sleep quality
☐Brain activity
☐Other
☐Urine composition
☐Blood volume pulse
☐Body water levels
☐Pressure levels
☐Galvanic skin response

Specify:

b) Choose the stages of care:

☐Preventative care

☐Wellness care

☐Diagnosis and screening

☐Treatment of diseases

☐Rehabilitation

c) Choose the intended user who will benefit / use from the data collected:

☐Users such as:

- Patients;
- Senior citizens, and Handicapped people
- Family and non-trained carers

☐Healthcare providers / Care givers

- Emergency services or paramedics
- Trained carers
- Doctors
- Nurses

Figure 4.1: Part of the questionnaire template used for interview

4.2.2 Interviewees

The interviewees were taken from different medical fields. A total of five subject matter experts were interviewed (see Table 4.1). The reasons why only five interviews were conducted were:

1. The interviews lasted 1 to 2 hours each, so they required a reasonably large period of time and commitment from the interviewees, all of whom have significant other demands on their time

2. The interviewees had some room for personal opinions in the feedback, but the information was largely factual and there was an expectation that the findings from the different interviews would be well-aligned.

The majority of the SMEs were employed by Stellenbosch University or the Western Cape provincial government.

Table 4.1: Subject matter experts interviewed

Interview Date	**Interviewee's area of expertise**	**Interviewee's geographical focus**
15/08/2017	General practitioner and project manager of the Ukwanda Rural Clinic School	Worked in Southern African countries for several years and spent the last few decades working in Western Cape.
17/08/2017	Paediatrician at Cape Gate Mediclinic Private Hospital , Head of the Biomedical Engineering Research Group, Extra-ordinary associate professor, Department of Anaesthesiology and Critical Care.	South Africa
22/08/2017	Neonatologist at Tygerberg Hospital	Works in Western Cape
06/09/2017	General Practitioner and Programme Coordinator of the Centre of Health Systems and Services Research Division of Community Health, Stellenbosch University.	Works and currently conducting research in Western Cape
15/09/2017	General Practitioner	Worked in Western Cape

There is some bias from the feedback from these experts because:

- Most of the doctors had specialised fields and were knowledgeable about certain diseases compared to others; and
- The study focuses on the SSA disease landscape and some of the interviewees just have experience with the diseases that affect the Western Cape or South Africa in general.

4.2.3 Summary of feedback from interviews

This section provides the feedback that was obtained from the different SMEs based on the questionnaire or any additional information they provided. Table C.1 provides the response from the five interviewees. The detailed description of the interview finding is provided in Appendix C. For all the different conditions they indicated the physiological signs they felt could play a role in monitoring them either in home or hospital settings. When analysing the responses from the interviewees the physiological signs identified were linked to the stages of care and the intended user.

4.2.3.1 Feedback on the physiological signs and stages of care for the respective diseases

The data in Table C.1 shows the predominant physiological signs and the stages of care that were agreed upon by the subject matter experts. The physiological signs that were identified by all of the interviewees will be used to cross reference the diseases to the wearable sensors applied. The responses given were consistent with the physiological sign found in literature (Refer to Section 2.2.2). The additional physiological signs that were suggested by the interviewees were haemoglobin levels [1], breathing sounds [2], bio-impedance (for body fluid and body fat) [3] and perfusion [4].

4.2.3.2 Feedback on the intended user(s)

During the interviews all the interviewees felt that for all the diseases that were presented to them they shared the sentiment that the patients and the healthcare providers would benefit from the data collected. Because this is an emerging technology some of the interviewees highlighted that they might be need to train the stakeholders to ensure efficient application of the technology. The level of training will be dependent

[1]The measurement for haemoglobin concentration plays a role in the monitoring of malaria. Haemoglobin concentration indicates the concentration of red blood cells in the body (Barker *et al.*, 2016).

[2] Continuous monitoring of the breathing sounds can indicate a lung problem such as an obstruction, inflammation, infection, asthma and fluid in the lungs (Stahlheber, 2015).

[3]Bio-impedance is a physiological sign that can be used to determine the body composition measurements such as lean mass and fluid volumes estimation. Bio-impedance information can be used to monitor conditions such as cardiac, pulmonary, renal, neural and infectious diseases (Khalil *et al.*, 2014).

[4] Blood perfusion is an important physiological parameter which can serve as an indicator of body hemodynamic function. For example, in circulatory failure, blood flow is diverted from the less important organs such as the skin to the vital organs. Thus monitoring blood perfusion can be an early marker of the hypo-perfusion of vital tissues (Zakharov *et al.*, 2009).

on the complexity of the data that needs to be interpreted. This information will be used in Chapter 6 on considering the potential of wearable technology.

The following points were made throughout the interview process by the SMEs:

- It was suggested that with the level of data presented to the users that it might be necessary to train stakeholders. This will enable the efficient use of the device and interpretation of data.
- To develop complex algorithms that can be used to detect diseases when monitoring the patients remotely and alert the healthcare providers of the condition as well as the patient.
- There is probable potential of using wearable technology in hospital settings in Level 1, 2 and 3 care for neonates to monitor their vitals. In addition to that the parents of the preemies that have just been released from hospital can benefit from wearable devices especially if they are still vulnerable to infections.
- Patients that have chronic conditions such as cardiovascular diseases and hypertension will benefit immensely from this technology as it will enable them to have a healthy lifestyle.
- When the healthcare providers are using wearable devices it would be beneficial, especially for patients suffering from chronic conditions, to have access to the medical history of the patient.
- There are three different parties involved in the monitoring of diseases using wearable technology, namely healthcare providers, patients and medical insurance companies. Medical insurance companies use wearable devices to monitor the activities of their beneficiaries ensuring they lead a healthy lifestyle.

Wearable technology can benefit various stakeholders and this technology plays different roles for the parties involved (Burri *et al.*, 2011). Wearable technologies are interesting interventions because they can be used for self-management or remote monitoring. Table 4.2 summarises the findings from the feedback that was provided by the SMEs on their perspective on the wearable technology requirements for the intended user.

Table 4.2: A summary of the SMEs' perspective on requirements to make wearable technology accessible to intended users (or stakeholders)

Stakeholders	Technical	Quality	Accessibility	Efficiency	Costs
Patients	Wearable device, smart phones and computers	Better care received given the sensors are reliable	Mobile network coverage, Internet access and usage	Training based on computer literacy in the region	Data transfer and storage
Healthcare providers	Computers, laptops , smart phones	Better care given, less administrative work	Mobile network coverage, Internet access and usage	Training based on computer literacy in the region hospitals	Data transfer, servers and storage

The interview process provided insight on the medical perspective and on how it is necessary to have a better understanding of the disease state analysis so that valid recommendations can be made based on this research.

4.3 Discussion of findings

In wearable technology a number of wearable sensors are being developed to measure physiological signs. Currently motion sensors, temperature sensors and heart rate monitors are widely used for fitness tracking. The list of the wearable sensors that are currently being used is provided in Table 3.1 in Chapter 3. For this study the list of physiological signs that were presented to the interviewees will be matched up to their wearable sensors as illustrated in Figure 4.3.

Figure 4.3 also illustrates that there are physiological signs that can be measured using multiple sensors. The sensors may be used to measure the same physiological signs; however, different algorithms have to be developed to analyse the data. These physiological signs are:

- Heart rate that can either be monitored using ECG electrodes (Guo *et al.*, 2016), piezoelectric film sensor (Park *et al.*, 2015) or PPG (Kroll *et al.*, 2016).

- Temperature measured using infrared thermopile (Texas Instruments, 2017), thermometers and thermistor (Hughes-Riley *et al.*, 2017).
- Motion can be measured using either accelerometer, gyroscope, pedometer and electromagnetic sensors (Majumder *et al.*, 2017).
- Breathing rate using either a respiratory inductive plethysmography (RIP) sensor, bio-impedance sensor (De Cannière *et al.*, 2015) and thermistor (Retory *et al.*, 2016).
- Body water levels for hydration can be determined using skin hydration sensor (Yao *et al.*, 2017), bio-impedance (body fluids) (De Cannière *et al.*, 2015) and trans-epidermal water loss sensor (Zak *et al.*, 2012).
- Haemoglobin can be measured using pulse CO-oximeter (Lindner and Exadaktylos, 2013) and chemical sensors that can detect the presence of haemoglobinuria in urine.

The physiological sign that were mentioned by the interviewees that have no sensors yet developed for wearable sensing is breathing sounds.

Table 4.3: Sensors cross-referenced to their physiological signs

Sensors	Physiological sign																				
	Heart rate	Temperature	Motion	Breathing rate	Activity	Oxygen saturation	Blood pressure	Blood sugar levels	Heart electrical activity	Sleep activity	Brain activity	Urine composition	Blood volume pulse	Body water levels	Pressure levels	Galvanic Skin Response	Haemoglobin	Breathing sounds	Bio-impedence	Perfusion	food intake
Accelerometer			X		X					X											
ECG electrodes	X								X												
Heart rate monitor	X																				
Thermometers		X																			
Respirotory meter				X																	
EEG electrodes											X										
Biomakers								X				X									
Infrared thermopile		X																			
Oximeter (PPG)						X															
Pressure sensor				X											X						
Blood pressure meter							X														
Gyroscope			X		X																
Pedometer			X																		
Electrodermal activity sensor																X					
Thermistor		X		X																	
Calorimeter																					X
Chemical sensor								X				X		X							
Magnetic sensors			X		X					X											
Phonocardiography																		X			
Impedance cardiography														X						X	
Transepidermal Water Loss Sensor														X							
Pulse CO-Oximetry																	X				

4.3.1 Feedback on the physiological signs and stages of care for the respective diseases

The section contains the detailed discussion on the physiological signs and the stages of care linked to the respective diseases. The discussions are based on the results presented in Table C.1.

4.3.1.1 Detailed feedback on physiological signs linked to diseases

This section contains a brief description of the expected use of monitoring various physiological signs for each of the diseases included in this research. These descriptions are based on the synthesised feedback received from the various SMEs.

Lower respiratory infections -This is a disease known to affect the respiratory tract. Based on the feedback from some of the SMEs when the body is infected there is a possibility of an immune response that is characterised by temperature increase (fever), heart rate to increase, increased breathing rate and the oxygen saturation levels will decrease. According to the SMEs these physiological signs can be monitored in the home or hospital setting and can provide reliable results.

HIV/AIDS - This is monitored efficiently through blood tests. The physiological signs that can be monitored for this condition are aimed at identifying the opportunistic infections in Stage 3 of the HIV infection. The physiological signs that are of importance include heart rate, temperature, breathing rate, oxygen saturation and brain activity. Opportunistic infections include diseases such as tuberculosis, pneumonia and meningitis. During the first two stages of infection the virus is dormant and no clear signs and symptoms can be used to clearly link it to its presence. There the use of wearable technology in the first two stages can be challenging. In other medical cases, HIV medicines present side effects that can affect the well-being of the patient. The side effects can be manageable or life threatening. Therefore a patient should be monitored to prevent the life-threatening side effects such as liver failure, kidney problems, heart disease, diabetes and nervous system as well as psychiatric effects.

Diarrhoeal diseases - These diseases can be monitored using body water levels in the form of trans-epidermal water loss levels or bio-impedance and urine composition. When a person is suffering from diarrhoea they lose a lot of fluids from the body and the dehydration can be monitored non-invasively. The loss of fluids affects the heart rate, breathing rate, temperature, oxygen saturation, blood pressure and blood sugar levels. The monitoring of these physiological signs can be used in home or hospital settings as they will be able to recommend the amount of fluids and electrolytes required for the body to return to normalcy.

Stroke - A stroke is an acute condition which occurs when the blood pressure increases so drastically that it affects the functionality of the body. The physiological signs that are important for the monitoring of this condition are motion, blood pressure, brain activity, heart rate, heart electrical activity and breathing rate. All these physiological signs can be used to identify a stroke and monitor a hypertensive patient as well as a stroke survivor.

Ischaemic heart diseases - These diseases affect the heart activity therefore can be monitored or detected using the heart rate, heart electrical activity and blood pressure. There are devices that have been developed with the main purpose of identifying and detecting ischaemic heart diseases.

Tuberculosis - This is a form of lower respiratory infection characterised by night sweats, fever and fatigue. The physiological signs that can be used to monitor tuberculosis are heart rate, temperature, breathing rate and oxygen saturation. One of the interviewees highlighted that tuberculosis meningitis can be monitored by sleep quality and brain activity as the infected person experiences delirium, seizures and drowsiness.

Malaria - The physiological signs that are important when monitoring malaria are heart rate, temperature, oxygen saturation, blood pressure, blood sugar levels and haemoglobin levels. The one challenge with malaria is that the symptoms may not develop for several months making it difficult to detect the presence of the infection.

Preterm birth complications - These are conditions that affect babies that are born weighing 500 grams to 2500 grams. There are a number of complications that were mentioned by one of the interviewees such as jaundice, anaemia, metabolism and heart defects. Preemies are known to lose heat through their skin so there is a need for constant monitoring of temperature. The vital signs need to be monitored continuously for preemies because their organs are not fully developed as highlighted by one of the interviewees who works in the Neonatal Intensive Care Unit at Tygerberg Hospital. The physiological signs that need to be monitored are heart rate, temperature, oxygen saturation, blood pressure, blood sugar levels and urine composition. One of the interviewees commented that having a device that can monitor these signs non-invasively will add value in the intensive care unit as at the moment preemies are monitored invasively.

Birth asphyxia and other infections - Birth asphyxia is a condition which occurs when the baby is deprived of oxygen before or during child birth. According to the interviewees both the mother and the baby need to be monitored. The physiological signs that require constant monitoring are heart rate, temperature, breathing rate, oxygen saturation, blood pressure and blood sugar levels.

Neonatal sepsis - Early-onset sepsis is associated with acquisition of micro-organisms from the mother. Transplacental infection or an ascending infection from the cervix may be caused by organisms that colonise the mother's genitourinary (GU) tract; the neonate acquires the micro-organisms as it passes through the colonised birth canal at delivery. According to the feedback from the SMEs, the vital signs that are necessary for the monitoring of neonatal sepsis are heart rate, temperature, motion, breathing rate and blood sugar levels.

4.3.2 Summarised feedback on stages of care

Detailed information on the various stages of care where SMEs indicated that monitoring of physiological signs would be useful has been provided in Table C.1. This information is summarised in a significantly less detailed format in Figure 4.4, to enable some high-level conclusions to be drawn.

Communicable diseases would benefit from wearable devices by using them for treatment and diagnostic purposes. These conditions are characterised by fever, increased heart rate, perfusion and elevated blood pressure in some instances blood sugar levels. For non-communicable diseases, especially chronic conditions, the wearable devices can be applied in all stages of care. Stroke is an acute NCD and can be prevented, diagnosed and rehabilitated using wearable devices.

Table 4.4: Sensors cross-referenced to their physiological signs

Diseases \ Stages of Care	Preventative Care	Wellness Care	Diagnosis and screening	Treatment	Rehabilitation
Lower respiratory infections			X	X	
HIV/AIDS			X	X	
Diarrhoeal diseases			X	X	
Malaria			X	X	
Birth Asphyxia and birth trauma			X	X	
Preterm Birth Complications			X	X	
Tuberculosis			X	X	
Neonatal Sepsis and infections			X	X	
Stroke	X		X		X
Ischaemic heart diseases	X	X	X	X	X

4.3.3 Sensors for the diseases

The information from Figure 4.5 and Table C.1 was used to cross-reference the sensors to the diseases that are being considered for this study. A total of 24 sensors are provided in Figure 4.3. A total of 13 of the 24 sensors can be used to monitor all the diseases being considered in this study. The sensors that were identified to monitor most of the diseases are utilised specifically for vital signs and motion activity.

On the market there are wearable devices that have a multisensor system (Samanta *et al.*, 2014; Shen *et al.*, 2012; Swan, 2012). A criteria has to be used to determine the important sensors that can be used for monitoring the respective condition. This will be conducted in Chapter 5.

Lower respiratory infections and tuberculosis have the least number of wearable sensors to monitor the disease. Pre-term birth complications, neonatal sepsis, stroke and ischaemic heart diseases are conditions which require constant monitoring of the vital signs, therefore these have the highest number of possible sensors that can be applied.

Table 4.5: Sensors cross-referenced to their diseases

DISEASE \ SENSORS	Accelerometer	ECG electrodes	Thermometers	Respirotory meter	EEG electrodes	Biomakers or Chemical sensors	Infrared thermopile	Pulse Oximeter	PPG	Pressure sensor	Blood pressure meter	Gyroscope	Pedometer	Electrodermal activity sensor	Thermistor	Magnetic sensors	Phonocardiography	Impedance cardiography	Transepidermal Water Loss Sensor	Pulse CO-Oximetry
Lower respiratory infections			x	x			x	x	x						x					
HIV/AIDS			x	x	x		x	x	x						x					
Diarrhoeal diseases			x	x		x	x	x	x		x				x			x	x	
Malaria			x	x		x	x	x	x		x				x					x
Birth Asphyxia and birth trauma			x	x		x	x	x	x		x				x					
Preterm Birth Complications	x	x	x	x		x	x	x	x		x	x	x		x	x				
Tuberculosis			x	x			x	x	x						x	x				
Neonatal Sepsis and infections	x	x	x	x		x	x	x	x		x	x	x		x	x				
Stroke	x	x	x	x	x	x	x		x		x	x	x		x	x				
Ischaemic heart diseases	x	x		x		x	x	x	x		x	x	x			x				

4.4 Conclusion: Cross-reference diseases to wearable sensors

This chapter began by a giving background of the interview process and the different types of interviews. This was followed by the findings from the interviews through a brief description of the questionnaire, subject matter experts and interview responses. Finally, the physiological signs that were identified from the interviews was used to cross-reference the diseases to the wearable sensors.

CHAPTER 5

DEFINE CRITERIA FOR PRIORITISING WEARABLE DEVICES

This section aims at defining the set of criteria that will be used for priority-setting in the wearable sensors sector in healthcare in SSA. The set of criteria used for this study will be determined from those that were predominantly used in previous studies that focus on priority-setting in healthcare. This section provides the different methods that can be used to weigh the selected set of criteria to determine a composite score. Finally, information will be provided on the scales that will be used to score the set of criteria that will be identified.

5.1 Background

Priority-setting is important in healthcare policy-making because no health system can afford all the health interventions they intend on introducing (Kapiriri and Norheim, 2004). SSA faces a challenge between the need for healthcare services and limited funding available. Priority-setting brings about transparent approaches and explicit debate about the principles and criteria used to make decisions on allocating healthcare resources.

A set of criteria can be determined in order to enable the prioritisation of new technologies (Shani *et al.*, 2000). The criteria chosen for the health intervention priority-setting can either be patient-related, disease-related or society-related. However in this study the focus will be disease-related as that is in the scope of this study. The process illustrated in Figure 5.1 will be utilised for this study to select the criteria for prioritising wearable sensors in SSA.

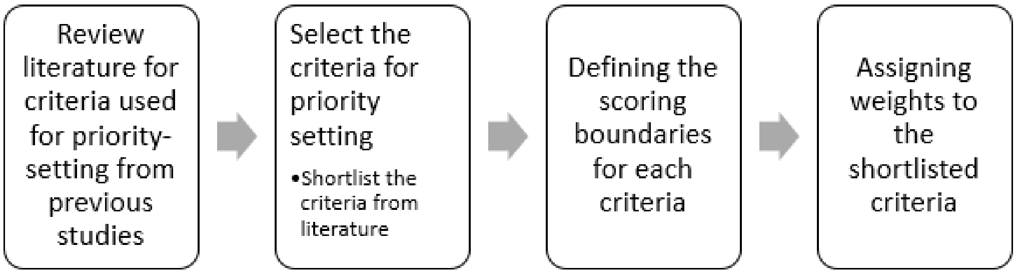

Figure 5.1: Illustration for the process followed for priority-setting for this study.

5.1.1 Published studies where priority-setting was investigated

The information provided in Table 5.1 gives the characteristics of nine studies conducted for priority-setting. The articles that were reviewed for this study were obtained from the Scopus database. In literature, there are no studies that are aimed specifically at priority-setting for wearable devices. Therefore, the articles that were reviewed focused on the introduction of various health interventions in healthcare. All the studies were published after 2004. Six of those studies were conducted in developing countries, namely Uganda, South Africa, Ghana and Nepal. The remainder of the articles focused on developed countries, namely Canada and The Netherlands.

Most of the studies (7 out of 9) primarily aimed at defining criteria for priority-setting in healthcare. The other two studies aimed at performing a field test on the framework developed for priority-setting and development of a model for health technology assessment, respectively. Eight of the studies reviewed focused on prioritisation conducted at national level, while one of the studies did not highlight the level where the prioritisation process was conducted. The studies covered a wide range of priority-setting areas: one study prioritised interventions across the healthcare system, two studies across several disease areas, two studies focused on health technologies and four studies concentrated on health interventions. All the criteria that were selected for each of the studies were identified through previous systematic reviews.

Table 5.1: The previous studies reviewed to obtain the criteria for priority-setting

Number	**Author**	**Study**	**Objective**	**Country**	**Decision-making level**	**Area of prioritisation**	**How to identify criteria**
1	Kapiriri and Norheim (2004)	*Criteria for priority-setting in health care in Uganda: exploration of stakeholders' values*	To explore stakeholders' acceptance of criteria for setting priorities for the health care system in Uganda	Uganda	National level	Health system	Criteria identified from a previous study
2	Tromp and Baltussen (2012)	*Mapping of multiple criteria for priority-setting of health interventions: an aid for decision-makers*	Aim to develop a conceptual mapping of criteria, based on the World Health Organization's Health Systems Performance and Health Systems Building Blocks frameworks. This map can be an aid to decision makers to identify the relevant criteria for priority-setting in their specific context.	The Netherlands	National level	Health interventions	Literature review
3	Noorani *et al.* (2007)	*Priority setting for health technology assessments: A systematic review of current practical approaches*	This study sought to identify and compare various practical and current approaches of health technology assessment (HTA) priority-setting	Canada	n/a	Health technologies	Literature review

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Table 5.1 – *Continued from previous page*

Number	**Author**	**Study**	**Objective**	**Country**	**Decision-making level**	**Area of prioritisation**	**How to identify criteria**
4	Miot *et al.* (2012)	*Field testing of a multi criteria decision analysis (MCDA) framework for coverage of a screening test for cervical cancer in South Africa*	The objective of the study was to field test the framework for decision making on a screening test by a private health plan in South Africa.	South Africa	National level	Health intervention for cervical cancer screening	Literature review of the CADTH, NICE and South Africa's Health Department
5	Baltussen *et al.* (2013)	*Balancing efficiency, equity and feasibility of HIV treatment in South Africa – development of programmatic guidance*	Aim: Propose an alternative approach that provides a better evidence base and outlines a fair policy process to improve priority-setting in HIV treatment.	South Africa	National level	Health interventions for HIV treatment	Based on a previous study
6	Mathew (2017)	*KNOW ESSENTIALS: A tool for informed decisions in the absence of formal HTA systems*	Developing a new model for evaluating health technologies for resource-limited setting lacking health technology assessment systems.	Developing countries and resource-limited settings	National level	Health interventions	Literature review

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Table 5.1 – *Continued from previous page*

Number	**Author**	**Study**	**Objective**	**Country**	**Decision-making level**	**Area of prioritisation**	**How to identify criteria**
7	Baltussen *et al.* (2006)	*Towards a multi-criteria approach for priority-setting: an application to Ghana*	Many criteria have been proposed to guide priority-setting in health, but their relative importance has not yet been determined in a way that allows a rank ordering of interventions	Ghana	National level	Several disease area	Literature review
8	Husereau *et al.* (2010)	*Priority setting for health technology assessment at CADTH*	The aim of this study was to describe a current practical approach of priority-setting of health technology assessment (HTA) research that involves multi-criteria decision analysis and a deliberative process.	Canada	National level	Health technology	Through a previously published systematic review
9	Baltussen *et al.* (2007)	*Priority setting using multiple criteria: should a lung health programme be implemented in Nepal?*	To identify and weigh the various criteria for priority-setting, and to assess whether a recently evaluated lung health programme in Nepal should be considered a priority in that country.	Nepal	National level	Several disease area	Through a previously published systematic review

5.1.2 Defining criteria

After reviewing the nine articles listed in Table 5.1, a total of 43 criteria that can be used during priority-setting were identified (see Appendix D, Table D.1). The selected criteria are listed in Table 5.2, the table also indicates in which of the nine studies listed in Table D.1 each criteria has been used for priority-setting. The criteria that were most frequently identified for priority-setting were: cost-effectiveness, severity of the condition and budget impact (6 studies). These were followed by cost of treatment, size of population affected by disease, burden of disease, effectiveness of treatment and age. Other criteria included improvement of patient-reported outcomes and number of people benefiting. The cost of treatment and effectiveness criteria overlap; therefore these can be combined when evaluating the cost-effectiveness analysis if necessary.

Table 5.2: The criteria that have been identified in previous studies for priority-setting.

Number	**Criteria**	**[1]**	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**	**[7]**	**[8]**	**[9]**	**Total**
1	Cost-effectiveness	1		1	1		1	1		1	6
2	Severity of the condition	1	1		1	1		1		1	6
3	Budget impact		1	1	1	1		1	1		6
4	Costs of treatment	1	1	1			1		1		5
5	Size of population affected by disease (Target group)				1	1	1	1		1	5
6	Burden of disease		1	1			1	1	1		5
7	Effectiveness of treatment	1	1		1	1	1				5
8	Age	1	1			1		1		1	5
9	Improvement of patient-reported outcomes		1		1		1			1	4
10	Number of people benefiting	1	1		1	1					4

The criteria were grouped into three different categories as performed in a previous study by Mathew (2017). The categories were economics, knowledge of need and intervention outcomes as shown in Figure 5.2. The economics category contains the follwing three criteria: unit cost or treatment cost, cost-effectiveness and budget impact analysis. The criteria in the knowledge of need category are: disease burden, disease severity, and size of population affected by disease. The interventions outcomes that are considered for this study are improvement of patient-reported outcomes, effectiveness and number of people benefiting from the intervention. In the remainder of this section, a brief overview of each of the three categories of criteria is provided.

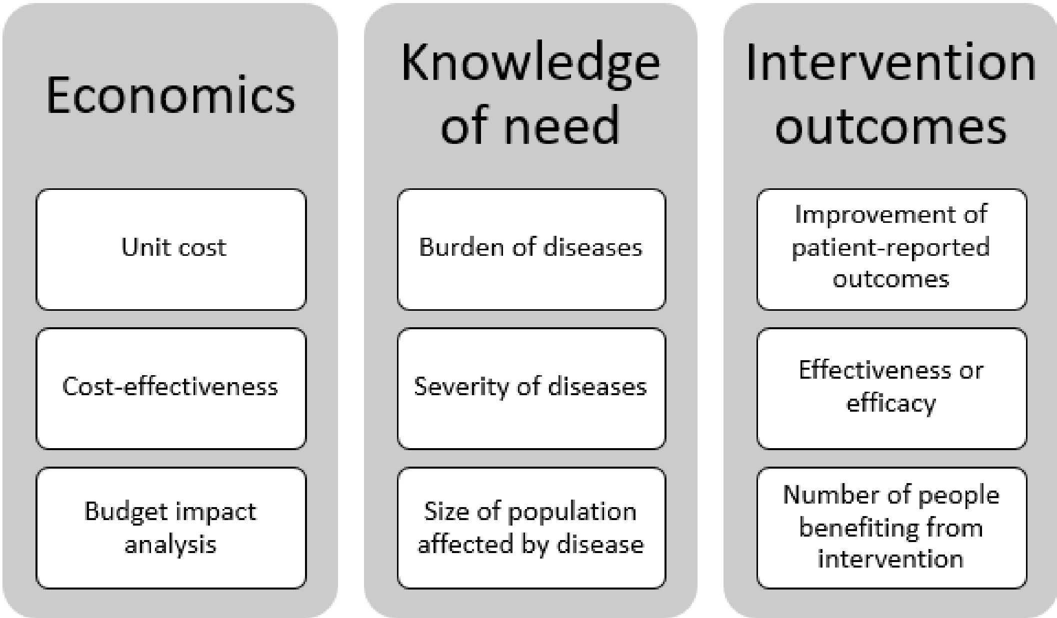

Figure 5.2: Categories for the selected criteria

5.1.2.1 Economics

In this context health economics is concerned with the costs that new interventions exert on the health system, government and society (Husereau *et al.*, 2010). Health economics help determine the value of the new health interventions in the health system and the impact on the health expenditure of a country relative to the DALYs averted. The costs could be in the form of direct and indirect costs[1] associated with the health intervention. The costs could be in terms of (i) cost of the health technology, (ii) cost of providing the technology, and (iii) cost-effectiveness (cost-to-benefit ratio) (Mathew, 2017).

WHO-CHOICE was a project developed by WHO in order to provide evidence when priority-setting about impact and cost-effectiveness (World Health Organization

[1] As stated in Chapter 2 direct costs refer to price that can be completely attributed to the production of specific goods or services (Investopedia, 2016). Indirect costs refer to the productivity loss that is faced as a result of absenteeism at work caused by either illness, presenteeism or premature death (Luppa *et al.*, 2007)

(WHO), 2014*b*). WHO-CHOICE provides data on the cost-effectiveness of some health interventions in 14 different epidemiological regions for leading causes of disease burden, including analysis of the interactions inherent in many combined interventions. In order to perform detailed cost-effectiveness the WHO-CHOICE OneHealth tool can be utilised (World Health Organization (WHO), 2014*b*).

A budget impact analysis is an assessment that approximates the financial outcomes after the inclusion of a new intervention in a system. The budget impact analysis takes into account the population of the affected people and multiplies it by the unit cost of an intervention to determine the total budget required to fund the intervention. The main purpose of the budget impact analysis is to determine whether an intervention is affordable (U.S. Department of Veterans Affairs, 2016).

If an intervention can not meet the paying capacity of the stakeholders then it can be neglected by the decision-makers. This can be used as a feasibility indicator on whether it is possible to add an intervention rather than keeping the current intervention(s) in place.

5.1.2.2 Knowledge of need

For this study, the disease burden metric used is the DALY metric that is mentioned in Chapter 2. This metric has been used in previous studies when determining the disease impact (Baltussen *et al.*, 2006; Kapiriri and Norheim, 2004; Mathew, 2017; Miot *et al.*, 2012). The severity of the disease is measured using the disability weights. The disability weights indicate the health levels of an individual associated with non-fatal outcomes (Haagsma *et al.*, 2015). Therefore, the severity of the disease that is targeted can be used to determine the value of the new health intervention(Miot *et al.*, 2012).

In determining the need for the intervention it is necessary to have knowledge of the number of people affected by the condition (shows the intended coverage of the intervention) among a specified population at a specified time. The number of affected people can be specified as the annual number of new cases (annual incidence) and/or proportion of the population affected at a certain point in time (prevalence) (Miot *et al.*, 2012).

5.1.2.3 Intervention outcomes

When a health intervention is introduced it is vital to have knowledge on the outcomes it provides in order to gauge the value it will add. In reality the management of a single healthcare condition can lead to multiple desirable outcomes. Stakeholders are usually interested in knowing the health outcomes through the mortality, morbidity or quality of life. When going through the decision making process it is necessary to use these health outcomes to make evidence-based decisions (Mathew, 2017).

The improvement in patient-reported outcomes are used to assess the capacity of the proposed intervention to produce beneficial changes in patient-reported outcomes (e.g., quality of life) above and beyond beneficial changes produced by alternative interventions (Miot *et al.*, 2012; Tromp and Baltussen, 2012). This assessment is important because it provides an idea of the improvement caused by interventions from a patient-centred perspective.

Effectiveness of health interventions was estimated based on published information on the magnitude of health gain (Hutubessy *et al.*, 2003; Miot *et al.*, 2012). Effectiveness was obtained by adjusting efficacy by a factor between 0 and 1 to allow for less than perfect adherence to recommended practices (Evans *et al.*, 2005). Efficacy is based on research data and estimates whether a health technology could work at all. It is evidence-based and readily available through systematic reviews, randomised trials, etc. Evidence of efficacy ought to be used only if evidence of effectiveness in the local population is not readily available (Mathew, 2017).

The number of people benefiting from an intervention reflects the economies of scale (Tromp and Baltussen, 2012). The economies of scale theory states that as more units are produced the cheaper the unit cost. Therefore, interventions that target a large number of people make the unit cost lower based on the economies of scale.

5.2 The availability of data

In order to perform evidence-based priority-setting for the application of wearable technologies to the prioritised diseases in the SSA landscape, there is a need to determine whether the necessary data to calculate the various criteria scores is available. In this section, the availability of data to evaluate each of the ten criteria will be considered.

5.2.1 Data availability for various economic criteria

There are a variety of databases that can be used to perform economic evaluations. However there is a lack of data in developing countries. The WHO-CHOICE project provides information that can be used to estimate cost-effectiveness and budget impact analysis (World Health Organization (WHO), 2014*b*).

5.2.1.1 Data availability for cost-effectiveness criteria

The unit cost is the cost incurred by a manufacturer to produce, store and sell one unit of a particular product (Tromp and Baltussen, 2012). The data for wearable sensors is available in catalogues for big manufacturing companies such as Digikey, Sensonor Electronics and Mouser Electronics (DigiKey Electronics, 2017; Mouser Electronics, 2017; Sensonor, 2017).

5.2.1.2 Cost-effectiveness

When performing a cost-effectiveness analysis there is a need to determine the costs incurred with the current health interventions. The analysis is performed by setting up different scenarios (Evans *et al.*, 2005):

- The no-intervention scenario - This is to evaluate the cost-effectiveness when the interventions are ceased over a period of time.
- Determine the effects of all the new interventions by either adding them singly or in different combinations in the health system.

The data that is used for cost-effectiveness can be collected from the World Bank health sector databases (The World Bank, 2016). These databases provide the data of the costs and effectiveness of health interventions aimed at major health problems for developing countries. In turn, the World Health Organization estimated costs per DALY for a wide range of health interventions for 14 epidemiological sub-regions (World Health Organization (WHO), 2014*b*). The burden of disease can be measured using the DALY metric highlighted in Chapter 2. In order to have an entire overview of the effects of the intervention other criteria have been defined. These include medical criteria (such as severity of disease) and non-medical criteria (such as patient age).

There is not enough information on the application of wearable sensors that can be used to perform cost-effectiveness analysis from these databases. The formulas provided in Chapter 2 can be used to determine the total cost of the interventions at a population level. The coverage of the intervention can be assumed to be 80 percent as done in previous studies (Hansen and Chapman, 2008).

Determining the costs associated with the healthcare providers is still questionable because there still needs to be a clear-cut distinction on their contribution and how much it will cost. When determining direct cost aspects such as travel cost may be removed, because wearable devices allow remote monitoring (Burri *et al.*, 2011).

Table 5.3: Direct and indirect costs associated with remote monitoring through the payer's perspective

Costs		Available	Unavailable	Comment
Direct costs	Medical Services		X	These values are associated with the consultation fees paid. The fees will be less compared to a regular in-office consultation.
	Medication Cost	X		This could be costs associated with insulin pumps
	Intervention cost	X		The wearable device cost and the home transmitter cost
	Travel Cost		X	Because it is remote monitoring the travel costs are reduced therefore estimating them can be difficult because it depends on the number of emergency cases.
Indirect cost	Productivity loss due to absentism		X	This can be determined because the data is collected for every person using a wearable device because there is access to personal records through EMR cost

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Table 5.3 – *Continued from previous page*

Costs		Available	Unavailable	Comment
	Productivity loss due to presentism		X	
	Productivity loss due to premature death		X	
Additional costs associated with indirect costs for remote monitoring	Patient education or training		X	Patient training provides them information regarding the proper use and installation.
	Maintenance and services of server	X		This is associated with maintenance of the server, telecommunications costs and staffing of the technical support helpline.
	Impact on device longevity		X	This is a long-term cost analysis of technical aspects of remote monitoring and costs associated with replacement and frequency of maintenance services
	Administrative work associated with setting up electronic medical records	X		Electronic medical records makes it easy for patients and physicians to have access to the patients history on the server.

The data available to perform cost-effectiveness for wearable sensors is not sufficient to draw comprehensive conclusions from it. This study aims at determining the areas of application, therefore making it infeasible to carry out a cost-effectiveness analysis at this point in time. In the future data will be available when wearable sensors have actively entered the SSA health system.

5.2.1.3 Data availability for budget impact analysis criteria

The budget impact analysis is performed alongside cost-effectiveness. When performing a budget impact analysis the data used is over a period of time and the analysis is focused on the differences between when the interventions were introduced as well as before that. The difference between the cost of these two scenarios costs is the impact. The time period when conducting the analysis can be between 1 and 5 years (Restelli *et al.*, 2017; Sullivan *et al.*, 2013).

The data that is required to perform the budget analysis include:

- **Target population**–The target population can be considered using the incidence rate. The incidence data is available.

- **Use and cost of current and new interventions**–The cost of the current interventions and new interventions. The impact can be determined through three changes: the new interventions replace one or more current interventions (substitution), the new intervention is added to the current interventions (combinations) and the new intervention is used in situations in which there has been no active intervention (only supportive care) or in patients who have stopped or would not use available interventions owing to intolerance, inconvenience, loss of effect, or any other reasons (expansion). These changes are analysed over a period of time (Sullivan *et al.*, 2013).

For wearable devices no budget impact analysis studies have been performed for the SSA setting. Therefore, budget impact analysis cannot be used for prioritisation in this research as there is insufficient data to carry it out.

5.2.2 Data availability for various 'knowledge of need' criteria

When decision-making it is essential to know whether there is a justifiable need for the new technology to address the healthcare challenge (Mathew, 2017). The challenge in developing countries is that they are faced with technologies that do not address local primary needs (Wright and Walley, 1998). If health services are to respond to the changing health needs of their local populations, then planners and managers need useful and timely information about the health status of these populations (Wright and Walley, 1998). For this study the data that can be used to identify the need of the local population is in terms of disease severity, disease burden, size of population affected by disease, urgency of need of care and alternative interventions.

5.2.2.1 Data availability for disease burden criteria

The data for the DALY metric is available in the public domains such as World Health Organization databases for the year 2016 (World Health Organization (WHO), 2016).

The data is arranged as cause-specific and age-specific for the prominent diseases, globally.For this study, the cause-specific data will be most relevant because of the need to prioritise through the knowledge of the healthcare challenges linked to the disease burden for the top diseases that are burdening SSA, as provided in Chapter 2.

5.2.2.2 Data availability for disease severity

Disability weights are quantitative estimates of health losses. The data for the different disability weights for the various diseases found globally can be found from GBD studies (Haagsma *et al.*, 2015). The GBD study that was conducted in 2013 estimated disability weights for 235 health states. The disability weights that will be considered for this study will be for the top diseases burdening SSA.

5.2.2.3 Data availability for size of population affected by disease

The data for the incidence or prevalence rate is available from the GBD study (Murray, 2015*a*). It would be ideal to use prevalence because it give the number of people affected by a disease over a period of time. In the case where prevalence data is not available incidence, of a disease is used instead (Husereau *et al.*, 2010; Miot *et al.*, 2012).

5.2.3 Data availability for intervention outcome-related criteria

In order to determine the availability of data on intervention outcomes, a literature review is performed to get information on the clinical trials or clinical evaluation of wearable sensors. These outcomes outline how effective and safe an intervention is when being used to address a healthcare challenge.

5.2.3.1 Data availability for patient outcomes criteria

The data for the patient outcomes of the wearable sensors are not available for some of the diseases being considered for this study. The data is acquired through randomised clinical trials and systematic reviews. The information on the improvement of patient-reported outcomes may be available for wearable sensors designed to monitor NCDs but not for infectious diseases. This is because devices for cardiovascular diseases (AiQ, 2016) and diabetes are already available on the market (Abott, 2016). Due to the fact that wearable devices have not yet been applied to many of the diseases for which its application is being considered in this research, the improvement of patient-reported outcomes criteria can not be used for prioritisation of interventions in this research.

5.2.3.2 Data availability for effectiveness or efficacy criteria

The effectiveness of the wearable sensors is challenging to determine because of the scarcity of clinical trials on the applications that are being suggested for this study (Burri *et al.*, 2011). Therefore for this study efficacy is going to be used for prioritisation. Efficacy is the capability of a health intervention to produce the desirable health outcomes.

Efficacy data for the wearable sensors is available in the form of accuracy, sensitivity[1] and specificity[2]. This data is available in literature where various investigations have been conducted to determine the performance of these wearable sensors. Therefore, this information is necessary because it shows whether the sensor can deliver accurate outcomes that meet the medical requirements.

5.2.3.3 Data availability for number of people benefiting criteria

The estimates of the number of people to benefit from the wearable sensors can not be determined now before a detailed business model is produced. The business model will be designed specifically to address the tackling of the diseases in SSA. Therefore, the data is not available and this criteria will be excluded from further considerations (Tromp and Baltussen, 2012).

5.2.4 Conclusion: Availability of data for priority-setting

In summary the short list of the criteria that will be used further for this study are: (See illustration in Figure 5.3.)

- For the economic category, the unit costs of the sensors will be used;
- For the knowledge of need category, the following three criteria will be used:

[1]Sensitivity is the ratio of the incremental change in the sensor's output to the incremental change of the measured input (Du, 2015)

[2]Specificity (also known as selectivity) is the sensing system's ability to measure a target measured in the presence of others interferences (Du, 2015).

(i) burden of disease;

(ii) disease severity;

(iii) size of population affected by the diseases;

- Intervention outcomes in the form of efficacy

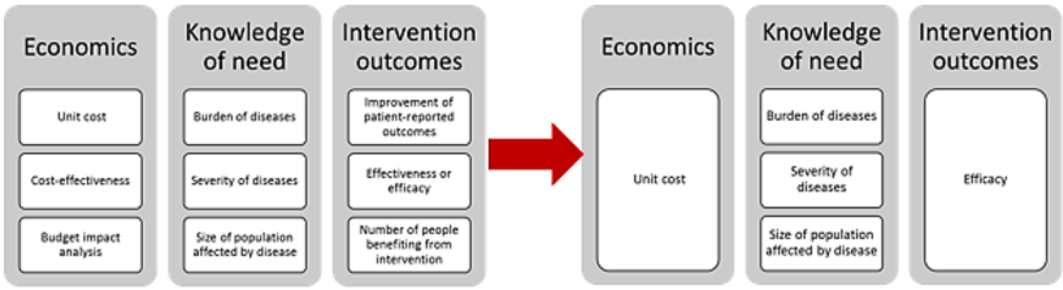


Figure 5.3: Categories for the selected criteria

5.3 Scoring the defined criteria

The criteria that are identified during priority-setting can easily be contradicted in terms of importance. Therefore, there is a need to determine the weights for the defined criteria (Baltussen and Niessen, 2006). The different weights allow rank ordering of interventions so that it becomes easier when prioritising based on a composite score.

5.3.1 Composite score

A composite score is the total score for the intervention against each criteria that will be considered. This score is used to rank the different interventions that are being investigated. The composite score is dependent on the weights attached to each evaluation criterion that reflect the relative importance of each criterion. Each criterion is assigned a numerical score based on the scale developed. The more favourable options are given a higher score and less favourable options score lower. The scoring can be based on a value function, which translates the weight on the criterion to a value score on the scale (Baltussen *et al.*, 2006). The methods that can be used to determine this composite score include the simple linear additive evaluation model, analytical hierarchy process and outranking methods.

The simple linear additive evaluation model is applied when it can either be proved, or reasonably assumed, that the criteria are preferentially independent [1] of each other. The linear model shows how an option's values on the many criteria can be combined into a composite score. This is done through multiplication of the value scored for each criterion by the weight of that criterion, and then adding all those weighted scores together (Baltussen *et al.*, 2006). The formula that can be used to determine the composite score is

$$S_i = \sum_j w_j x_{ij} \tag{5.3.1}$$

where S_i is the composite score of the i^{th} intervention, w_j is a predetermined weight of the j^{th} criterion and x_{ij} is assigned quantitative score of each criteria.

5.3.2 Weighting methods

As discussed, criteria can be given either equal or differentiated weights, reflecting the relative importance of the various criteria. Assigning differentiated weights significantly influences outcomes of the composite score (Freudenberg, 2003) and this approach should therefore only be followed after careful consideration. Greater weight should be given to components which are considered to be more significant in the context of the composite score. The different criteria can be weighted using different approaches namely equal weighting, statistical models and participatory methods (Freudenberg, 2003; Nardo *et al.*, 2005; Pizzol *et al.*, 2017).

Equal weighting is when all the variables are given the same weight. When there is insufficient knowledge of causal relationships or a lack of consensus then a prudent approach is to assign all the variables an equal weighting in the composite score (Nardo *et al.*, 2005; Pizzol *et al.*, 2017). For instance, Youngkong *et al.* (2012) performed a study where they had to perform a multi-criteria decision analysis for health interventions that are in the universal health coverage benefit package in Thailand. In this study, the panel agreed to use the equal weighting method because they could not meet

[1] Preferential independence is when the preference order over one attribute does not change regardless of where the values are fixed.

a consensus on the weights to be used.

Statistical models that are considered for the weighting methods include principal component analysis, regression analysis and factor analysis. These could be used to group individual criteria according to their degree of correlation. In order for this method to be applied there needs to be a correlation between the different criteria (Freudenberg, 2003; Nardo *et al.*, 2005). For example, in a study performed by Baltussen *et al.* (2007), they used the regression analysis method to determine the weights for the different criteria that can be used for a decision-making process to determine if a lung-health programme should be implemented in Nepal.

The participatory method includes the involvement of various stakeholders such as subject matter experts, citizens and government officials. These stakeholders assist in the assigning of weights for the different criteria defined. This approach is feasible at the national level when there is a well-defined base of evidence to motivate differentiating between the relative importance of the various criteria. For international comparisons the challenge is that the results are likely to be contradictory as the value that is attached to various criteria likely differs from one region or country to another, based on contextual factors. Opinion-based weighting approaches can be quite subjective and introduce new distortions to a composite score (Nardo *et al.*, 2005). In previous studies the weights that were used were dependent on the opinion that was provided by the public, health providers and government officials (Miot *et al.*, 2012; Noorani *et al.*, 2007)

For this study the method that is selected is equal weighting because there is insufficient knowledge of the causal relationship between the different criteria. Conducting a participatory method and obtaining weightings from health experts and the public is beyond the scope of this research.

5.4 Criteria scales

This section provides the scale that will be used to ensure that the various technologies and their potential applications are evaluated in a consistent manner for each criterion. The scale simplifies the evaluation and makes it possible to compare criteria with different dimensions. The scores that are determined from the scales can be used to calculate the composite score for each criteria.

In this study, in the event that a criteria is considered to have high priority it is given a score of 5 and when it has lowest priority it is assigned a score of 1. This is illustrated in Table 5.4 where a scoring scale is provided for each criterion. The scales provided in Table 5.4 are briefly discussed::

(i) The most expensive sensors that are currently on the market are approximately \$2000 per unit cost and the lowest cost for the sensors identified in Chapter 3 was \$0.59 (DigiKey Electronics, 2017). Decision-makers favour sensors that have the lowest unit cost because this shows minimum costs associated with the production of a single unit.

(ii) Youngkong *et al.* (2012) used the disability weights to estimate the severity of diseases based on the GBD study weights (World Health Organization, 2004). When a person is perfectly healthy the disability weight is 0 and in a fatal condition it is 1. Therefore, interventions that target fatal conditions are most likely to be prioritised by decision-makers because they add more value to the healthcare system.

(iii) The size of population affected by disease indicates the impact of the disease on the population and can be expressed in terms of prevalence. For this study the prevalence rate per 100,000 will used to prioritise the diseases. If the prevalence of the disease affects less than 10 percent of the total population in a specific area it is defined as a rare disease, receives a low score. In the case when the prevalence rate is above 30 percent then it is considered as high.

(iv) Burden of diseases is scaled according to the percentage of the DALYs of that disease to the total DALYs in SSA. According to the World Health Organization (WHO) (2016) databases the high burden diseases in each region were approximately 10 percent of the regions' total DALYs.

(v) Efficacy of wearable sensors was scored based on the scale developed by U.S. Food and Drug Administration (2013) that stated the lowest accuracy that is acceptable is 60 percent for medical purposes.

In addition to these criteria, criterion will be considered to focus on the possible applications of wearable sensors based on the SMEs feedback. This information data will be useful in prioritising wearable sensors as it indicates the importance of each sensor. The application will cover the different stages of care as highlighted in Chapter 4. The score was based on the responses from the SMEs. In order to have a clearer picture on the adoptability of wearable sensors a TRL assessment was added as a criterion. The data is available from literature and will be used to define the levels for the respective wearable sensors.

Table 5.4 indicates the different scales and the scores that are used to quantify each criterion shortlisted for this study. The scores will be used in Chapter 6 to determine the composite score and prioritise the diseases and the wearable sensors.

Table 5.4: The scores for the different criteria

Criteria	Parameter	Scale	Score	Comments
Unit cost	US dollar	more than $150[1]	1	The society favours interventions that are within their paying capacity and not expensive.
		$100-150	2	
		$50-100	3	
		$1-50	4	
		less than $1	5	
Severity of the condition	Disability weight	less than 0	1	The society is prone to prioritise interventions that target the severely ill people because of their need for medical attention. Therefore an improvement in health from a severe condition is valued more than from a less severe condition
		0,01 -0,2	2	
		0,21-0,4	3	
		0,41-0,6	4	
		more than 0,6	5	
Size of population affected by disease	Incidence rate	less than 100	1	Decision-makers may want to give preference to health interventions that target a larger population because they have a larger impact for society
		100-499	2	
		500-999	3	
		1000-1499	4	
		more than 1500	5	
Burden of disease	% DALYs in SSA	less than 1 %	1	Interventions that focus on high burden disease are more likely to be prioritised
		2-3 %	2	
		4-6 %	3	
		7-9 %	4	
		more than 10 %	5	
Efficacy of health interventions	Accuracy, specificity and sensitivity	less than 60%	1	Societies favour interventions that are highly effective for treatment, rehabilitation, diagnostic and preventative purposes.
		61-70%	2	
		71-80%	3	
		81-90%	4	

Continued on next page

[1] The sensors that cost over $500 were based on the manufacturers that produce expensive sensors on the market whereas for the same products there are sensors available at cheaper prices of less than a $1

Table 5.4 – *Continued from previous page*

Criteria	Parameter	Scale	Score	Comments
		More than 90%	5	
Applications of wearable sensors	Number of identified applications	less than 1	1	Societies favour interventions that can be used to address a wide variety of application during disease management.
		1	2	
		2	3	
		3	4	
		More than 4	5	
Technology Maturity	TRL Assessment	TRL 1-2	1	Societies favour interventions that have been fully developed and can be easily adopted by people with little or less resistance.
		TRL 3	2	
		TRL 4-5	3	
		TRL 6-7	4	
		More than TRL 8	5	

5.5 Conclusion: Define criteria for prioritising wearable devices

The purpose of this chapter was to define the criteria that can be used to prioritise the wearable sensors. This process included a literature review to identify the various criteria that are utilised when prioritising health interventions. Then the lists were short-listed based on the frequency of use in previous studies and the availability of data, followed by the description of the scoring methods and motivating the weighting methods used in this study. Finally, the scales set from previous studies and the score (from 1 to 5) that will be used for priority-setting were defined. Therefore, Table 5.4 will be used in Chapter 6 to prioritise the diseases and the wearable sensors.

CHAPTER 6

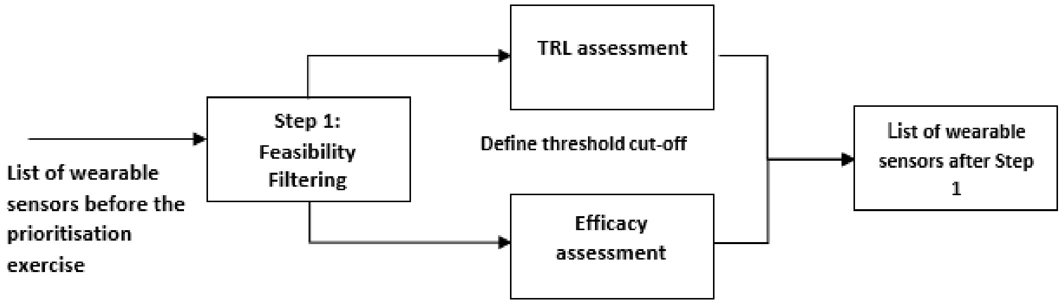
POTENTIAL OF WEARABLE SENSORS

This chapter comprises a prioritisation exercise to make recommendations on wearable technologies applications that have significant potential, presented in Sections 6.1 to 6.4. In Section 6.5 a stakeholder perspective analysis is conducted, which should also be taken into consideration when further developing the recommended applications.

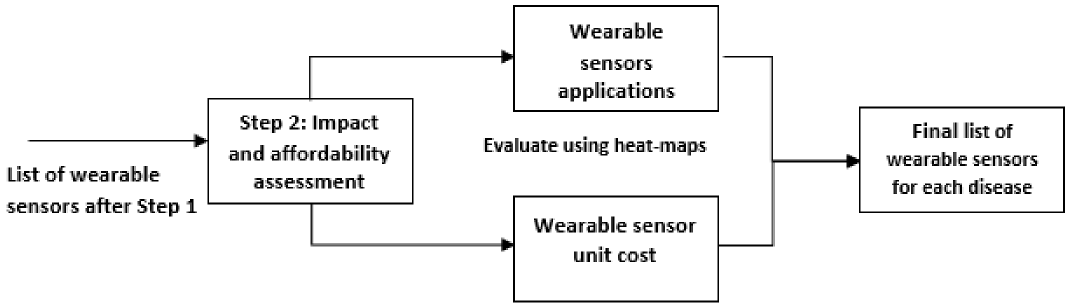
6.1 Introduction: Prioritisation approach

The prioritisation approach was used to determine the potential of wearable technology. The approach highlights the wearable sensors and diseases that will receive highest priority when introducing wearable technology in SSA. The prioritisation approach has been used to determine the potential of health interventions in order to enable decision-makers to make informed decisions especially in regions that are resource limited (Kapiriri and Norheim, 2004).

Figure 6.1 shows the process followed for the prioritisation approach. The prioritisation is divided into two different steps namely: (i) feasibility filter, and (ii) impact and affordability assessment.



(a) The process followed during Step 1 of the prioritisation approach



(b) The process followed during Step 2 of the Prioritisation Approach

Figure 6.1: The process followed during the prioritization approach

Step 1 of prioritisation is a feasibility filter. During this step only the following two criteria are considered: efficacy, and TRL. Sensors will be further considered for the remainder of the study if they pass the specified threshold in terms of both of these criteria as shown in Figure 6.1a.

Step 2 of the prioritisation is an impact and affordability assessment which relies on a heat map approach, only sensors that passed the minimum feasibility threshold in Step 1 are included for consideration in Step 2. The heat maps therefore contain only the following criteria: DALYs, incidence rate, disease severity, number of applications and unit cost. In this step efficacy and TRL are omitted from the heat maps as they have been taken into account during the feasibility filtering performed in Step 1. The process followed for Step 2 is shown in Figure 6.1b.

The results of the two prioritisation steps inform a qualitative discussion outlining the potential of wearable technology for each of the diseases discussed in this study.

Finally, recommendations will be made based on wearable applications that appear to show significant potential and should therefore be prioritised for development.

6.2 Prioritisation Step 1: Feasibility filter

This section aims at assessing the feasibility terms of the TRL and the efficacy separately and provide a summary of the sensors that are excluded from further consideration based on a joint consideration of the two criteria. In this section general recommendations are provided for wearable technology after the TRL assessment.

6.2.1 Technology readiness of wearable sensors

The feasibility cut-off point for the technology readiness is TRL 6 because at this level the prototype is fully functional and awaiting testing on the subjects. Research and development of wearable devices is possible through public and private financial support. The financial support in SSA is focused on the reduction of infectious diseases such as TB, HIV and malaria. Limited funds will force policy-makers to favour the introduction of wearable devices that require minimum or no research and development costs. Therefore sensors that have a TRL below level 6 will be excluded from the rest of the study.

6.2.1.1 Technology readiness assessment of sensors

The indicators that were utilised to allocate the wearable sensors in their respective levels are:

- Research and development–the availability of data on the research conducted towards the development of the technology.
- Clinical trials–research on the health-outcomes or efficiency of the readings of the wearable sensors.
- Technical performance–the availability of discoverable technical performance information.
- Regulatory environment–the maturity of the planning, permitting and standards relating to the technology.

- Industry supply chain and skills–the development of a competitive and efficient industry product and skills supply chain required to support a commercially viable sector.

Technology maturity is used to determine the level of development and the performance of the technology. Figure 6.2 illustrates the maturity of wearable sensors that have currently been developed.

The accelerometers, magnetic sensors, gyroscopes, pedometer, PPGs, ECG electrodes, pulse oximeter, blood pressure meter, infra-red thermopile, respiratory meter, biosensor and EEG have reached their technology maturity level TRL 9 where the technology has undergone all the levels. In the market the demand for accelerometers is growing and the driving force for the markets are factors such as huge demand from the consumer electronics industry; stringent government regulations; the emergence of efficient, economic and compact MEMS technology; growing adoption of automation and rising demand from emerging economies. Accelerometers have the highest market share, followed by ECGs and PPGs.

ECG and accelerometers have reached the highest level of commercial readiness compared to all the devices because of their use in the industry. This is because there are several types of ECG electrodes being developed and there is immense competition to produce effective and efficient electrodes for healthcare purposes both at hospital and home settings. Apple has developed a version of Series 4 smartwatch with an ECG sensor which has recently been FDA approved will soon be available on the market.

Pedometers, magnetic sensors, blood pressure meter and biosensors are at a stage where they are experiencing commercial scale-up. During commercial scale-up the wearable sensors are introduced to the market on a bigger scale and target a bigger market. Policies are starting to be implemented to regulate the use of these wearable sensors. The companies that are currently dominating the wearable technology market are:

- Fitbit
- Samsung

- Apple
- Xiaomi
- ODG

The wearable sensors that are below the threshold are pulse CO-oximetry, transepidermal water loss sensor, electrodermal activity sensor, phonocardiography, EMG electrodes and impedance cardiography. These sensors are still undergoing research and development and prototypes that have been developed have not undergone clinical trials, therefore they will not be considered for further studies.

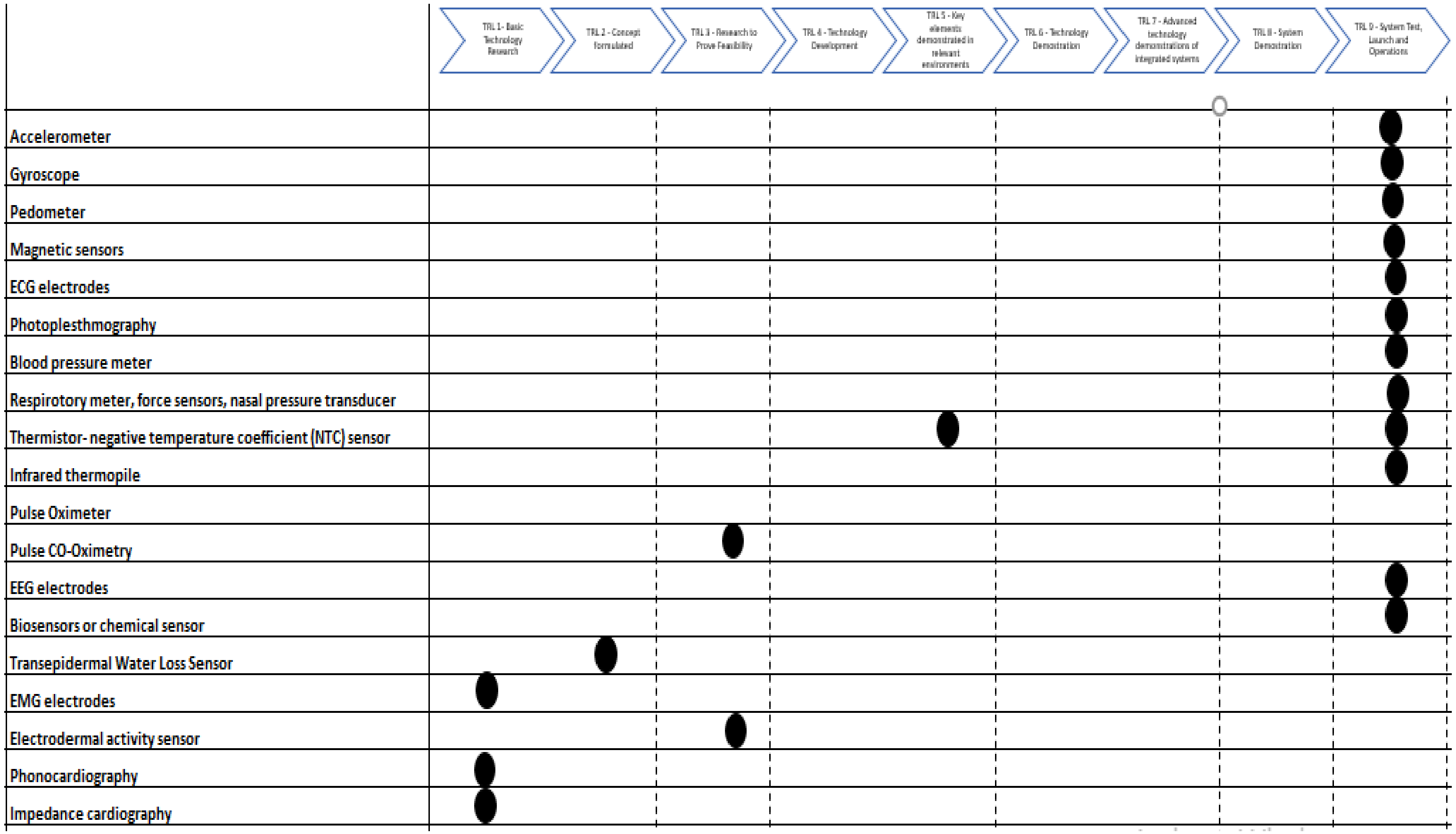


Figure 6.2: The TRL Assessment of the wearable sensors

6.2.1.2 Infeasible sensors, according to technology readiness assessment

The wearable sensors that are below the threshold include:

- Pulse CO-oximetry;
- Transepidermal water loss sensor;
- Electrodermal activity sensor;
- Phonocardiography; and
- Impedence cardiography.

6.2.1.3 General recommendations based on technology readiness assessment

This section briefly describes the general recommendations that can be made for wearable technology after the technology readiness assessment. The general recommendations that can be made are:

- As of now the wearable sensors that have been identified are already competitive on the market can be introduced to SSA and will not need much research and development.
- Perform clinical trials with some of these wearable sensors on people of African ethnicity as most of the devices were tested on Caucasian people. Previous studies have proven that PPG's efficiency is affected by the level of melanin.
- Perform pilot studies and determine the adoption and commercial readiness on the application of wearable sensors in healthcare facilities in the region.
- Perform a technology acceptance study and get more detail on the factors that affect the adoption of wearable sensors and the development.
- The introduction of sensors such as accelerometers and gyroscopes will be easier as already people have been exposed to them through using them in smart phones.

6.2.2 Efficacy of sensors

In this section the efficacy of the wearable sensors will be assessed using the three criteria identified in Chapter 5, namely accuracy, sensitivity and specificity. The U.S. Food and Drug Administration (2013) stated that the lowest accuracy that is acceptable is 60 percent for medical purposes, the reason being if the wearable sensor is unreliable it puts the user at high risk. Using the scale developed in Chapter 5 the feasibility cut-off score is 3.

6.2.2.1 Efficacy assessment of sensors

Table 6.1 provides the data of the wearable sensors that will be used for priority-setting in Section 6.1. The accuracy of temperature sensors namely infra-red thermopile and thermistors is stated as the tolerance (as shown in Table 6.1) were the tolerance is ±9.5 °C and ±0.2 °C, respectively. For the rest of the sensors they utilise 'gain error' which depends on the magnitude of the input signal and is expressed as a percentage of the reading, such as 90 percent.

Table 6.1: The data collected on wearable sensors for the prioritisation process

Wearable Sensors	**Accuracy**	**Sensitivity**	**Specificity**	**Sources**
Accelerometer	93%	83%	67%	(DigiKey Electronics, 2017; Yang and Hsu, 2010)
ECG electrodes	97-98%	87,5-99,34%	91,67-99,31%	(Digikey, 2017; Guo *et al.*, 2016; Harmon *et al.*, 2015; Shyamkumar *et al.*, 2014)
PPG	89 %	91%	88%	(NeuroSky, 2016; Yu *et al.*, 2006),
Respiratory meter (force sensors), nasal pressure transducer	75 ± 13%	92%	72%	(BaHammam, 2004; Mouser Electronics, 2017; Yang *et al.*, 2015)
EEG electrodes	63%	62-70%	86-90%	(Rubin *et al.*, 2014)
Biosensors or Chemical Sensors	89%			(Bruen *et al.*, 2017)
EMG electrodes	80%	77%	71%	(DigiKey Electronics, 2017)
Infrared thermopile	±9.5 °C			(DigiKey Electronics, 2017)
Oximeter	99,47%	100%	100%	(Floyd *et al.*, 2015; Jubran, 1999; Khalifa *et al.*, 2012)
Blood pressure meter	44%	80%	68%	(Shahbabu *et al.*, 2016)

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Table 6.1 – *Continued from previous page*

Wearable Sensors	Accuracy	Sensitivity	Specificity	Sources
Gyroscope	$78 \pm 1\%$	91%	92%	(DigiKey Electronics, 2017; Sensonor, 2017)
Pedometer	56%			(Husted and Llewellyn, 2017)
Electro-dermal activity sensor	89%	93,90%	85,36%	(Zangróniz *et al.*, 2017)
Thermistor-negative temperature coefficient (NTC) sensor, nasal or oronasal thermistor	$\pm 0.2\,°C$			(Mouser Electronics, 2017)
Magnetic sensors	71%			(Kunze *et al.*, 2010; Mouser Electronics, 2017)
Phonocardiography	no available data			
Impedance cardiography	no available data			
Transepidermal Water Loss Sensor	no available data			
Pulse CO-Oximetry	63,9-83,1%	43,5-91,8%	54.5-100%	(Barker *et al.*, 2016; DigiKey Electronics, 2017)

A detailed discussion of the efficacy of the respective wearable sensors is provided in Appendix E Table E.1.

6.2.2.2 Infeasible sensors, according to efficacy assessment

The wearable sensors that are disqualified based on the threshold efficacy level are:

- Infra-red thermopile;
- EEG;
- Blood pressure meter;
- Pedometer;
- Phonocardiography;
- Impedance cardiography;
- Transepidermal water loss sensor; and
- Pulse CO-oximetry

6.2.3 Conclusion: Feasibility filter

This section contains a list of sensors that are excluded from the remainder of the prioritisation exercise. They were disqualified based on either the TRL assessment or the efficacy feasibility filtering. The list is as follows:

- infra-red thermopile;
- EEG;
- Blood pressure meter;
- Pedometer;
- Phonocardiography;
- Impedence cardiography;
- Electrodermal activity sensor;
- Transepidermal water loss sensor; and
- Pulse CO-oximetry

6.3 Prioritisation Step 2: Impact and affordability

This section aims at assessing the impact and the affordability in terms of the following criteria, defined in Chapter 5: the burden of disease, the severity of the disease, the size of the population affected, and the unit cost. In addition, considering the number of potential applications of each sensor for each disease.

6.3.1 Input data: Impact and affordability

This section contains the data that will be used to determine the impact and affordability of wearable sensors. Table 6.2 provides the data of the diseases that are considered for the rest of the study. The data was collected from the WHO database and previous studies conducted by Beck *et al.* (2010); Haagsma *et al.* (2015); Murray (2015*a*); World Health Organization (2004) to estimate the incidence rate and disability weights.

Table 6.2: The data collected for the disease burden, incidence rate and disability weights for the diseases considered for prioritisation

Diseases	% DALYs [1]	Incidence per 100000 people [2]	Disability weights [3]
Lower respiratory infections	10,30%	13103	0,28
Diarrhoeal diseases	7,10%	91242	0,11
Preterm birth complications	5,10%	364	0,11
Tuberculosis	2,90%	272	0,27
Neonatal sepsis and infections	2,50%	260	0,28

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Table 6.2 – *Continued from previous page*

Diseases	% DALYs	Incidence per 100000 people	Disease severity
Stroke	2,10%	3158	0,92
Ischaemic heart disease	1,80%	50	0,44

1. % DALY column from World Health Organization (WHO) (2016)
2. Incidence per 100000 people data from Beck *et al.* (2010); Murray (2015*a*)
3. Disability weights data from Haagsma *et al.* (2015); World Health Organization (2004)

Table 6.3 provides the data of the unit cost of the wearable sensors that have passed the threshold from Step 1.

Table 6.3: The data collected for the unit cost of the wearable sensors

Wearable sensor	**Unit cost**
Accelerometer	$0,65
Gyroscope	$1.80
Magnetic sensors	$0.59 to $0.84
ECG electrodes	$43 to $250
PPG	$20.95 to 75
Respiratory meter	$250
Thermistor	$0.67 to 1.88.
Pulse oximeter	$20 to $30.
Biosensors or chemical sensors	$65 to $87.25.

The data used to select the sensors based on the criteria is based on the SMEs feedback. If the three respondents gave the same answer for an application then it is considered viable. The data of the feedback is in Chapter 4. The impact of the wearable sensor will be determined based on the number of possible wearable sensors that can be used to address the respective diseases.

6.3.2 Impact and affordability heat maps

The heat maps include only the following criteria: the burden of disease, the severity of the disease, the size of the population affected, the unit cost, and the number of potential applications of each sensor for each disease. The sensors that have been disqualified in Step 1 are excluded from the heat maps. In the heat maps the green-coloured cells indicate the highest score of 5 and the lowest score of 1 is indicated by the red-coloured cells. The scores were based on the information provided in Table 5.4.

The diseases that have the highest burden based on the three criteria of burden of disease, disease severity and the size of population are (refer to Figure 6.3):

- Lower respiratory infections (see Figure 6.3a);
- Stroke (see Figure 6.3b);
- Diarrhoeal diseases (refer to Figure 6.3d);
- TB (see Figure 6.3e); and
- HIV/AIDS (see Figure 6.3i).

The diseases that have the highest disease impact scores as well as score for all the sensors are lower respiratory infections (see Figure 6.3a), stroke (see Figure 6.3b), diarrhoeal diseases (refer to Figure 6.3d) and tuberculosis (see Figure 6.3e).

Looking at the heat maps the diseases that have the highest potential to apply wearable technology are ischaemic heart diseases and stroke. They have the highest potential of wearable sensors that can be used. Based on the unit cost respiratory meters and ECGs will be excluded because they are pricey.

Disease	Wearable sensors	DALYs	Incidence rate	Disease severity	Applications	Unit cost
Lower respiratory infection	Accelerometer	5	5	3	1	5
	ECG	5	5	3	1	2
	PPG	5	5	3	2	4
	Respiratory meter	5	5	3	2	1
	Biosensors	5	5	3	1	3
	Pulse oximeter	5	5	3	2	4
	Gyroscope	5	5	3	1	4
	Thermistor	5	5	3	2	4
	Magnetic sensors	5	5	3	1	5

(a) Lower respiratory infections

Disease	Wearable sensors	DALYs	Incidence rate	Disease severity	Applications	Unit cost
Stroke	Accelerometer	2	5	5	3	5
	ECG	2	5	5	3	2
	PPG	2	5	5	1	4
	Respiratory meter	2	5	5	3	1
	Biosensors	2	5	5	3	3
	Pulse oximeter	2	5	5	1	4
	Gyroscope	2	5	5	3	4
	Thermistor	2	5	5	1	4
	Magnetic sensors	2	5	5	3	5

(b) Stroke

Disease	Wearable sensors	DALYs	Incidence rate	Disease severity	Applications	Unit cost
Diarrhoeal diseases	Accelerometer	4	5	2	1	5
	ECG	4	5	2	1	2
	PPG	4	5	2	2	4
	Respiratory meter	4	5	2	2	1
	Biosensors	4	5	2	2	3
	Pulse oximeter	4	5	2	2	4
	Gyroscope	4	5	2	1	4
	Thermistor	4	5	2	2	4
	Magnetic sensors	4	5	2	1	5

(c) Diarrhoeal diseases

Disease	Wearable sensors	DALYs	Incidence rate	Disease severity	Applications	Unit cost
Preterm birth complications	Accelerometer	3	2	2	2	5
	ECG	3	2	2	2	2
	PPG	3	2	2	2	4
	Respiratory meter	3	2	2	2	1
	Biosensors	3	2	2	2	3
	Pulse oximeter	3	2	2	2	4
	Gyroscope	3	2	2	2	4
	Thermistor	3	2	2	2	4
	Magnetic sensors	3	2	2	2	5

(d) Preterm birth complications

Disease	Wearable sensors	DALYs	Incidence rate	Disease severity	Applications	Unit cost
Tuberculosis	Accelerometer	2	5	5	1	5
	ECG	2	5	5	1	2
	PPG	2	5	5	3	4
	Respiratory meter	2	5	5	3	1
	Biosensors	2	5	5	1	3
	Pulse oximeter	2	5	5	2	4
	Gyroscope	2	5	5	1	4
	Thermistor	2	5	5	2	4
	Magnetic sensors	2	5	5	1	5

(e) Tuberculosis

Disease	Wearable sensors	DALYs	Incidence rate	Disease severity	Applications	Unit cost
Neonatal Sepsis and infections	Accelerometer	2	2	3	2	5
	ECG	2	2	3	2	2
	PPG	2	2	3	3	4
	Respiratory meter	2	2	3	2	1
	Biosensors	2	2	3	2	3
	Pulse oximeter	2	2	3	2	4
	Gyroscope	2	2	3	2	4
	Thermistor	2	2	3	2	4
	Magnetic sensors	2	2	3	2	5

(f) Neonatal sepsis

Disease	Wearable sensors	DALYs	Incidence rate	Disease severity	Applications	Unit cost
Ischaemic Heart Diseases	Accelerometer	1	1	4	3	5
	ECG	1	1	4	4	2
	PPG	1	1	4	5	4
	Respiratory meter	1	1	4	3	1
	Biosensors	1	1	4	3	3
	Pulse oximeter	1	1	4	3	4
	Gyroscope	1	1	4	3	4
	Thermistor	1	1	4	2	4
	Magnetic sensors	1	1	4	3	5

(g) Ischaemic heart diseases

Disease	Wearable sensors	DALYs	Incidence rate	Disease severity	Applications	Unit cost
Birth Asphyxia	Accelerometer	3	1	3	2	5
	ECG	3	1	3	2	2
	PPG	3	1	3	2	4
	Respiratory meter	3	1	3	2	1
	Biosensors	3	1	3	2	3
	Pulse oximeter	3	1	3	2	4
	Gyroscope	3	1	3	2	4
	Thermistor	3	1	3	2	4
	Magnetic sensors	3	1	3	2	5

(h) Birth Asphyxia

Disease	Wearable sensors	DALYs	Incidence rate	Disease severi	Applications	Unit cost
HIV/AIDS	Accelerometer	4	5	4	1	5
	ECG	4	5	4	1	2
	PPG	4	5	4	2	4
	Respiratory meter	4	5	4	2	1
	Biosensors	4	5	4	2	3
	Pulse oximeter	4	5	4	2	4
	Gyroscope	4	5	4	1	4
	Thermistor	4	5	4	2	4
	Magnetic sensors	4	5	4	1	5

(i) HIV/AIDS

Figure 6.3: The results for the prioritisation of wearable sensors for the different diseases

6.3.3 Impact and affordability: Qualitative discussion

This section provides the qualitative discussion of the each of the diseases' impact and affordability assessment. The wearable sensors that have an impact will be identified then further short-listing will be performed based on the unit cost of the wearable sensors.

Lower respiratory infections have a disease severity of 0,28 which is characterised by coughing, chest tightness, increased breathing rate, breathlessness and wheezing. It is an acute condition and if not treated can be fatal. The DALYs for LRI is the highest in the region recording about 10 percent of the total disease burden in the region. The data in the WHO database indicates that children under the age of five are heavily burdened by LRI. The incidence rate is approximately 13 000 per 100 000 people in the population. Based on the feedback from the SMEs, wearable sensors are mainly used for treatment and diagnostic purposes. The potential applications identified by the SMEs mainly cater for treatment and diagnostic purposes. The wearable sensors that will have the highest impact are:

(i) PPG;

(ii) Thermistor;

(iii) Respiratory meter; and

(iv) Pulse Oximeter.

Develop a wearable device that targets children under the age of five because they are the most susceptible to contract the disease. Based on the disease management of LRI it is necessary to monitor the temperature for fever and breathing rate for breathlessness during treatment and for diagnostic purposes.

Severe acute diarrhoea caused by the rotavirus, shigellosis and cholera has a severity of 0,11 where the affected person suffers from fluid curtailment. *Cholera gravis* is the severest type of diarrhoeal diseases and it is characterised by severe watery diarrhoea, vomiting and dehydration. The disease burden caused by cholera is high. It occurs as an endemic in the region causing an average of 2 percent case fatality ratios. SSA has the highest proportion of DALYs in the world for diarrhoeal diseases. In high-risk areas the average is 2 infected people per 1 000 annually. The incidence rate of diarrhoeal diseases is higher in summer especially in tropical areas. The wearable sensors that have the highest applications that are above the threshold are:

(i) PPG;

(ii) Thermistor;

(iii) Respiratory meter; and

(iv) Pulse Oximeter.

Develop a wearable device that can measure the fluid level during treatment and diagnostic purposes. Patients from diarrhoeal diseases such as cholera lose a lot of electrolytes and fluids as they vomit and pass loose stools.

Preemies are born with underdeveloped organs resulting in complications that can be fatal. If monitored carefully the baby can be healthy. The complications are dependent on the baby's weight. The babies born prematurely will either survive, die or live a life of disability. The disease severity is high. In SSA the incidence rate of preemies born is 15 percent of total births. Wearable sensors that have highest applications are:

(i) PPG;

(ii) Thermistor;

(iii) Accelerometer;

(iv) Bio-sensor;

(v) ECG;

(vi) Respiratory meter; and

(vii) Pulse oximeter.

The causes of premature complications are unknown 50 percent of the time. Develop an intervention that can continuously measure arterial blood gases to regulate oxygen requirements such as this can be possible using a pulse oximeter. The preemies' breathing rate needs to be monitored using respirometers as their lungs are not fully developed. The babies can develop hypothermia therefore there is a need for continuous monitoring of body temperature as they lose heat easily. Bio-sensors are needed to monitor the body fluid levels and electrolytes composition. Monitoring of high-risk pregnant women suffering from diabetes and hypertension is needed using wearable sensors such as invasive biosensors and blood pressure meters. The monitoring of the mother's blood sugar levels if they are diabetic. Bio-sensors can be used to monitor the preemies for the presence of bilirubin in their urine for liver dysfunctions. The wearable sensors can be used for treatment and diagnostic purposes.

Tuberculosis is characterised by two levels of severity, depending on whether or not the infected person has HIV. When a person is infected by HIV and the severity is at a level of 0,408 and when non-infected it is 0,333. There is a high risk of fatality when the person is infected by HIV. When the person is under treatment the disease severity is less as the disease will be contained as long as the patient follows the treatment religiously. Because of the health interventions that have been developed for TB the disease burden has reduced over the past years. TB usually affects children under five and adults above 30 years (these are the ages where the largest part of the population is infected by HIV). It causes 2.9 percent of the disease burden in the region. The incidence rate of TB is 272 per 100 000 people in the region. The wearable sensors that have the highest applications that are above the threshold are:

(i) PPG;

(ii) Thermistor;

(iii) Respiratory meter; and

(iv) Pulse Oximeter.

TB is characterised by persistent cough which is unresponsive to antibiotics. A sensor can be used that can use a microphone for cough count. The infected person has reduced movement which can be monitored using accelerometers and magnetic sensors. The vital signs that are necessary to measure are temperature and respiratory rate. The best method for diagnosing TB is the smear test. As identified by the SMEs these wearable sensors can be applied for treatment and diagnostic purposes.

Neonatal sepsis occurs in stages where there is systemic infection (early sepsis) then Systemic Inflammatory Response Syndrome (SIRS), organ failure (severe sepsis) and finally septic shock. The early sepsis is not as severe compared to the septic shock which can result in fatality. The severity of neonatal sepsis is approximately 0,28. Neonatal sepsis accounts for 2,5 percent of the disease burden in the region. The incidence rate for neonatal sepsis is 260 per 100 000 live births annually. The wearable sensors that have the highest applications that are above the threshold are:

(i) PPG;

(ii) Thermistor;

(iii) Respiratory meter; and

(iv) Pulse Oximeter.

For a condition such as sepsis there is a need for early recognition by healthcare providers. When the infection spreads around the body through the bloodstream the patient will experience a mild hypo-tension which can be detected using the wearable sensors identified by the SMEs. The wearable sensors will have the highest impact monitoring the patient for diagnostic and treatment purposes.

Stroke is an acute condition that results in brain attack with a severity scale of 0,92. It is a major cause of disability because the affected person may suffer from neurological deficits, slight headache, speech deficits, visual problems and confusion. The disease burden of stroke in SSA is 2,1 percent of the total DALYs in the region. In SSA stroke affects people in the age group between 30 to 50 which is deemed the productive age group therefore more YLDs. The incidence rate of stroke is 3158 per 100000 of the population in SSA. Strokes are associated with hypertension, diabetes and heart diseases. The risk factors are physical inactivity, inadequate diet and alcohol abuse. The wearable sensors that have the highest applications that are above the threshold are:

(i) Accelerometer;

(ii) ECG;

(iii) PPG;

(iv) Thermistor;

(v) Magnetic sensors;

(vi) Gyroscope;

(vii) Respiratory meter; and

(viii) Pulse oximeter.

Therefore, the wearable sensors can be used for preventive, wellness, diagnosis and rehabilitative purposes.

Ischaemic heart disease is a chronic condition that can cause acute heart failure. This condition can be fatal and cause a disease severity of 0,44. This can cause severe arrhythmias, rupture of ventricular walls, pulmonary or cerebral embolism and recurrence. The disease burden of ischaemic heart diseases in SSA are 1,8 percent of the total DALYs in the region. The incidence rate is relatively low in SSA at an estimated rate of 50 per 100000 people in the population. It is common amongst the middle aged people and the elderly. The wearable sensors that have the highest applications that are above the threshold are:

(i) Accelerometer;

(ii) ECG;

(iii) PPG;

(iv) Magnetic sensors;

(v) Gyroscope;

(vi) Respiratory meter; and

(vii) Pulse oximeter.

Develop a wearable device that monitors the heart activity using ECG and PPG. The disease is also influenced by lifestyle and wearable devices can be used to monitor the level of activity using pedometers, accelerometers and gyroscopes. The wearable sensors can be used for preventive, wellness, treatment, diagnostic, and rehabilitative purposes.

For HIV the disability weights vary with whether the infected person is on ARV treatment or not. If the person is on ARVs the disease severity will be 0,135 and when not on ARVs and it develops to AIDS it is 0,505. Currently, about 66 percent of adults and 59 percent of children are on ARVs. The disease burden of HIV or AIDS was estimated to be 7 percent. The incidence rate of HIV or AIDS was estimated to be 2 549 per 100 000 people in the population in 2015. The wearable sensors that have the highest applications that are above the threshold are:

(i) PPG;

(ii) Thermistor;

(iii) Respiratory meter; and

(iv) Pulse Oximeter.

Develop wearable devices that will focus mainly on identifying the opportunistic infections. There is a need to assess the vital signs for cardiovascular and respiratory systems. The wearable sensors are mainly used during treatment and diagnosis of HIV or AIDS.

Birth asphyxia is when a child's brain has experienced oxygen deprivation. The disability weights for the disease is 0.505 which is characterised by seizures, low heart rate, weak reflexes, not breathing or very weak breathing and too much acid in the blood. The disease burden affects 5 percent of the population in the region and incidence rate is approximately 20 percent of the live births. Babies born in sub-Saharan Africa have a very high risk of birth asphyxia. The wearable sensors that have the highest applications that are above the threshold are:

(i) PPG;

(ii) Thermistor;

(iii) Biosensor;

(iv) Respiratory meter; and

(v) Pulse Oximeter.

The wearable sensors that will be excluded because they are too pricey are ECG and the respiratory meter because they both have unit cost approximately above $250. Below is a list of all the diseases and the potential wearable sensors that will have an impact and relatively affordable.

- **Lower respiratory infection**–PPG, thermistor and pulse oximeter.
- **Diarrhoeal diseases**–PPG, thermistor and pulse oximeter.
- **Premature birth complications**–PPG, thermistor, accelerometer, pulse oximeter, magnetic sensor, gyroscope and biosensor.

- **TB**–PPG, thermistor and pulse oximeter.
- **Stroke** –PPG, accelerometer, magnetic sensor, gyroscope, thermistor and biosensor.
- **Ischaemic heart diseases**–PPG, accelerometer, magnetic sensor, gyroscope, pulse oximeter and biosensor.
- **HIV or AIDS**–PPG, thermistor and pulse oximeter.
- **Birth asphyxia**–PPG, thermistor, biosensor and pulse oximeter.

A thermistor can serve two purposes; as a temperature sensor and as a respiratory meter. Biosensors can be used to determine electrolyte composition, blood sugar levels and urine composition. These wearable sensors that have multiple purposes can be developed in such a manner that they have algorithms that can be used to interpret all the readings at once to monitor the patient. The wearable sensors that will most likely have the highest impact based on the potential application looking at the overall applications for most diseases are PPGs, thermistors, pulse oximeter and biosensors. These sensors can be grouped to form a wearable medical kit that can be used for the monitoring of multiple diseases through the use of complex algorithms.

6.4 Prioritisation conclusion

In this section, recommendations will be made for the diseases that should be prioritised for the development of wearable technology. The findings will be based on the results from Section 6.2 and 6.3. The diseases that will be considered based on the potential applications are ischaemic heart diseases, stroke and premature birth complications.

Ischaemic heart diseases are chronic conditions that require regular monitoring of heart activity and daily activities. They are monitored using heart rate, respiratory rate, blood pressure, oxygen saturation, heart electrical activity and urine composition. From this list the wearable sensors that can be used based on the findings in Section 6.2 and 6.3 are namely: PPG, accelerometer, magnetic sensor, gyroscope, pulse oximeter and biosensor. Based on the findings the suitable sensors that can be incorporated in the wearable device for heart monitoring are a PPG and pulse oximeter. The pulse oximeter can be used in the diagnosis of acute heart failure using the oxygen saturation. Biosensors can measure the C-reactive protein in bloodstreams, which, when elevated, indicates inflammation that could be linked to heart attack, stroke, coronary artery disease, and a host of other medical diagnosis. The other best way to manage heart diseases is through monitoring daily activities such as step counts using wearable devices with accelerometers and gyroscopes.

Currently, most of the wearable devices on the market are designed for addressing heart diseases and are even being sold in SSA. The patient engagement in the monitoring of heart diseases allows patients to monitor and track their own progress, and make real-time decisions based on the data collected. As a result, they are more likely to take responsibility for their own health. ECG, blood pressure meter and respiratory meters are currently pricey therefore research should be put in to ensure the development of cheaper sensors that can be used in the region. ECG is important because it can be used for the monitoring of the heart's electrical activity. Research needs to be done to determine the adoption rate of these wearable devices in SSA and the acceptability of this technology. The wearable sensors can be used for preventive, wellness, treatment, diagnostic and rehabilitative purposes.

Fatality due to stroke is on the rise and can be reduced through making early and accurate detection. Endovascular therapy within 24 hours of stroke onset is considered the window of opportunity for treating emergent large-vessel occlusion. The chances of a good outcome, however, decrease by about 20 percent for every hour that passes before treatment starts. Therefore, developing a wearable device that can accurately detect a stroke and warn the paramedics immediately so that they come and attend to the patient can increase the patient's chances of survival. Therefore, wearable technology for treatment and diagnosis purposes will save a lot of lives and will have a high impact. Based on the wearable sensors that have been identified for the monitoring of stroke a device can be developed to monitor the users. Wearable technology can be used for gait analysis technique. This technique uses 3-axis accelerometers, gyroscopes and magnetic sensors to detect if the cerebellum is affected and any abnormalities in locomotion which is a huge sign when someone is experiencing a stroke.

After experiencing a stroke it is necessary to monitor the blood pressure, heart rhythm, oxygen saturation, blood glucose and body temperature to prevent the reoccurrence of another stroke. Wearable technology is necessary because there will be continuous monitoring and availability of real-time data. The patient can manage their own health and ensure they live a healthy life so that they avoid the occurrence of another stroke.

The causes of premature complications are unknown 50 percent of the time. There is a need to develop an intervention that can continuously measure arterial blood gases to regulate oxygen requirements. Using wearable technology this can be made possible using a pulse oximeter. The breathing rate of preemies needs to be monitored using respirometers as their lungs are not fully developed. These babies can develop hypothermia, therefore there is need for continuous monitoring of body temperature as they lose heat easily. Use of biosensors is necessary to monitor their body fluid levels and electrolyte composition. Monitoring of high-risk pregnant women suffering from diabetes and hypertension can be done using wearable sensors such as invasive biosensors and blood pressure meters. The monitoring of the mothers' blood sugar levels if they are diabetic. Biosensors can be used to monitor the preemies for the presence of bilirubin in their urine for liver dysfunctions. The wearable sensors can be used for treatment and diagnostic purposes. At the moment preemies are monitored using invasive methods and it will be great to have an intervention that can monitor the babies continuously non-invasively. This is where wearable technology comes into play and babies can be continuously monitored without any pain and the wearable devices can be used at home by the parents and health practitioners will have access to the data of the babies and monitor their progress after being discharged.

6.5 Stakeholder perspective analysis

As wearable technology is likely to be introduced in the African health systems it will be ideal to have an understanding of all the parties involved in the delivering of care to the patients. The purpose of this analysis is to understand how these entities are affected by the healthcare challenge and to determine their requirements (or their stake) in how it is addressed. This analysis carries forward the findings from the SMEs about the intended users of wearable technologies and concludes how each of them influence the adoption rate. Stakeholders have different perspectives. For instance, some will benefit if the healthcare challenge is addressed, but others may be adversely affected. Uncovering these perspectives and any potential conflicts is critical to shaping and refining the needs statement and needs criteria. It also allows the innovator to anticipate resistance, as well as to define and prioritise the requirements that will shape the eventual solution to maximise its chance of adoption among the most important and influential stakeholders.

For these reasons, stakeholder analysis should start early in the innovation process, while needs are being identified and assessed. It can then be repeated as more information becomes known and progress is made. The data for the stakeholder analysis will be determined from the feedback received from the clinical subject matter experts and previous studies.

6.5.1 Stakeholder analysis of the intended users

Figure 6.5 illustrates the different stakeholders are:

(i) Patients;

(ii) Physicians;

(iii) Nurse Practitioners;

(iv) Health care facilities; and

(v) Medical insurers.

Figure 6.4: The potential stakeholders involved in wearable technology in healthcare as per feedback from SMEs.

In order to understand the stakeholders it is necessary to have an understanding of the cycle of care. The cycle of care analysis indicates the interaction between the patients and the medical system. There is a need for the understanding of disease management in the different stages of care and the parties involved at each stage.

In Figure 6.5, the cycle of care is mapped out to show the interaction between the medical system and the patients. Initially, the patient will be healthy and will be monitored using wearable devices and real-time data is captured and analysed. Below are the steps followed during the generic wearable technology cycle of care:

- In a case where the patient is critical and the paramedics are required then the patients medical history and vital signs readings are sent to them. This data will be utilised so that the paramedics can immediately identify what is wrong with the patient.
- In another instance the data is automatically sent to the physician especially when an anomaly is detected in real time. The physician can either call in the patient for further laboratory tests or the physician can review the data and make a diagnosis based on the data recorded from the patient.

- During the treatment process the patient is monitored using a wearable device to monitor their progress either at home or in the hospital setting.

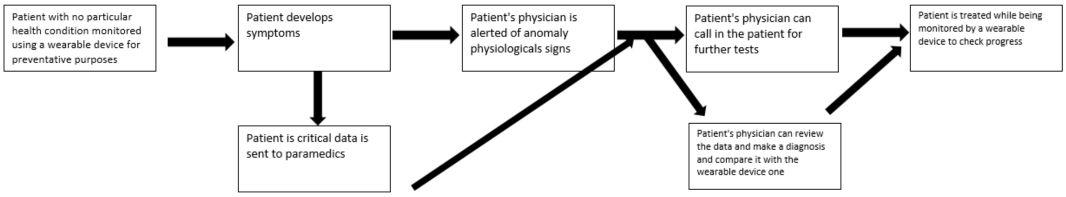

Figure 6.5: Cycle of care analysis for wearable devices.

Once all key stakeholders in a clinical area have been identified, comprehensive analysis can be performed to further evaluate the barriers that might cause a stakeholder to resist the adoption of a new innovation, as well as the benefits that may drive their adoption. An effective stakeholder analysis analyses the costs and benefits to each stakeholder identified. Direct costs and benefits should be considered (for example loss or gain in revenue, decrease or increase in profitability, decrease or increase in time away from work).

The analysis summarises the key stakeholders, outlines the primary benefits and costs associated with a new solution to address the defined need, and provides a subjective assessment of the overall net impact of a new technology on each stakeholder (see Table 6.4, 6.5, 6.6 and 6.7).

Table 6.4: Patients' stakeholder interests

Clinical outcomes	**Safety**	**Convenience**	**Perceived risk**
Reduced invasiveness	Monitoring using a wearable device has minimal risk associated with it.	It can be used in real-time and can be worn as a watch. The battery life can be of concern to the user because that would mean downtime when the device is being charged. Internet connectivity and might require training for proper use of the device. Wearable technology allows for the patient to monitor their own vitals.	Security issues, reliability of the data. Reaction to the technology may vary based on people's view on technology. Technology forward people will be willing to try out wearable technology. Then those that have techno-phobia will be reluctant to adopt the technology

Table 6.5: Physicians' stakeholder interests

Agency	**Clinical outcomes**	**Risks**	**Work-flow**	**Ease of use**	**Reputation**
Concerns with confidentiality of the patient's medical history and data collected.	Provide more accurate diagnosis because of the availability of data and assistance of the complex algorithms that can be utilised to detect anomalies in the patient's health	The reliability of the data may result in a doctor making a wrong call resulting in malpractice and put risk on the life of the patient.	Wearable technology requires for the medical to be trained on how to use it and the workflow will include having regular access to data that reports on the patients and giving medical expertise remotely without them coming to the hospital. Remote monitoring of outpatients. Reduce the number of patient visits.	Wearable technology will ease the work of doctors especially those that have conditions that require regular monitoring. Can be used for preventive purposes, treatment and diagnostic purposes. This will require training to improve technical skills	This will increase their reputation for giving efficient services and are up to date with their patients. The introduction will reduce their visibility but they will be in constant interaction with their in or out patients. This will increase patient satisfaction. In SSA there are less practitioners compared to the patients therefore wearable devices will increase access.

Table 6.6: Medical facilities stakeholder interests

Economic Impact	Risk	Reputation
Increase of capital expenditure–the hospital and patients will require access to a PDA, computers and reliable internet connection. Reduce the number of visits by patients and stays in hospitals as they can be monitored remotely.	Wearable technology may put the hospital at risk of the patients medical records being hacked.	A hospital can gain momentum for being technology forward and can attract a certain group of early adopters.

Table 6.7: Medical insurers stakeholder interests

Clinical outcomes	Competition	Reputation
Wearable technology has the potential to improve the health of a person longer term.Through the elimination of symptoms earlier before they prevail or even drug side effects for conditions such as HIV/AIDS.	In SA medical insurers have already started encouraging the use of wearable devices and they collect the data. Momentum and Discovery have already started encouraging the use of wearable devices in order to give incentives. This has attracted a lot of health-conscious patients.	Wearable technology is perceived as costly at the moment and payers may be reluctant based on this fact as there are other cheaper alternative forms of treatment.

Table 6.8: The stakeholder analysis summary

Stakeholders	Primary Benefits	Primary Costs	Assessment of net impact
Patients	Increased accessibility, Self-management, Better care received, Quality of life, Reduced mortality and morbidity	Need for wearable device, smart phone and Internet costs.	**Negative:** The costs required for patient to use the wearable device efficiently include internet costs, the device and training of use wearable devices.

Continued on next page

Table 6.8 – *Continued from previous page*

Stakeholders	**Primary Benefits**	**Primary Costs**	**Assessment of net impact**
Physicians	Increased access to patient data, Better care given, increased reputation, increased flexibility and reduced follow up visits, less administrative work, Easy referrals especially with the transfer of data	Learning technical skills and availability of regular and reliable Internet connection	**Positive:** This will ease the work of the doctors and there will be more effective in the provision of their services as they will be reduced paper work and data will be at their disposal. Physicians are more likely to embrace a technology that ease their work and does not alter their work-flow.
Facilities	Networking of patient data, increase their reputation, increased satisfaction of personnel, more efficient use of hospital resources.	Transmitter purchase, Internet connections such as LAN and Wi-Fi. Mobile devices for the personnel, database servicing, set up a helpline, data analysis, patient education, restructuring of the hospital departments.	**Negative:** The capital expenditure that the hospital might potentially face will be high in order to set up the wearable technology system. Most hospitals in the region do not have access to Internet connections and electronic medical records.
Medical Insurers	Easy access to data on patient's healthcare use, better patient care, management of healthcare system	Transmitter, fewer cost-intensive clinical events	**Positive:** Less cost will be incurred by the payers. They can possibly set up an incentive programme were people are promoted for healthy living therefore improving the quality of life of the patients especially for NCDs which have high health expenditures.

Patients are the primary stakeholders in this instance. Based on the information on the stakeholder interests presented in Table 6.4 it shows that the primary benefits of wearable technology from the patient's perspective are increased access to health practitioners, improved care delivery, increased quality of life and reduced mortality as well as morbidity. The primary costs are associated with acquiring the wearable device and the internet costs associated with the transfer of data. Weighing on the benefits and costs of wearable technologies on the patient, the technology will negatively impact them and they might face some level of resistance, the main reason being the costs associated with the use of a wearable device daily especially data cost for the synchronisation of data from the wearable device to the hospital server **?**. Wearable technology can increase the access of patients to healthcare providers especially in remote areas. In SSA there are already early adopters that have started incorporating wearable devices mainly for fitness tracking. Therefore, these are the people that view wearable devices positively. On the other hand the majority of the people will view the technology as a luxury and very pricey based on the costs associated with using the device.

With mHealth technologies, the data collection applications can monitor and track health indicators in real time providing insight on valuable data enabling health workers to better serve the patients and patients to be more proactive in their own health. There are always concerns by health providers on the issue of liability. The main concern is the issue of security and accuracy of the data collected. Therefore the doctor will need to have constant access to data. The primary costs are associated with training of physicians, the technical skills and Internet connections but the overall impact of the technology is positive.

In SSA there is limited access to the Internet because of the high costs of data and low Internet connectivity. Most hospitals still use traditional paper-based methods and it may take time for them to use electronic medical records because of the high cost of set-up and maintenance as this requires more IT people working in the hospital as part of the hospital staff. This is due to poor existing infrastructure, frequent power outages and network failure. In facilities with electronic records, use is sub-optimal because of the need for parallel entry of data to paper and computer which increases the workload of overstretched staff. Hospitals will have to increase the capacity of computers and tablets giving doctors real-time access to their patients data increasing the accuracy of diagnosis and treatment. The introduction of wearable technology in the hospital will increase capital expenditure and direct cost. The main challenge is the fact that most hospitals are not equipped for proper data analytics and data overload as there will be real-time readings. Therefore, wearable technology from the viewpoint of the facilities in SSA may have a negative impact as more has to be done to develop a functional system.

Medical insurers can benefit through offering incentives for healthy living, therefore reducing the health expenditure. This helps promote people to increase health through improved lifestyle (Shekar, 2012). In South Africa there is Momentum, a medical insurer, they have an initiative called Active Dayz™which gives you points when you reach 10 000 steps using a wearable device. These rewards points will then be used for cash back and discounts on Momentum products.

6.5.2 General recommendations based on the stakeholder perspective analysis

The recommendations to ensure reduced resistance from the intended stakeholders of wearable technology:

- At the moment in SSA there is a lack of healthcare providers that are technically versed. There is a need to train the healthcare providers on how to be more technically versed and use wearable devices effectively. The healthcare providers will need to know how to interpret the data presented to them. The patients also need to be trained on how to use the device accurately so that reliable readings are collected.
- Design a wearable device that will be user friendly to the end users. In previous studies they have gathered that wearable technology users stop using the device within 6 months. More research has to be performed to determine why the end users stop using the devices.
- The use of incentives by medical insurers to ensure better quality of life for their patients and allowing them the capability to monitor the patients' data and their

activity levels. This will allow them to reduce their expenditure on patients especially for chronic diseases that can be prevented through a change in lifestyle.

- Improve the ICT platforms that can be used by patients, healthcare providers, medical facilities and medical insurers to improve the assess to data and ensure infrastructures are set up to increase connectivity.
- Perform a detailed cost analysis (economic impact and opportunity cost) so that facilities can perform a detailed cost-benefit analysis. In literature there is a lack of information on cost-analysis for the use of mHealth technologies especially wearable technologies as this is an emerging technology.

6.6 Conclusion: Prioritisation of wearable technology

This chapter presented the prioritisation exercise of the wearable sensors and short-listed diseases in SSA. The results from the prioritisation exercise were presented. Results were discussed in detail and general recommendations were made. Finally the stakeholder perspective analysis was presented for all the entities that will be affected by the introduction of wearable devices.

CHAPTER 7

SUMMARY AND CONCLUSIONS

This chapter intends to provide a summary of the research findings of each chapter, discuss the research contributions and recommendations for future studies.

7.1 Project summary

The project aimed at determining the potential of wearable technology in SSA based on the disease landscape. A prioritisation approach was used to determine the wearable sensors that will have the highest impact based on the feasibility, impact and affordability. A stakeholder perspective analysis was performed and is discussed.

Chapter 1 introduced the project, rationale, research design and methodology and research structure. Chapters 2 and 3 presented the background to the disease landscape and wearable technology. Chapter 2 introduced the comprehensive overview of diseases in SSA. This included information on the quantifying of diseases, cost-effectiveness analysis, communicable and non-communicable diseases. Finally,the chapter presented the data of the SSA disease landscape based on DALYs, and fatality rate and disease were selected for further studies. Chapter 3 provided the background of the wearable technology landscape well as the key enabling technologies associated with wearables. Based on the data collected of the wearable devices in Appendix B, Table B.7 the key enabling technologies were identified and an TRL assessment to determine the technology maturity was carried out.

Chapter 4 presented the feedback that was collected from the interviews conducted with clinical SMEs who provided information based on their expertise to identify the physiological signs, stages of care and intended user(s) of wearable technology for the respective diseases. The data was used to cross-reference the diseases to wearable sensors using the physiological signs identified by the SMEs.

In Chapter 5, a brief description of the prioritisation approach was presented and previous studies were used to define the sets of criteria that were used for the prioritisation of wearable sensors. The defined sets of criteria were short-listed by checking the availability of data. The methods that are used for the prioritisation of wearable devices were described briefly and the one that was going to be considered for the rest of the study was selected. The criteria scales were set based on the data from literature and how they scaled the set of criteria in those studies.

Chapter 6 discussed the prioritisation approach was performed in two steps namely: (i) feasibility filtering and (ii) impact and affordability assessments. This was used to identify the wearable technology that would have the highest impact in the region and the diseases that would be addressed effectively using wearable devices. Based on these findings general recommendations were made. A stakeholder perspective analysis gave an idea of the adoption of the technology based on how the intended user(s) perceive wearable technology. Chapter 7 discussed the project summary, research contribution and the possibility of future work.

7.2 Research Findings

The main finding from this study was that the wearable sensors that are feasible to be introduced to the region are accelerometer, PPG, Thermistor, pulse oximeter, gyroscope, magnetic sensor and biosensors. The exercise to reach this conclusion is presented in Figure 7.1. The first step in assessing the feasibility was in terms of the TRL and efficacy separately. The TRL had a cut-off point at TRL 6 where the prototype has been developed and can start being used for clinical trial. A couple of sensors were considered to be infeasible according to the TRL. Considering the wearable sensors the data of their efficacy was used to determine their performance and if they meet the recommended FDA standards. A collective of the wearable sensors that were considered to be infeasible by both the TRL and efficacy assessment were disregarded for the rest of the study, as they require more work for development and improved performance. This would be a burden for SSA based on its stringent resources and healthcare expenditure funds.

Step 2 aimed at assessing the impact and affordability of the wearable technology. This is performed using the set of defined criteria from Chapter 5 which were: disease burden, disease severity, incidence rate, applications and unit cost of the wearable sensors. The impact was determined using the heatmaps. For each disease the wearable sensors that would have the highest impact were considered based on the number of possible applications for the different stages of care. The final list of wearable sensor was selected based on the unit cost (as shown in Figure 7.1). The diseases that were considered to benefit immensely from wearable technology were ischaemic heart diseases, stroke and premature birth complications. These diseases were selected based: (i) on the applications; (ii) a large number of feasible wearable sensors that can monitor the disease; and (iii) the data can be used to detect diseases with conclusive results.

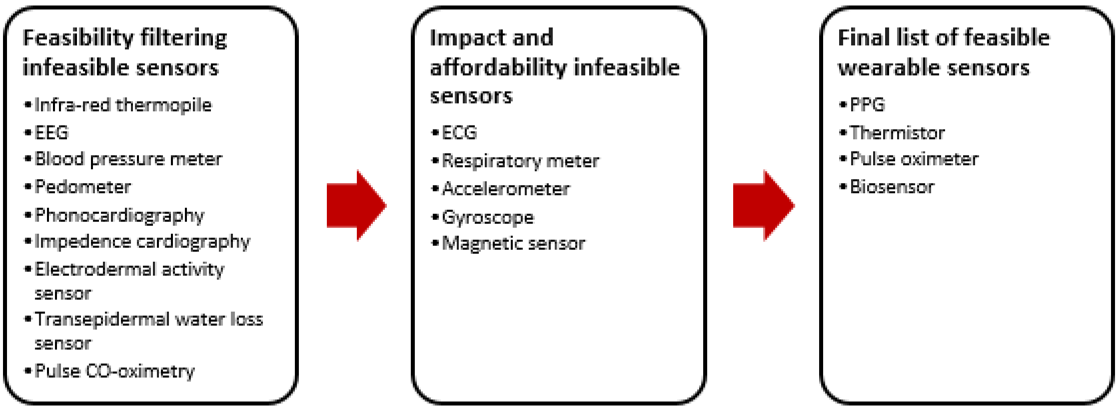

Figure 7.1: The findings from the study

Based on the stakeholder analysis the patient will be resistant to wearable devices because of their current price. An average person in the region can not afford to buy a wearable device. However, the elite or early adopters have already started using wearable devices to monitor their daily activities. Physicians will appreciate the use of wearable devices as this will ease their work and allow them to be more effective in their provision of healthcare services. Wearable devices will not disrupt their work flow but will make it easier by allowing them to have access to data, to make informed decisions and to reduce the chances of inaccurate diagnosis. The downside will be that the physicians would have to go through training on how to interpret the data and make sound recommendations for patients. Overall, the physicians will be receptive to wearable devices.

The medical facilities will have to incorporate the use of wearable technology in their structures by restructuring of the hospital departments or divisions. The availability of wearable devices will allow for the medical facilities to use their resources efficiently. The downside is the capital expenditure associated with the introduction of wearable technology infrastructure. Most hospitals in the region are still developing ICT platforms for their hospitals therefore integration of wearable technology will be financially intensive as a system has to be built from the ground up.

The medical insurers are advocating the use of wearable technology to increase the health of their medical insurance users through self-management. They encourage the improvement of lifestyle through incentives. For example Momentum has a programme called Multiply whereby users get points if they take 10 000 steps a day and do a work-out that burns a certain amount of calories. This will reduce members' health expenditure by reduction of cost-intensive clinical events.

7.3 Research contributions

This research contributes to both the academic literature and the potential introduction of wearable technology in the SSA health systems.

(i) It adds to the academic literature by providing an approach that can be used to determine the potential of wearable technology in SSA through prioritisation.

(ii) It documents the current SSA disease landscape and the wearable technology landscape.

(iii) It assesses the feasibility of the current wearable sensors that have been developed through TRL and efficacy assessment and can be introduced in SSA with minimal work as product development will require more resources.

(iv) It adds to the literature by identifying the wearable sensors that can be applied in SSA to address the prominent diseases based on their impact and affordability.

(v) The project provides information on the different stakeholders' perspectives and the potential resistance they might raise based on how they perceive wearable technology.

(vi) The data limitations faced in this study were presented with regard to health economics, specifically budgetary impact, cost-effectiveness and opportunity cost and this may inform future research.

7.4 Opportunities for further work

It is recommended that the following opportunities are explored further to add value to determining the potential of wearable technology in SSA:

(i) Conduct interviews and develop a framework that can be used for the technology-acceptance model specifically for wearable technology. This study will be used to determine other factors that can lead to resistance against wearable devices in SSA that can be used by developers and decision-makers.

(ii) Future studies can be performed by increasing a defined set of criteria by adding cost-effectiveness and budget impact. These will assist policy-makers in identifying the wearable devices that will be sustainable, based on the costs and health outcomes of the users. The data will be essential especially for countries or regions that are resource limited.

(iii) Use the approach that was developed on a country level and develop a business model for wearable technology in healthcare on different settings either hospital setting or country setting. Business models provide insight on how wearable devices can be made economically feasible through value creation and revenue streams.

7.5 Closing summary

In Chapter 7 a summary of the project was described, and the research findings were provided. Thereafter, the contributions of this research were explained, and the possible opportunities for furthering this research were described.

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APPENDIX A

MORE DETAIL ON THE DISEASE LANDSCAPE

The appendix presents additional information on the global disease landscape in the form of cause-specific mortality mentioned in Chapter 2. The other section describes the diseases that are being considered in this study.

A.1 The top causes of deaths in the different global regions

This section provides information on the causes of deaths in the different regions in the world according to the World Health Organization (WHO) (2016) database. The different regions are: East Asia and Pacific (Table A.1), Europe and Central Asia (Table A.2), Latin America and Caribbean (Table A.3), Middle East and North Africa (Table A.4), North America (Table A.5) and South Asia (Table A.6).

Table A.1: Causes of Death in East Asia and Pacific

Rank	**Causes of death**	**Deaths thousands (000)**
1	Stroke	3 012
2	Ischaemic heart disease	2 459
3	Chronic obstructive pulmonary disease	1 284
4	Trachea, bronchus, lung cancers	872
5	Lower respiratory infections	673
6	Liver cancer	547

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Table A.1 – *Continued from previous page*

Rank	Causes of death	Deaths thousands (000)
7	Alzheimer disease and other dementias	471
8	Stomach cancer	432
9	Diabetes mellitus	421
10	Road injury	408
11	Kidney diseases	373
12	Hypertensive heart disease	365
13	Cirrhosis of the liver	328
14	Colon and rectum cancers	280
15	Tuberculosis	253
16	Self-harm	229
17	Oesophagus cancer	227
18	Falls	174
19	Pancreas cancer	128
20	Breast cancer	121

Table A.2: Causes of Death in Europe and Central Asia

Rank	Causes of death	Deaths thousands (000)
1	Ischaemic heart disease	2 423
2	Stroke	1 136
3	Alzheimer disease and other dementias	417
4	Trachea, bronchus, lung cancers	411
5	Chronic obstructive pulmonary disease	333
6	Lower respiratory infections	260
7	Colon and rectum cancers	259
8	Diabetes mellitus	174
9	Cardiomyopathy, myocarditis, endocarditis	172
10	Breast cancer	160
11	Hypertensive heart disease	142
12	Kidney diseases	140
13	Stomach cancer	138
14	Self-harm	127
15	Pancreas cancer	120
16	Prostate cancer	119
17	Cirrhosis of the liver	115
18	Falls	94
19	Lymphomas, multiple myeloma	88
20	Road injury	80

Table A.3: Causes of Death in Latin America and Carribean

Rank	Causes of death	Deaths thousands (000)
1	Ischaemic heart disease	534
2	Stroke	280

Continued on next page

Table A.3 – *Continued from previous page*

Rank	Causes of death	Deaths thousands (000)
3	Diabetes mellitus	243
4	Lower respiratory infections	233
5	Interpersonal violence	167
6	Chronic obstructive pulmonary disease	153
7	Road injury	119
8	Kidney diseases	105
9	Cirrhosis of the liver	98
10	Trachea, bronchus, lung cancers	76
11	Alzheimer disease and other dementias	68
12	Hypertensive heart disease	62
13	Stomach cancer	56
14	Colon and rectum cancers	55
15	Prostate cancer	53
16	Congenital anomalies	51
17	Breast cancer	49
18	HIV/AIDS	46
19	Self-harm	45
20	Preterm birth complications	38

Table A.4: Causes of Death in Middle East and North Africa

Rank	Causes of death	Deaths thousands (000)
1	Ischaemic heart disease	455
2	Stroke	227
3	Collective violence and legal intervention	108
4	Lower respiratory infections	94
5	Diabetes mellitus	94
6	Road injury	86
7	Alzheimer disease and other dementias	81
8	Cirrhosis of the liver	77
9	Kidney diseases	67
10	Preterm birth complications	53
11	Congenital anomalies	48
12	Chronic obstructive pulmonary disease	45
13	Hypertensive heart disease	42
14	Cardiomyopathy, myocarditis, endocarditis	32
15	Trachea, bronchus, lung cancers	29
16	Birth asphyxia and birth trauma	29
17	Breast cancer	27
18	Liver cancer	24
19	Lymphomas, multiple myeloma	21
20	Colon and rectum cancers	21

Table A.5: Causes of Death in North America

Rank	Causes of death	Deaths thousands (000)
1	Ischaemic heart disease	517
2	Alzheimer disease and other dementias	287
3	Chronic obstructive pulmonary disease	195
4	Trachea, bronchus, lung cancers	182
5	Stroke	145
6	Lower respiratory infections	87
7	Diabetes mellitus	87
8	Colon and rectum cancers	70
9	Kidney diseases	64
10	Breast cancer	53
11	Self-harm	50
12	Cirrhosis of the liver	50
13	Pancreas cancer	45
14	Lymphomas, multiple myeloma	44
15	Hypertensive heart disease	41
16	Falls	38
17	Road injury	37
18	Prostate cancer	37
19	Drug use disorders	36
20	Cardiomyopathy, myocarditis, endocarditis	33

Table A.6: Causes of Death in South Asia

Rank	Causes of death	Deaths thousands (000)
1	Ischaemic heart disease	1 915
2	Chronic obstructive pulmonary disease	1 051
3	Stroke	982
4	Lower respiratory infections	802
5	Tuberculosis	603
6	Diarrhoeal diseases	530
7	Preterm birth complications	474
8	Diabetes mellitus	402
9	Road injury	340
10	Cirrhosis of the liver	314
11	Kidney diseases	304
12	Self-harm	230
13	Birth asphyxia and birth trauma	225
14	Falls	220
15	Hypertensive heart disease	193
16	Congenital anomalies	166
17	Alzheimer disease and other dementias	162
18	Neonatal sepsis and infections	161
19	Asthma	146
20	Rheumatic heart disease	132

A.2 Detailed description of the top diseases

This section provides detailed information on the diseases that are being considered in this studies. For each diseases there is a short description of the signs and symptoms, causes, preventative measure and treatments.

Table A.7: Detailed descriptions of the top leading disease in Sub-Sahara Africa in 2015

Disease	**Description**	**Signs and Symptoms**	**Causes**	**Preventative Measures**	**Treatments**
HIV/AIDS	It is a retro- virus that affects the immune system of infected persons by destroying certain white blood cells, called T-cells, which the body relies on to fight infection. (Mayosi et al., 2009)	Initial stages have flu-like symptoms. In due course, start suffering from diseases that indicate a weak immune system namely TB, shingles, oral or vaginal thrush and herpes simplex virus. If the immune system is suppressed to less than 200 then the person is considered to have AIDS	Transmitted through body fluids mainly blood, semen and vaginal fluid. It is mainly transmitted through sex, sharing sharp objects with an infected person, through mother-to-child transmission through pregnancy, giving birth and breastfeeding	No vaccine available. Use of condoms to prevent the transmission during sexual intercourse.	Antiretroviral drugs can be used to reduce the viral load of HIV in the body and delay the progression of HIV infection to AIDS. The use of Nevirapine to reduce mother-to-child transmission.
Lower respiratory infections	These infections include acute bronchitis and bronchiolitis, influenza and pneumonia	For bronchitis the cough is typically a yellow-grey phlegm. Then the infected person suffers from a sore throat and wheezing. Pneumonia - symptoms occur after 24 to 48 hours. Cough which may be dry or produce thick yellow, green, brown or blood-stained mucus. May experience difficulty breathing, rapid heart beat, fever, sweating and shivering, chest pain, and loss of appetite. Then influenza the infected person gets a fever, feels tired and weak, headache, general aches and pains, dry chesty cough.	Identifying the causative agents for bronchitis is quite difficult. In the clinical studies they have managed to identify less than 30% of the causative agents. Almost 90 % of the causes are related to viruses such as adenovirus, coronvirus, para-influenza, influenza and rhino-virus and 10 % to bacteria such as Bordetella Pertussis. Respiratory syncytial virus is the most common cause of severe acute infection of bronchiolitis.	For influenza it can be prevented using antivirals such as adamantanes and neuraminidase vaccination	For the treatment of bronchitis and pneumonia use antibiotics

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Table A.7 – *Continued from previous page*

Disease	**Description**	**Signs and Symptoms**	**Causes**	**Preventative Measures**	**Treatments**
Diarrhoeal diseases	this is passing of three or more loose or liquid stools per day. Diarrhoea is a symptom of an infection. Types of diarrhoea are : cholera, dysentry and frequent diarrhoea	dehydration resulting in thirst, decreased skin elasticity, sunken eyes. In severe cases shock, with diminished conciousness, lack of urine	Can be caused by bacterial , viral, parasitic organisms	safe drinking water, use of improved sanitation, hand washing with soap, exclusive breastfeeding for the first six months of life, rotavirus vaccination	Use of oral rehydration salts solution, intravenous drip, zinc supplements
Malaria	Caused by Plasmodium parasite.	Fever, headaches, chills and vomiting if not treated within 24 hours it can progress to severe illness, often leading to death. In children the following symptoms may occur such as severe anaemia, respiratory distress or cerebral malaria.	The parasites are spread to people through the bites of infected female Anopheles mosquitoes, called malaria vectors.	Vector control is the main way to reduce and prevent malaria. The two forms are use of insecticide-treated mosquito nets and indoor residual spraying. Antimalarial drugs (chemoprophylaxis) are used to prevent travellers from getting infected. Drugs for pregnant women in order to avoid transmission.	Treatment using artemisinin-based combination therapy (ACT).

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Table A.7 – *Continued from previous page*

Disease	**Description**	**Signs and Symptoms**	**Causes**	**Preventative Measures**	**Treatments**
Stroke	occurs when the blood supply to part of your brain in interrupted or severely reduced, depriving brain tissue of oxygen and nutrients	trouble with understanding and speaking and paralysis, numbness of the face, arm or leg, trouble with seeing in one or both eyes, headache and trouble with walking	may be caused by a blocked artery or leaking or bursting of a blood vessel	Lower the blood pressure by reducing salt content, avoid high-cholesterol, be more active through exercise, and quit smoking. Lose weight by trying not to eat more than 1500 to 2000 calories a day. Exercise more ad treat diabetes	Thrombolysis is a treatment to dissolve dangerous clots in blood vessels or surgery.
Pre-term birth complications	these are deliveries that occur at less than 37 weeks gestational age.	Some of the signs are infection or inflammation, uteroplacental ischaemia or haemorrhage, uterine overdistension, stress and other immunologically mediated processes.	spontaneous labour with intact membranes, pre-term premature rupture of the membranes and labour induction, black race, periodontal disease and low maternal body-mass index, short cervical length and a raised cervical vaginal foetal fibronectin concentration.	use of maternal progesterone supplementation, surgical closure of the cervix with cerclage, prevention of exposure of pregnant women to cigarette smoke, judicious of fertility treatments and dedicated pre-term birth prevention clinics.	treating intra-uterine infections, improvements in maternal nutrition and lifestyle modifications to ameliorate maternal stress, use of papillomavirus vaccination in girls and women

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Table A.7 – *Continued from previous page*

Disease	**Description**	**Signs and Symptoms**	**Causes**	**Preventative Measures**	**Treatments**
Birth asphyxia and birth trauma	Asphyxia means lack of oxygen. Birth asphyxia happens when a baby's brain and other organs do not get enough oxygen, during or right after birth. Cells cannot work properly and this waste products build up in the cells and cause temporary or permanent damage.	baby is not breathing or breathing very weak. Skin colour is bluish or pale, heart rate is low muscle tone is poor or reflexes are weak, too much acid in the blood the amniotic fluid is stained with meconium (first stool) the baby is experiencing seizures.	too little oxygen in the mother's blood before and during birth. Problem with the placenta separating from the uterus too soon. Very long or difficult delivery. Baby airway is blocked, anaemia	Using a cardiograph for screening the fatal well-being during labour and to identify the possibility of asphyxia	Breathing support until they can breathe well enough on their own, In a severe case then a mechanical ventilation, respiratory therapy, fluid and medicine to control blood pressure and prevent seizures.
Ischaemic heart disease	Also known as coronary heart disease. In which a waxy substance called plaque builds inside the coronary arteries. The function of these arteries is to supply oxygen-rich blood to your heart muscle.	Angina is chest pain or discomfort that occurs if an area of your heart does not get enough oxygen-rich blood, shortness of breath, heart attack, arrhythmia is a problem with rate of the heart beat.	There are a risk factors associated with the diseases namely: a family history of heart disease, high blood pressure, smoking, high cholesterol, obesity, sedentary lifestyle.	This can be prevented by making lifestyle changes such as maintaining a healthy diet and avoiding high risk behaviours including smoking and excessive alcohol uptake.	Medications and surgery depending on the severity of the damage done to the heart. Changing to a healthy lifestyle.

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Table A.7 – *Continued from previous page*

Disease	**Description**	**Signs and Symptoms**	**Causes**	**Preventative Measures**	**Treatments**
Tuberculosis	it is an infectious disease caused by *Mycobacterium* tuberculosis as well as other mycobacteria species such as *M. bovis* and *M. africanum*	The symptoms are: lethargy, weight loss, fever and night sweats. The infection affects the lungs resulting in coughing, chest pain and coughing up blood and sputum.	TB is spread when the germs of the infected person are released into the air through coughing, sneezing and talking and inhaled by another person	Early detection systems to avoid the spread of the disease by identifying the infected people effectively. Vaccination using the TB vaccine called Baccillus Calmette-Guerin (BCG). TB treatment can be administered to avoid the recurrence of TB especially people who had active TB. Coughing etiquette, when someone is infected they should contain their sputum and should sleep alone.	

APPENDIX B

MORE DETAIL ON WEARABLE TECHNOLOGY

This appendix contains additional information on topics presented and discussed in Chapter 3.

B.1 Structured Review

In this section, the findings from the structured review described in Section 3.3.

B.1.1 Detailed Inclusion and Exclusion Criteria

Table B.1: Inclusion and exclusion criteria of the different articles reviewed

Paper Number	**Reference**	**Paper Title**	**Inclusion**	**Exclusion**	**Reason for selection**
1	Pantelopoulos and Bourbakis (2010)	A survey of wearable sensor-based systems for health monitoring and prognosis	X		Describes components in a wearable system such as physiological sensors, transmission modules and processing capabilities (real time decision support systems)
2	Chan *et al.* (2009)	Smart homes - Current features and future perspectives	X		Describes components such as vital signs, sounds, images and body motion measured, communication means (wireless or wired networks), sleep patterns, daily activities. Software used for data analysis and application
3	Tao *et al.* (2012)	Gait analysis using wearable sensors.	X		Application of the device and features of wearable sensors
4	Xinguo Yu (2008)	Ambulatory monitoring of physical activities in patients with Parkinson's disease	X		Describes the components necessary for monitoring such as sensors, data analysis
5	Salarian *et al.* (2007)	Approaches and principles of fall detection for elderly and patient		X	Focuses on characteristics of falls and methods of fall detection
6	Shull *et al.* (2014)	Quantified self and human movement: A review on the clinical impact of wearable sensing and feedback for gait analysis and intervention	X		Clinical applications, wearable sensors used, diseases that can be monitored using gait analysis
7	Zhang and Sawchuk (2013)	Human daily activity recognition with sparse representation using wearable sensors		X	Focuses on sparse representation using wearable sensors
8	Pantelopoulos and Bourbakis (2008)	A survey on wearable biosensor systems for health monitoring	X		Important features that can be used to best desccribe the functionality and characteristics of wearable biosensors.

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Table B.1 – *Continued from previous page*

Paper Number	**Reference**	**Paper Title**	**Inclusion**	**Exclusion**	**Reason for selection**
9	Raveendranathan *et al.* (2012)	From modeling to implementation of virtual sensors in body sensor networks		X	Focuses on modelling and implementation of Virtual sensors
10	Alam and Hamida (2014)	Surveying wearable human assistive technology for life and safety critical applications: Standards, challenges and opportunities	X		Describes the Applications, characteristics and requirements of wearable technologies
11	Riazul Islam *et al.* (2015)	The Internet of things for health care: A comprehensive survey	X		Reviews network platforms, applications, security and privacy features for wearables in healthcare.
12	Zollo *et al.* (2011)	Quantitative evaluation of upper-limb motor control in robot-aided rehabilitation		X	Provides a performance indices on patient motor
13	Zhang and Sawchuk (2012)	Motion primitive-based human activity recognition using a Bag-of-Features approach		X	Describes human activity modelling and recognition using wearable sensors
14	Lee *et al.* (2016)	A radial basis classifier for the automatic detection of aspiration in children with dysphagia		X	Focuses on the development of a classifier for automatic classification of aspiration and swallow vibration signals non-invasively recorded on the neck of children with dysphagia
15	Amjadi *et al.* (2016)	Stretchable, Skin-Mountable, and Wearable Strain Sensors and Their Potential Applications: A Review		X	Review of wearable strain sensors - applications, characteristics of strain sensors material
16	Egbogah and Fapojuwo (2011)	A survey of system architecture requirements for health care-based wireless sensor networks	X		Review of wireless sensor networks - architecture of hardware and framework of software.
17	Chio-In Ieong *et al.* (2012)	Title: A 0.83-μW QRS detection processor using quadratic spline wavelet transform for wireless ECG acquisition in 0.35-μm CMOS		X	Describing how a processor functions to detect arrhythmia using a wireless ECG
18	Fu *et al.* (2015)	Title: A Bayesian approach for sleep and wake classification based on dynamic time warping method		X	Describes an approach that is used to classify sleep and wake.

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Table B.1 – *Continued from previous page*

Paper Number	Reference	Paper Title	Inclusion	Exclusion	Reason for selection
19	Trung and Lee (2016)	Title: Flexible and Stretchable Physical Sensor Integrated Platforms for Wearable Human-Activity Monitoring and Personal Healthcare	X		Provides characteristics that are used for flexible and stretchable physical sensors and applications
20	Ugulino *et al.* (2012)	Title: Wearable computing: Accelerometers' data classification of body postures and movements		X	Focuses on data analysis method - human activity recognition
21	KATAYAMA *et al.* (2009)	Channel model on various frequency bands for wearable Body Area Network		X	Article in Japanese and unavailable
22	Attal *et al.* (2015)	Physical human activity recognition using wearable sensors		X	Comparing the different algorithms that can be used for human activity recognition
23	Chavez-Santiago *et al.* (2012)	Title: Cognitive radio for medical body area networks using ultra wideband		X	Provides the architect of medical body area networks (MBAN)
24	Watanabe *et al.* (2011)	A preliminary test of measurement of joint angles and stride length with wireless inertial sensors for wearable gait evaluation system		X	Provides a wearable sensro system for gait evaluation
25	Xu *et al.* (2012)	Title: Equation environment coupling and interference on the electric-field intra-body communication channel		X	Investigates the effects of the environment on the EF-IBC channel.
26	Van Helleputte *et al.* (2014)	18.3 A multi-parameter signal-acquisition SoC for connected personal health applications		X	Investigates a multi sensor interface
27	Cruz *et al.* (2008)	The future of extra corporeal support	X		Characteristics of implantable devices
28	Jara *et al.* (2011)	Title: Mobile IP-based protocol for wireless personal area networks in critical environments		X	Investigates the use of low-power personal area networks.
29	Chen *et al.* (2009)	Title: A design of power supply for neonatal monitoring with wearable sensors		X	Describes the components necessary for neonatal monitoring with wearable sensors. Not available

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Table B.1 – *Continued from previous page*

Paper Number	**Reference**	**Paper Title**	**Inclusion**	**Exclusion**	**Reason for selection**
30	Xie *et al.* (2012)	Title: Heterogeneous integration of bio-sensing system-on-chip and printed electronics		X	Focuses on the circuits that are used in bio-sensing applications.
31	Banos *et al.* (2014)	Title: PhysioDroid: Combining Wearable Health Sensors and Mobile Devices for a Ubiquitous, Continuous, and Personal Monitoring	X		Describes a wearable systems for health monitoring
32	Hu *et al.* (2008)	Title: Low-cost wireless sensor networks for remote cardiac patients monitoring applications	X		Describes a wireless sensor network that is used by wearable devices and proposes a sensor network system that composes of wearable vital sign sensors and workstation monitor.
33	Naslund *et al.* (2015)	Title: Feasibility of popular m-health technologies for activity tracking among individuals with serious mental Illness		X	It provides a study on the acceptance of activity tracking devices.
34	Tolkiehn *et al.* (2011*b*)	Title: Direction sensitive fall detection using a triaxial accelerometer and a barometric pressure sensor.		X	The wearable system used for fall detection
35	Khattak *et al.* (2011)	Title: Towards smart homes using low level sensory data		X	The wearable sensor-based system used to monitor Alzheimer's
36	Jayakumar *et al.* (2014)	Title: Powering the Internet of Things		X	The main components that make a wearable system
37	Butala *et al.* (2012)	Title: Wireless system for monitoring and real-time classification of functional activity	X		The main components of wearable devices used for health monitoring.
38	Cavalli *et al.* (2010)	Title: Hemodialysis: Yesterday, today and tomorrow		X	Describes an innovative technology for hemodialysis
39	Gaggioli *et al.* (2014)	Title: Experiential virtual scenarios with real-time monitoring (interreality) for the management of psychological stress: A block randomized controlled trial		X	It is a study of how virtual reality can help improve physiological sensors.
40	Tolkiehn *et al.* (2011*a*)	Title: Direction sensitive fall detection using a triaxial accelerometer and a barometric pressure sensor			Repeated

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Table B.1 – *Continued from previous page*

Paper Number	**Reference**	**Paper Title**	**Inclusion**	**Exclusion**	**Reason for selection**
41	Ren *et al.* (2007)	Title: Experimental evaluation of on-body transmission characteristics for wireless biosensors		X	Comparing the wireless and wired connections for bio-sensors.
42	Sankaralingam and Gupta (2012)	Title: Effects of bending on impedance and radiation characteristics of rectangular wearable antenna utilizing smart clothes	X		Characteristics of a garment-integrated wearable device.
43	Hovsepian *et al.* (2015)	Title: CStress: Towards a gold standard for continuous stress assessment in the mobile environment		X	Development of a stress model used for data collection
44	Liu and Xiao (2011)	Title: Temporal accountability and anonymity in medical sensor networks	X		Provides the characteristics of medical sensors and wearable devices
45	Mahoney and Mahoney (2010)	Title: Acceptance of wearable technology by people with alzheimers disease: Issues and accommodations	X		Features necessary for wearable devices for Alzheimers diseases
46	Lewis *et al.* (2007)	Title: Using an electronic activity monitor system as an intervention modality: A systematic review		X	Focuses on the different tracking devices.
47	Ghasemzadeh *et al.* (2015)	Title: Power-aware computing in wearable sensor networks: An optimal feature selection		X	Focuses on features of data analysis techniques
48	Cole *et al.* (2014)	Title: Dynamical learning and tracking of tremor and dyskinesia from wearable sensors		X	Testing of wearable sensors algorithms for tracking of tremor and dyskinesia
49	Bofeng Zhang *et al.* (2012)	Title: State of the art in gait analysis using wearable sensors for healthcare applications		X	Focuses on the walking analysis using inertial sensors.
50	Ribeiro *et al.* (2011)	Title: A novel dry active biosignal electrode based on an hybrid organic-inorganic interface material		X	Focuses on the characteristics of the ECG electrodes
51	Di Rienzo *et al.* (2010)	Title: Linear and fractal heart rate dynamics during sleep at high altitude: Investigation with textile technology		X	Focuses on the characteristics of sleep using wearable device

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Table B.1 – *Continued from previous page*

Paper Number	Reference	Paper Title	Inclusion	Exclusion	Reason for selection
52	Hansora *et al.* (2015)	Title: Performance of hybrid nano-structured conductive cotton materials as wearable devices: An overview of materials, fabrication, properties and applications		X	Focuses on the application, characteristics of different cotton textiles used for wearable devices.
53	He *et al.* (2015)	Title: User privacy and data trustworthiness in mobile crowd sensing		X	Characteristics of mobile crowding sensing
54	Tanantong *et al.* (2014)	Title: Toward continuous ambulatory monitoring using a wearable and wireless ECG- Recording system: A study on the effects of signal quality on arrhythmia detection		X	Comparison of 5 well-known arrhythmia classification algorithms
55	Samanta *et al.* (2014)	An energy efficient, minimally intrusive multi-sensor intelligent system for health monitoring of elderly people		X	Describes the features of wearable systems. (Not available)
56	Cipresso *et al.* (2012)	Title: Inter-reality in the evaluation and treatment of psychological stress disorders: The INTERSTRESS project		X	Focuses on the evaluation and treatment of psychological stress disorders
57	Chen *et al.* (2011)	Title: Wearable electromyography sensor based outdoor-indoor seamless pedestrian navigation using motion recognition method		X	Describes the different motions that can be measured using EMG sensors
58	Segerståhl and Oinas-Kukkonen (2011)	Title: Designing personal exercise monitoring employing multiple modes of delivery: Implications from a qualitative study on heart rate monitoring	X		Investigates the characteristics of heart rate monitoring using wearable devices
59	Chan *et al.* (2012)	Title: Smart wearable systems: Current status and future challenges	X		
60	Lukowicz *et al.* (2004)	Wearable systems for healthcare applications	X		

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Table B.1 – *Continued from previous page*

Paper Number	**Reference**	**Paper Title**	**Inclusion**	**Exclusion**	**Reason for selection**
61	Patel *et al.* (2012)	A review of wearable sensors and systems with application in rehabilitation	X		
62	Swan (2012)	Sensor Mania! The Internet of Things, Wearable Computing, Objective Metrics, and the Quantified Self 2.0	X		

B.1.2 Detailed Structured Review Findings

Table B.2: Sensing Technology

Paper Number	**References**	**Hardware description**	**Physiological signals or vital signs or measurable**
1	Pantelopoulos and Bourbakis (2010)	miniature sensors such as skin/chest electrodes, arm cuff-based monitor, temperature probe or skin patch, piezoelectric, pulse oximeter, galvanic skin response, phonocardiograph, strip-base glucose meters, scalp-placed electrodes, accelerometer. Smart textiles, actuators, power supplies, control and processing units.	Biosignals–electrocardiogram (ECG), blood pressure, body or skin temperature, respiration rate, oxygen saturation, heart rate, perspiration or skin conductivity, heart sounds, blood glucose, electromyogram (EMG), electroencephalogram (EEG), body movements
2	Chan *et al.* (2009)	Sensors - accelerometer, thermal conductivity sensor, skin temperature sensor, skin electrical conductivity, two lead ECG, respiratory meter, enzyme electrodes	Vital signs or biomedical signals - blood pressure, respiration, body temperature, heart or pulse rate, body or weight or fat, blood oxygenation, ECG, activity, blood glucose

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Table B.2 – *Continued from previous page*

Paper Number	**References**	**Hardware description**	**Physiological signals or vital signs or measurable**
3	Tao *et al.* (2012)	Sensors - accelerometer, gyroscope and magnetoresistive, flexible goniometer, piezoelectic fabric, force sensors, electromyography (EMG) sensor, video cameras	motion, mobility, fall
4	Salarian *et al.* (2007)	Sensors - bi axial accelerometer, gyroscope	
5	Shull *et al.* (2014)	Sensors - accelerometer, gyroscope, magnetometers, goniometer, force sensitive resistor, bend sensors, electric field sensor	motion, mobility, fall
6	Pantelopoulos and Bourbakis (2008)	miniature sensors such as skin/chest electrodes, arm cuff-based monitor, temperature probe or skin patch, piezoelectric, pulse oximeter, galvanic skin response, phonocardiograph, strip-base glucose meters, scalp-placed electrodes, accelerometer. Smart textiles, actuators, power supplies, control and processing units, microcontroller board.	Heart rate, blood pressure, body and skin temperature, ECG
7	Alam and Hamida (2014)	sensors - accelerometer, gyroscope, gas sensor	physiological parameters: temperature, blood pressure, heart pulse rate, energy expenditure, stress level, glucose concentration, blood flow, ECG, respiratory rate, blood pH etc. Surrounding environment: toxic gases, humidity, heat, etc. location using GPS position. Body movement: body posture and orientation, activity, fall detection, etc. EMG, EEG, blood oxygenation
8	Riazul Islam *et al.* (2015)	medical terminals into hybrid computing grids. Sensors-EEG sensor, BP sensor, EMG sensor, ECG sensor.	Vital signs - blood pressure, body temperature, ECG and oxygen saturation
9	Egbogah and Fapojuwo (2011)	sensors such as pulse oximeters, electrocardiographs and accelerometers. Battery power, physiological monitors (sensors), GUI display information	

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Table B.2 – *Continued from previous page*

Paper Number	**References**	**Hardware description**	**Physiological signals or vital signs or measurable**
10	Trung and Lee (2016)	Electrodes of electrogram systems, rigid circuit boards, power supplies, temperature sensor, pressure sensor (Piezoelectric) and strain sensors. Temperature sensors - pyroelectric detectors, resistive temperature detectors, thermistors	ECG, EEG, EMG, body and skin temperature, blood pressure, pulse, skin strain and infared radiation. The voice, heart beat rate, muscle movement, bodily motion.
11	Cruz *et al.* (2008)	Solute sensor and volume sensor. Control module	solute concentration
12	Banos *et al.* (2014)	mobile 12 lead ECG, plethysmogram, wearable monitoring device, radio frequency transceiver	measure ECG, heart rate, oxygen saturation, Blood flow rate, non-invasive blood pressure, skin temperature, fluid status, posture, activity, acceleration data. Measuring physiological and behavioural data.
13	Hu *et al.* (2008)	Sensor board	ECG, heart rate, pulse oximeter, blood pressure
14	Khattak *et al.* (2011)	wireless sensor network, video, accelerometer, 2D camera and 3D camera,	location and physiological data and environmental data
15	Butala *et al.* (2012)	sensors, micro-electro-mechanical systems (MEMS) devices, low powered, microcontroller, accelerometer, gyroscope, coin cell battery, circuit board, smart phone, laptop or computer, graphical user interface (GUI) , RF Transceiver	ECG/EKG, pulse, blood oxygen, blood glucose, temperature, gait, limb movement, etc.
16	Sankaralingam and Gupta (2012)		
17	Liu and Xiao (2011)	micro-electro-mechanical systems (MEMS), cryptography, and digital electronics,	ECG, heart rate, blood pressure, pulse oximetry
18	Mahoney and Mahoney (2010)	ECG sensors, accelerometers,	fall detection, breathing and heart rate, skin temperature and activity
19	Segerståhl and Oinas-Kukkonen (2011)	EMG sensors, gyroscope	EMG, human locomotion,

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Table B.2 – *Continued from previous page*

Paper Number	**References**	**Hardware description**	**Physiological signals or vital signs or measurable**
20	Chan *et al.* (2012)	Microfluidics and micro-fabrication. Sensors: skin electrodes, scalp-placed electrodes, accelerometer, piezoelectric, phonograph, glucose meter, pulse oximeter, temperature probe or skin patch, woven metal electrodes.	body and skin temperature, heart rate, ECGs, EEGs, EMGs or blood oxygenation, activity, mobility fall, respiration rate, heart sounds, blood glucose, galvanic skin response
21	Lukowicz *et al.* (2004)	Textile sensors, textile actuators, ultra-thin solar cells, power generation device, microsystems that contain a sensor, power generators and processor, electronic sensors,	
22	Patel *et al.* (2012)	Wearable sensors, sensing , body worn sensors, PPG sensor, microphone, biochemical sensors, glucose monitor, pH sensor, accelerometer,	heart rate, respiratory rate, blood pressure, blood oxygen saturation, muscle activity, body temperature, position, movement
23	Swan (2012)	Sensors - accelerometer, GSR sensor, temperature sensor, heart rate sensor, glucose monitors, battery technology	movement, sound, light, electrical potential, temperature, moisture, location, heart rate, heart rate variability, galvanic skin response or skin conductivity, ECG, EMG, EEG, PPG

Table B.3: Disease(s) or condition(s)

Paper Number	**References**	**Disease(s) or Condition(s)**
1	Pantelopoulos and Bourbakis (2010)	Parkinson's disease, epilepsy seizure detection,chronic diseases such as CVD, sleep apnoea,
2	Chan *et al.* (2009)	Diseases such as asthma, diabetes, chronic obstructive pulmonary disease, heart diseases.
3	Tao *et al.* (2012)	
4	Salarian *et al.* (2007)	Parkinson's disease motor abnormalities such as tremor, bradykiesia and gait

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Table B.3 – *Continued from previous page*

Paper Number	References	Disease(s) or Condition(s)
5	Shull *et al.* (2014)	osteoarthritis, Parkinson's disease, hemiplegia, head trauma, Improving walking stability, reduce joint loading
6	Pantelopoulos and Bourbakis (2008)	
7	Alam and Hamida (2014)	
8	Riazul Islam *et al.* (2015)	
9	Egbogah and Fapojuwo (2011)	
10	Trung and Lee (2016)	Malignancy and cancer, diabetic foot ulceration, hypertension, CVD, sleep apnea, Parkinson's disease, posture and movement, wound healing
11	Cruz *et al.* (2008)	Congestive heart failure, kidney failure
12	Banos *et al.* (2014)	cardiac arrhythmias, sleep disorders, ischeamic cardiac events
13	Hu *et al.* (2008)	cardiac diseases
14	Khattak *et al.* (2011)	Alzheimer's disease, heart attacks
15	Butala *et al.* (2012)	Parkinson's disease
16	Sankaralingam and Gupta (2012)	
17	Liu and Xiao (2011)	patient's physical status
18	Mahoney and Mahoney (2010)	
19	Segerståhl and Oinas-Kukkonen (2011)	human locomotion,
20	Chan *et al.* (2012)	Cardiovascular diseases, diabetes mellitus, renal diseases, respiratory diseases, cancer, posture, motion control, neurological disorders and brain simulation, Parkinson's disease, stress, recognizing emotions, sudden infant death syndrome
21	Lukowicz *et al.* (2004)	
22	Patel *et al.* (2012)	congestive heart failure, chronic obstructive pulmonary disease, stroke survivors
23	Swan (2012)	mental performance optimisation, emotion reading, mapping and management programs

Table B.4: ICT - Data Communication

Paper Number	References	Communication Devices	Data Transfer	
			Wired connections	Wireless connections

Continued on next page

Table B.4 – *Continued from previous page*

Paper Number	**References**	**Communication Devices**	**Data Transfer**	
			Wired connections	**Wireless connections**
1	Pantelopoulos and Bourbakis (2010)	Smart phones, PC and laptops and Central node - Personal Digital Assistant (PDA) or a microcontroller board.	Wired networks	Wireless communication - short-range such as Body area network (BAN) include Bluetooth and ZigBee. Long range data transmission to a remote station or device - WLAN, GSM, GPRS, UMTS and WiMAX.
2	Chan *et al.* (2009)	PDA	Wired - Telecommunications systems, connections in textiles,	Wireless networks to a service centre, GPRS, Telecommunications systems,
3	Tao *et al.* (2012)			
4	Salarian *et al.* (2007)			
5	Shull *et al.* (2014)			
6	Pantelopoulos and Bourbakis (2008)	Central node - Personal Digital Assistant (PDA) or a microcontroller board.Smart phones, PC and laptops	Wired networks.	Wireless communication - short-range such as Body area network (BAN) include Bluetooth and ZigBee. Long range data transmission to a remote station or device - WLAN, GSM, GPRS, UMTS and WiMAX.
7	Alam and Hamida (2014)	Smart phones		Wireless sensor networks, WiFi Access Points or Broadband Cellular networks eg GSM, GPRS, 3G, LTE, etc. Personal Area Network (PAN) - Bluetooth, Bluetooth Low Energy (BLE), Wireless sensors network (WSN) - Zigbee and Ultra Wideband (UWB) and Wireless Local Area Network (WLAN) - WiFi.
8	Riazul Islam *et al.* (2015)	laptops, smart phones, gateways		Networks: WiMAX, Internet protocol (IP) network and global system for a mobile (GSM) and access service networks. WPAN, WBAN, 6LoWAN, WSN, UWB, BLE, NFC, RFID

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Table B.4 – *Continued from previous page*

Paper Number	**References**	**Communication Devices**	**Data Transfer**	
			Wired connections	**Wireless connections**
9	Egbogah and Fapojuwo (2011)	PDA devices, Network gateways	relay points, Routing methodology : multicast, intra-cluster and inter-cluster data relay	Internet, wireless sensor networks,
10	Trung and Lee (2016)		transmission modules	
11	Cruz *et al.* (2008)	PDA		Wireless network. Direct connection
12	Banos *et al.* (2014)	Mobile device can be smart phone or tablet. Gateways		Bluetooth connection, WiFi or 3G network. API platform. Apple iOS platform and Android,
13	Hu *et al.* (2008)	wearable devices, receiving stations, Wireless sensor network grouped into 2 devices: mobile platforms and receiving station. Mobile platforms: patient data collection are distributed using wearable devices.	USB connections.	wireless sensor networks, data transfer through the workstation using a MATLAB server is created to transfer from a Java runtime environment into the MATLAB workspace via local host connection, IEEE 802.15.4-compliant radio capabilities.
14	Khattak *et al.* (2011)	Gateway such as PDAs or cell phones, GPRS modem.		Body networks
15	Butala *et al.* (2012)	Dongle, mobile devices such as smart phone, laptop or computer,		Near field communication, wireless connection- Bluetooth (IEEE 802. 15.1), ZigBee (IEEE 802. 15.4) and ANT. Android and iOS operating systems. API used to configure, transmit and receive messages to and from the dongle. Smartphone App
16	Sankaralingam and Gupta (2012)	Wearable antenna plays an important role in the optimal design of wearable devices		Bluetooth industrial, scientific and medical (ISM) band used for WLAN applications.

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Table B.4 – *Continued from previous page*

Paper Number	References	Communication Devices	Data Transfer	
			Wired connections	**Wireless connections**
17	Liu and Xiao (2011)	PDA which can be wearable device	Wired channels can also be used to transfer information to the remote center	Wireless communication. Wireless transmission of data to monitor centers via a wireless channel.
18	Mahoney and Mahoney (2010)			Remotely communicate the location using GPRS or GSM network
19	Segerståhl and Oinas-Kukkonen (2011)			
20	Chan *et al.* (2012)	Gateways - PDA as a wearable computer.Smart phones		Data transmission via wireless body communication networks. The Body area network (BAN) consists of wearable sensor Then Personal Area Network (PAN) can include smart phone sensor, video sensor, and environmental sensors. Gateways that operate via a wide area network (WAN) such as WLAN, GSM, GPRS, UMTS and WiMAX, 4th generation (LTE), Bluetooth and ZigBee. Application program interface (API),
21	Lukowicz *et al.* (2004)	mobile computers and PDAs, mobile phones,		Bluetooth, wireless LAN (WLAN), connection using a BAN, cellular connection
22	Patel *et al.* (2012)	mobile phones or personal computers,		Wireless communication using Internet, ZigBee and Bluetooth tethering communication systems. Ultra-wide-band (UWB) impulse radio, Information transmitted to hospital servers. Data transmitted from sensor network to information gateways such as mobile phones or personal computers. Universal broadband connectivity, 4th generation (LTE),

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Table B.4 – *Continued from previous page*

Paper Number	**References**	**Communication Devices**	**Data Transfer**	
			Wired connections	**Wireless connections**
23	Swan (2012)	mobile phones		Wi-Fi, Bluetooth, ANT, ZigBee, USB, 2G, 3G, and 4G. Bluetooth low-enery (BTLE), API for example Dropbox, Facebook, Fitbit, Flickr, Instagram

Table B.5: ICT - Data handling

Paper Number	**References**	**Storage and computation**	**Data analysis**	**Data encryption and security**
1	Pantelopoulos and Bourbakis (2010)		Data extraction and decision making	Encrypted transmission of measured signals and authentication requirement for private data access.
2	Chan *et al.* (2009)		Software used to evaluate data collected from motor activity and health data to detect emergency situations. Nearest neighbour technique, signal processing techniques, devices capable of integrated analysis support for making decisions and diagnosis	
3	Tao *et al.* (2012)	Transfer of data to centralised medical location and processed by trained medical personnel.	Gait kinematics, gait kinetics and EMG signal processing	
4	Salarian *et al.* (2007)		Analysis algorithm for detection of Stand-sit and sit-stand transitions, walking periods and lying periods	

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Table B.5 – *Continued from previous page*

Paper Number	**References**	**Storage and computation**	**Data analysis**	**Data encryption and security**
5	Shull *et al.* (2014)		Kinematics and kinetics for gait analysis	
6	Pantelopoulos and Bourbakis (2008)		Decision support system, signal processing	Privacy of medical data
7	Alam and Hamida (2014)	Cloud server		Communication systems should have some security. 3 levels of security: Level 0 - unsecured communication, Level 1 - authentication but no encryption, Level 2 - authentication and encryption. Data storage security requirement, data access security requirements, data communication security requirements
8	Riazul Islam *et al.* (2015)			Features of security and privacy - security requirements such as confidentiality, integrity, authentication, availability, data freshness, etc. vulnerabilities, threat models and countermeasures. Proposed Security model
9	Egbogah and Fapojuwo (2011)	Back-end servers, remote storage for further analysis.	Extraction and classification techniques, ECG data mining	Low overhead and low complexity encryption and decryption security scheme. Session keys (SK) issued by gateways.
10	Trung and Lee (2016)			
11	Cruz *et al.* (2008)			

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Table B.5 – *Continued from previous page*

Paper Number	References	Storage and computation	Data analysis	Data encryption and security
12	Banos *et al.* (2014)	remote persistent storage system to store data from multiple users. Cloud computing and the big data	Medical applications that provide clinicians with medical calculators and decision support that apply to General Practice, internal medicine, cardiology, surgery, neurology, etc. Limited proprietary processing of the information-filtering and low level knowledge extraction	Security provided by operating systems, authentication through the application
13	Hu *et al.* (2008)	Receiving station meant for data gathering and communicates actively with mobile platforms	Signal processing, image processing and pattern recognition. Feature extraction locates points of interests from multidimensional space. Feature extraction algorithm	
14	Khattak *et al.* (2011)	Cloud computing	Human activity recognition and manipulation system	Cloud computing secured
15	Butala *et al.* (2012)			
16	Sankaralingam and Gupta (2012)			
17	Liu and Xiao (2011)		Real-time data analysis using a professional software	End-to-end security scheme: sensor to sensor communication protected using low cost symmetrical ciphers and authentication and encryption through extremely light-weight security schemes. User anonymity - protects the user's privacy and also complies with the principle of least information. Information integrity

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Table B.5 – *Continued from previous page*

Paper Number	**References**	**Storage and computation**	**Data analysis**	**Data encryption and security**
18	Mahoney and Mahoney (2010)			
19	Segerståhl and Oinas-Kukkonen (2011)		Motion recognition assisted pedestrian dead reckoning (PDR) algorithm, azimuth to calculate position	
20	Chan *et al.* (2012)		Real-time processing of data.	
21	Lukowicz *et al.* (2004)		Signal processing	
22	Patel *et al.* (2012)	Cloud-based systems, remote centre, hospital servers	Signal processing, pattern recognition and artificial intelligence-based methodologies	
23	Swan (2012)	cloud services - vendors such as AT&T and Qualcomm, Microsoft's Azure, Amazon web	Image recognition, emotion detection	

Table B.6: Wearable Technology Healthcare Services

Paper Number	**References**	**Stages of Care**	**Intended User**
1	Pantelopoulos and Bourbakis (2010)	Ambient assisted living, preventative, diagnosis, rehabilitation, health and wellness	

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Table B.6 – *Continued from previous page*

Paper Number	**References**	**Stages of Care**	**Intended User**
2	Chan *et al.* (2009)	disease management, assisted living, preventative, diagnostic, wellness	elderly people, disabled people, patients, people who suffer from chronic conditions, hospital based health professionals
3	Tao *et al.* (2012)	rehabilitation, health diagnostics, wellness	
4	Salarian *et al.* (2007)	preventative, diagnostic, disease management	
5	Shull *et al.* (2014)	Treatment, diagnostic,	Subject type: healthy, chronic conditions, handicapped
6	Pantelopoulos and Bourbakis (2008)		
7	Alam and Hamida (2014)	disease management, assisted living, treatment, preventative, emergency services	
8	Riazul Islam *et al.* (2015)	Assisted living, community healthcare, children health information, rehabilitation system, medication management,	
9	Egbogah and Fapojuwo (2011)	Preventative, diagnostic, disease management, emergency management	Patients, doctors and nurses
10	Trung and Lee (2016)	diagnostics, preventative, treatment, health and wellness	
11	Cruz *et al.* (2008)	treatment of diseases, diagnostic and therapeutic interventions	Patients
12	Banos *et al.* (2014)	disease management, wellness, prognosis, diagnostics,	patients, relatives, caregivers, practitioners, institutions and companies
13	Hu *et al.* (2008)	diagnostics	Cardiac patients
14	Khattak *et al.* (2011)	health and wellness, emergency services, clinical care services,	
15	Butala *et al.* (2012)	rehabilitation, preventative and recuperative, disease management,	
16	Sankaralingam and Gupta (2012)		
17	Liu and Xiao (2011)	Medical records	doctors, nurses, patient

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Table B.6 – *Continued from previous page*

Paper Number	References	Stages of Care	Intended User
18	Mahoney and Mahoney (2010)		
19	Segerståhl and Oinas-Kukkonen (2011)	medical diagnosis, rehabilitation	
20	Chan *et al.* (2012)	emergency services, preventative, diagnostic, treatment, health and wellness	healthcare providers alerted in case of emergency, handicapped, elderly, suffering from chronic diseases and injured with special needs
21	Lukowicz *et al.* (2004)	Health monitoring, assisted living systems, mobile treatment and novel information management tools for medical personnel, fitness	
22	Patel *et al.* (2012)	rehabilitation, assisted living	Family members, caregivers, clinical personnel
23	Swan (2012)	wellness	

B.2 Reviewed wearable devices

This section gives the details on the wearable devices reviewed for the analysis for Chapter 3.

Table B.7: Reviewed wearable devices

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
1	Wearable sweat sensors	Use of sweat to look for signs of diseases. Sodium and potassium in sweat help detect dehydration and muscle cramps. Glucose for blood sugar levels. Lactate level indicate blood flow problems and skin temperature for overheating.	TRL 4 - Technology development and the safety of the device is demonstrated	The data is fed to a flexible board of microchips that processes signals from sensors.	Thermometer, blood sugar monitor and biomarkers	Sync data to Bluetooth to wirelessly transmit data to a smart phone.	Smart phone app that plots data in real time.	molecules ranging from complex proteins to electrically charged ions , skin temperature, glucose levels, lactate levels, sodium and potassium	lack of body fluids, muscle cramps

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
2	Allergy Amulet	Can detect food allergy and provide additional information to the consumer about the food they are about to eat	TRL 8 - Completed clinical evaluations and ready for the market	Disposable chemistry-based test strip that detects the presence or absence of allergens.	Chemistry-based strips	Sync data to a smart phone to alert the user	Chemistry-based test strips	Peanut protein per trillion (ppt)	food allergy

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
3	TZOA	Detects harmful particles in the air	TRL 9 - Commercialisation	Laser/photo-diode for particle detection	Optical particulate sensor, humidity sensor, pressure sensor, UV sensor and ambient light sensor	USB, SD card and Bluetooth. SD card and Bluetooth are for data read out and USB for internal configuration. TZOA-R App available for Android phones	Smart phone app	Internal Sensors to measure air quality, temperature, humidity, atmospheric pressure, ambient light and UV(sun) exposure	Prevents inhalation of particles called PM2.5 that affect people with respiratory conditions, cardiovascular diseases and autoimmune disorders.

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
4	Google contact lens	Scan barcodes, price tags and coupons, authenticate identities, help manage allergies, monitor blood alcohol content and body temperature, track glucose levels, and generate solar and ambient-light sourced power.	TRL 5 - Developed prototypes and still undergoing various clinical research	smart solar-powered contact lenses	glucose measuring sensor, light sensors	electronic circuits , radio, sync data using Bluetooth, smart-phone	Smart phone app	blood sugar levels	diabetes and eyesight improvement

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
5	Code4armour	Provides a medical personnel with personal health information about the wearer	TRL 9 - Commercialization Product launched in 2014	worn on the wrist	No sensors	Smart phone	smart phone app with personal health information	Personal Medical records	Autism, alzheimer's, dementia, asthama, diabetes, non-verbal people, heart conditions
6	Monica AN24	Accurate foetal monitoring for BMI patients	TRL 9 - Commercialisation	Abu Blue R and Ambu Blue VLC ECG electrodes and internal processor that extracts data in real time	ECG Sensor and EMG Sensor	Monica IF24 interface device, Bluetooth	L&D monitor	heart electrical activity	Foetal health
7	OM Bra	Records the heart rate and other vital data for fitness and everyday use.	TRL 9 - Commercialization	The fitness data is continuously recorded onto small box attached to the shirt can also be connected to the phone via Bluetooth.	heart rate monitor, respiratory monitor and pedometer	Internet connection, Bluetooth, smart phone	Smartphone app and online information	heart rate, step count and breathing rate	Healthy lifestyle

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
8	Empatica E4 Wristband	Is a data provider.	TRL 9 - Commercialization	The data is recorded and stored in an internal memory. The data are downloaded via USB through the Empatica Manager.	accelerometer , clock and heart rate monitor, Photo plethysmography (PPG) sensor, Electrodermal activity sensor, infrared thermopile	Bluetooth	Smart phone Real-time and mobile API app and the Empatica cloud platform	skin temperature, heart rate, blood volume pulse, sympathetic nervous system arousal	stress levels and cardiac activity
9	Insulet Ominpod	Insulin management system	TRL 9- Have performed studies on Post market surveillance	A pod that is worn anywhere on the body. The pod collects the data	test strip port	Wireless communication between Pod and PDM (Personal Diabetes Manager).	PDM has a built in blood glucose meter, extensive food library with carbohydrate counts and bolus calculator.	blood sugar levels, insulation levels	diabetes
10	Bodytel Pressuretel	Blood pressure monitor and management system	TRL 9 - Commercialization	Worn on the arm. It is compatible with iOS and Android smart phones and tablets as well as Nokia and Symbian phones running on Java applications.	Blood pressure meter	Bluetooth-enabled device, compatible with smart phones or tablets and online patient diary on Body Tel Centre		blood pressure	

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
11	Quell	drug free pain relief	RL 9 - Commercialization	Can be worn anywhere on the body. Stimulates the sensory nerves. The sensory nerves carry neural pulses to the brain. These neural pulses trigger a natural response that blocks pain signals in your body.	Accelerometer			sleep monitoring	Chronic pain

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
12	NOVII wireless patch system	accurate foetal monitoring for BMI patients	TRL 9 - Commercialization	Worn on the torso. It uses a peel and stick patch to send raw data to existing foetal monitors via Bluetooth	ECG and EMG sensor	Bluetooth		The Monica Novii monitors foetal heart rate (FHR), maternal heart rate (MHR) and uterine activity (UA), all with a single 'peel and stick' patch.	Muscle and nerve disorders, coronary heart disease, heart failure, arrhythmia, congenital heart disease, cardiomyopathy, heart failure.

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
13	Unaliwear kanega	Offers reminders to the wearer when to take medications and can detect when the user has fallen. Offers directions to the user	TRL 8 - Still undergoing device tests	Worn on the wrist. Standalone smart watch. Voice activated and allows its user to interact with it hands free.	Accelerometer	smart watch, voice activated directions, GPS		Movement detection, fall detection	Old age people
14	Smart Diaper	It is a passive system that uses chemical markers that react with the child's urine and change colour accordingly.	TRL 9 - Launched in May	Worn on the pelvis and the patch on the diaper can be photographed using a smart phone and then can be assessed using an app. data stored on Amazon's S3 and Amazon databases.	Chemical markers	Phone app and cloud service	Algorithms used to analyse the data and	water levels, sugar levels and urine composition	Screen type 1 diabetes, dehydration, urinary tract infections and kidney problems

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
15	Netatmo June	UV monitor that's designed to keep you safe from the sun's harmful rays.	TRL 9 - Commercialization	It is a bracelet designed to resemble a piece of jewellery.	UVA and UVB sensors	Connects to the smart phone through a low-power Bluetooth connection	Smartphone app for data analysis and gives the UV index in real time.	UV index in real time.	skin cancer and skin diseases
16	Sunfriend	UV monitor that's designed to keep you safe from the sun's harmful rays.	TRL 9 - Commercialization - The price of the product is going down	Worn on the wrist and it comprises microprocessor	UVA and UVB sensors	LEDs to indicate the levels of sun exposure.	Customised algorithms in the device	UV index in real time.	skin diseases
17	Hygreen	Hand hygiene tracking system to record and remind users to wash their hands.	TRL 9 - Commercialization	The system comprises of wall-mounted sensors and a clippable wearable device worn on each user. Data is stored on a database called HyMark	sensor to detect hand hygiene activity	LED, wireless signals to the Hospital systems	Analysis done in Excel	Hand wash	Spread of infections

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
18	Sproutling baby monitor	Used to sense a child's well-being and environment and provide useful insights for a parent.	TRL 8	Worn on the baby's ankle. This device is for babies from 0 to 18 months old.	Accelerometer, thermometer, heart rate monitor, hygrometer, ambient light sensor and microphone.	Companion app on the smart phone for iOS users	smart baby monitors	Heart rate, motion and position. The baby's sleep patterns	Baby's well being
19	Fitguard	Detects head injuries for athletes	TRL 8 - Completed clinical tests awaiting for the product to be released.	The device has an acceleration sensor detects head movement.	Accelerometer	LED used to indicate the force of impact and Bluetooth technology transfers data to FIT smart phone app.	The amount of acceleration will determine the force of the head impact which can be used to analyse severity of head injuries. Processes through propriety algorithm	Linear and angular acceleration	Head tremors

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
20	Sensus Pain Management system	This device is worn on the leg that provides relief of chronic pain to the user. This device comfortably stimulate the sensory nerves in the legs.	TRL 9 - Commercialization	This device is worn on the leg, just below the knee and it is activated by simply one push of a button.	No sensor	No communication hardware	No data analysis	No measurable	leg chronic pain

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
21	Chrono solution	This device helps smokers to stop smoking by gradually decreasing amounts of nicotine to the user. The device has an electrode.	TRL 9 - Commercialization	It's worn on the wrist. It has wireless connectivity that synchronize the information to smart phones.	Detects the cravings of the user and it provides small amounts of nicotine according to the cravings.	Bluetooth connect wirelessly to the smart phone. Compatibility with iOS, Android, Windows and Nokia devices.	Smart phone app	Nicotine levels	Prevent diseases associated with smoking

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
22	Rewalk personal 6.0	It is for clinical rehabilitation for people that suffered lower limb injuries. Good for exercise and	TRL 8 - Phase III Clinical trials	Worn on the body and it is adjustable to fit anyone whose height ranges between 160 cm to 190 cm. It is a wearable exoskeleton.	Undisclosed	No communication hardware	No data analysis	No measurable	Improve bowel and bladder function, mental health, posture and balance, sleep and fatigue, decrease body fat and pain.
23	Esight eyewear	A digital eyewear that enables people with low vision to see.	TRL 8 - Clinically validated	Worn on the body and		uses advanced, high-resolution video camera to capture what the wearer is looking at and the images are processed in real-time and then projected onto the two LED screens.			Low vision eyesight

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
24	Hyginex wristband	This device warns the doctors and nurses if they need to wash their hands.	TRL 8 - Commercialization - Pilot studies	It is worn on the wrist and has built in sensors that detects if the hand is clean or not. It also equipped with	Microbial sensors and overbed Beacon sensor.			hand washes	Prevent infectious diseases

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
25	Swipe sense	A complete hygiene system that monitors hygiene control using wearable hand sanitizer with monitoring sensors, wall mounted dispensers, flexible data collection badges and data collections hubs.	TRL 7: Technology Transfer	Worn on the body (anywhere). Cloud based platform that all the data is collected.	Monitoring sensors and dispensers	Communication hubs that are centralised. Data is transfer via Wi-Fi or Ethernet to secure servers.	Data analysed using an application	hand washes	Prevent infectious diseases

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
26	Ultroz elite	Aims to reduce pain, treat muscle spasms, treat joint conjecture and increase circulation.	TRL 6 - Preclinical evaluations finished	This technological device massages the internal tissue and creates heat to warm the muscle.	No sensor	No communication hardware	No data analysis	No measurable	splints, suspensory ligaments and tendons, muscle strains, stiff joints, arthritis and bone fracture
27	Surrosense RX system	The SurroSense Rx System is a wearable device that helps prevent foot ulcers by collecting pressure data.	TRL 9 - Commercialization	This technology has real-time feedback and the sensors on the shoe inserts and wirelessly transmits data to the smart watch.	Pressure sensor	Data transmitted wirelessly to the smart watch from shoe inserts.	The data is analysed to an Orpyx Connect account. Information presented as digital charts and data tracking.	pressure levels	Foot ulcers

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
28	Zoll Lifevest	Wearable defibrillator used for cardiac monitoring and to protect the user from cardiac arrest.	TRL 9- Clinical trials completed and FDA approval. Ongoing clinical trials	Garment that detects and delivers shocks	ECG electrodes, therapy pads	USB cable connection between the lifevest and the monitor	Data analysed used using complex algorithms for arrhythmias	Heart rhythm	Cardiac arrest. Heart attack, cardiomyopathy and congestive heart failure.
29	Zio XT Patch	Wearable device that continuously measures heart rate in a discreet and wireless manner.	TRL 9 - Commercialization	Worn anywhere on the body and the technology records heartbeats during sleeping time as well as other day-to-day activities, up to 14 days. After the recording period, the data is sent to the iRhythm clinical app for analysis, using FDA-cleared algorithms.	ECG sensor and another one which is not disclosed		Proprietary algorithm	Heart rate	Cardiovascular diseases

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
30	Sentimoto	Smart wearable watch that captures the users' physiological and environmental data, in order to determine their overall physical well-being.	Wearable device taken off the market	Worn on the wrist and measurements can be viewed on mobile devices using the cloud analytic software.	Accelerometer, heart rate monitor, thermometer and hygrometer			Sentimoto includes sensors that analyse heart rate, body temperature, activity level, room temperature and humidity.	old people carer

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies: Data collection hardware	Key enabling technologies: Sensors	Key enabling technologies: Communication Hardware	Key enabling technologies: Data analysis	Physiological signs	Diseases
31	Visi Mobile	A wearable device worn around the wrist which allows clinicians to be in touch with their patients and check on their vital signs at any given moment.	TRL 9 - Commercialization	This device has 3 sensors and it's able to transmit data in a wireless manner, so vital signs can be analysed on a remote computer or portable tablet. By monitoring health-related indicators, Visi Mobile can be used to alert doctors and nurses if patients require urgent care.	Oximeter, blood pressure meter, ECG Sensor			Monitoring ECG, heart rate, pulse rate, blood pressure, and respiration rate and body temperature.	Cardio activity, cardiovascular diseases, respiratory diseases.
32	Aquapulse heart rate monitor	Heart rate monitor designed by Finis for swimmers to keep track of their heart rate while swimming.	TRL 9 - Commercialization	This wearable device can be attached to the inside of the goggles strap near the earlobe.	Infrared sensors, bone conduction technology and heart rate monitor			Heart rate	Cardio activity

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
33	Phyode W/Me	Heart rate monitor that uses heart rate variability to determine respiration, emotion, and autonomic nervous system state.	TRL 6 - About to commence preclinical evaluations	It is worn on the wrist. The wearable device pairs with a mobile application that can be used to assist with tracking data and also provides breathing exercises.	Heart rate monitor, respiratory monitor and ECG sensor			heart rate	Autonomic nervous system
34	Seraphim sense angel wristband	An activity monitor with vital sign capabilities.	TRL 6 - About to commence preclinical evaluations	It is worn on the wrist. It is designed to have a minimalist appearance and has no display. However, all the information on the wearable device is easily accessible and open to further development.	Oximeter, accelerometer, gyroscope and heart rate monitor.			Pulse, blood oxygenation, acceleration, steps skin temperature, sleep quality, activity.	Healthy lifestyle

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
35	Interaxon muse	Mental activity tracking device that helps reduce stress and settle the mind.	TRL 9 - Commercialization	Worn on the head and uses 7 sensors that are applied to the occipital lobes.	EEG sensor and Accelerometer	Bluetooth		Brain activity	Mental health
36	IMEC EEG headset	Wearable health monitor with electroencephalographic (EEG) capabilities.	TRL 5 - Developed prototype	It is designed to be worn during daily activities and allows for comfortable, continuous, and reliable health monitoring. It is sensitive, intelligent, compact, and low-power and is able to deliver real-time data to Bluetooth enabled devices.	EEG sensor, ECG sensor and respiratory monitor			Heart rate, activity, breath rate, heart electric activity.	Health monitoring for all diseases

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
37	Leaf health-care ulcer sensor	This device is designed to alert a person when it is time to turn and do some moving in order to combat no moving around.	TRL 5 - Developed prototype and undergoing clinical research	Single use, disposable device that is adhered to a patient's chest. Real-time patient status	Tri-axial accelerometer			Movement, orientation, position and activity measurement	Pressure sores
38	iSono Health	This device is used to monitor breast health.	TRL 5 - Developed prototype	3D ultrasound technology coupled with our powerful machine learning algorithm allows you to track any changes over time without any radiation at the convenience of your home. The ultrasound scanner gets attached to a wearable accessory; 2 to 3 minutes a month is all that it takes for you to automatically scan your breasts.	Ultrasound scanner			Detect any changes in the breast	Breast cancer, breast lumps

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
39	Abbott Diabetes Care	Glucose monitoring system for people who suffer from diabetes.	TRL 9 - Commercialization	This is a sensor placed on the back of the upper arm for 14 days. It is a companion app and smart phone accessible product where then a doctor can read over the information when the patient goes to the doctor.	Blood sugar monitor			Blood sugar levels	Diabetes
40	HealthPatch MD	New technology for healthcare professionals to be able to keep tabs on the vital information of their patients.	TRL 9 - Commercialization	The HealthPatch® MD biosensor has two components: the reusable sensor module and the disposable patch.	ECG sensors, 3 axis accelerometer, thermistor	HealthPatch pairs over Bluetooth Low-Energy with a mobile device for WiFi connectivity		Heart rate, breathing, temperature, steps and even detects body position.	Health monitoring for all diseases

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
41	Adamm	The device and the app will be able to alert you when you experiencing an asthma situation, journalling, treatment plans, displays, and the tracking and information on the treating of symptoms.	TRL 7: Technology Transfer	A patch-type, flexible wearable with a rechargeable battery that can be worn anywhere on the upper torso, front or back. Move it around from day to day as you choose.	Cough counter, Respiration pattern, heartbeat sensor and thermometer			Cough counting, respiration, wheeze and heart rate	Asthma
42	Nuubo nECG Minder	This wearable device is an activity monitor.	TRL 7: Technology Transfer	This device is designed to record ECG signals (when paired with Nuubo's nECG Shirt) as well as body position and physical activity.	Accelerometer and ECG			Activity and cardiac activity	Healthy lifestyle

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
43	Preventice body-guardian	The Body-Guardian is a wearable body sensor that is capable of recording biometric data for clinical use.	TRL 9 - Commercialization	The technological device is designed to adhere to the body without impairing user mobility. All data is delivered securely to the cloud-based Preventice Care Platform which can be viewed by the user's doctors.	ECG sensor and respiratory monitor			Heart rate, breathing rate,	Cardiac activity

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
44	T.ware T.Jacket	The T. Ware T. Jacket is an intelligent jacket that reproduces dynamic pressure to simulate hugs. This wearable device is generally used in childcare, to soothe and comfort autistic children even when direct contact is not possible.	TRL 9 - Commercialization	The system is remotely controlled via a smart phone's application, which can also be used by parents or caregivers to track children's level of activity and response to the T. Jacket.	accelerometer			activity	autism

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
45	Withings Blood pressure monitor	The Withings Blood Pressure Monitor is a wearable technology worn on the arm that measures blood pressure and heart rate.	TRL 7 - Technology transfer collaborated with Nokia	Connected to an iOS device it tracks, saves and displays data that can then be used as a personal or medical health recorder.	heart rate monitor and blood pressure meter			heart rate and blood pressure	hypertension
46	Hexoskin	Comfortable way to monitor precise cardiac, respiratory, sleep and activity data	TRL 9 - Commercialization	Hexoskin shirt and device used for the data collection.	ECG, accelerometer	Hexoskin app available for Android and iOS. The data syncs HxServices for online dashboard. Bluetooth pairing between the device and the phone	Raw data is synced to the online. There is a ViviSense data analysis software	Heart rate zones, breathing rate, minute ventilation, heart rate maximum, resting heart rate, heart rate recovery, cadence. Sleep activity, step count, calories	Heart conditions, healthy lifestyle

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
47	Sony smartband, Jawbobe UP series, Mio Active, Amiigo	It is tracking device worn on the wrist.	TRL 9 - Commercialisation	Data is collected on to the smart phone app	Heart rate, GPS, accelerometer	Bluetooth, Host app (Android or iOS compatible) LED indicators, NFC, USB	Data analysis on the smart phone app	Measure pulse and stress level, heart rate, activity and step count	Heart conditions and healthy lifestyles

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
48	Somaxis	It is a,wearable sensor that is used for Muscles, Heart, Brain, Posture, and,Movement. It is,used for research, ergonomics, physical therapy, occupational therapy, Biofeedback,sports science, and physical rehabilitation.	TRL 6 - Not yet certified	Data is collected on the halospere app that is recorded the sensor	Cricket EMG, ECG, EEG and accelerometer	Data from the sensor is synced via Bluetooth to the Chirp app that wirelessly to Halosphere cloud server.	Data is analysed externally to Halosphere software on the computer.	Muscle tension, heart and brain activity and posture	Occupational therapy and physical rehabilitation

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
49	Zio iRhythm	Captures beat-to-beat cardiac rhythm for up to 14 days, continuously recording and storing both symptomatic and asymptomatic events 24 hours a day.	TRL 9 - Commercialization	Continuous data collection from the Zio monitor	ECG	Wireless connection between the patch and the software	Complex algorithms that can detect when there is arrhythmia	Heart rhythms	Arrhythmias
50	Emotiv	It's a device used to measure brain activity	TRL 9 - Commercialization	EEG measure the brain activity and data is recorded	EEG	Wireless connection Windows, OSX, Linux, Android and iOS compatible. Bluetooth	Application for Emotiv mobile	Performance metrics, mental commands, facial expressions	Brain fitness and performance

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
51	Neurosky		TRL 9 - Commercialisation	Neurosky chip and collect electrical signals	EEG and ECG	Phone Apps, web apps and cloud server. iOS, Android, PC and Mac compatible	Biometric algorithms that translate data from ECG to heart-health index	Heart rate, heart age, breathing index, blood pressure, emotion intensity. The brain activity is translated signal to brain activity	Heart diseases, brain activity and mental effort
52	EQ02 LifeMonitor	This is a multi-parameter ambulatory monitoring device.	TRL 9 - Commercialisation	LifeMonitor senses and records data from the user.	Accelerometer, ECG, infared sensor, heart rate monitor, pedometer, respirometer, thermometer, GPS	Wirelessly connect the device to the Sensor Electronics Module (SEM) and the sensor belt. Bluetooth and proprietary.	eqView software	Heart rate, respiratory rate, skin temperature, accelerometer, body position, motion status, fall alert.	Health vital signs

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
53	3L Labs foot-logger	A wearable fitness tracking device that aims at spotting health problems early, as well as logging daily activity.	TRL 6 - Preclinical evaluation	LASIS server for data collection	Pressure sensor	Wireless connection via Bluetooth, Wi-Fi, SMS transfer	LASIS server for analysis	Motion status, fall detection.	Detection of dementia, spinal disease, accidents from falling, rehabilitation (stroke, paralysis), recovery, gait correction

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
54	BalanSens	The first wearable device that measures the centre of mass of a patient, providing an accurate balance assessment for clinicians.	TRL 9 - Commercialisation	BalanSens app that collects and records the data	Accelerometer, gyroscope	Wireless connect via Bluetooth. Compatible with Android, iOS and Windows	App has instant charting and analysis	Sway index, sway velocity, centre of mass motion and sway area of the patient	Balance assessment
55	SoundBite	A unique wearable hearing aid designed to be worn on the inside of the mouth.	TRL 7: Technology Transfer	Audio signal send to the bone conduction speaker.	No sensor	Wireless connection via Wi-Fi	The BTE (behind the ear) unit uses digital signal processing technology to process the sound and transmit the sound to the ITU (In the mouth) piece.	vibrations	Hearing problems

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
56	BTS Surface EMG	A wearable synchro-myography device used for monitoring muscular activity.	TRL 9 - Commercialization	Wireless gel electrodes that amplify the signal received by the electromyogram.	EMG Sensor	Wireless connection via Wi-Fi. Compatibility with Windows.	Data is send to the computer and analysed in real-time. There are 3 models FREEEMG, FREE-WALK and TMJOINT	Muscular activity	Orthopaedic and neurological dysfunctions, muscular activity and correction occlusion interferences.
57	Metria IH1	A disposable wearable device that detects the user's skin temperature and activity.	TRL 6 - Preclinical evaluation	The device is worn on the upper left arm and sticks to the skin of the user and data is collected.	Accelerometer, galvanometer, thermometer	USB connection used to transfer data from the device to a computer. Compatibility: Windows and OSX	Data is viewed and analysed on a computer or smart device.	Activity and skin temperature	Health

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Table B.7 – *Continued from previous page*

Number	Device	Function	Technology maturity	Key enabling technologies				Physiological signs	Diseases
				Data collection hardware	Sensors	Communication Hardware	Data analysis		
58	Vincense	It facilitates real-time patient care through continual remote monitoring of vital signs in an unobtrusive and non-invasive manner.	TRL 9 - Commercialization	Data collected by the device continuously.	Oximeter, infrared sensor, thermometer and heart rate monitor.	Wireless connection Wi-Fi, data connection, Bluetooth and Android compatibility	Android aoo and web interface VinCense.	Heart rate, temperature, blood pressure.	Heart conditions

APPENDIX C

DETAILED INTERVIEW TRANSCRIPTS

The appendix provides the detailed transcripts of the interviews conducted in Chapter 4.

C.1 Detailed interview transcripts

Table C.1 is summarised from the information provided in this section.

C.1.1 Lower respiratory infections

The lower respiratory infections such as influenza, pneumonia, asthma and other chronic conditions.

Choose the physiological signs and their respective stage of care:

- Preventative care – one of the interviewees indicated the importance of the monitoring of the heart rate variability for preventative care.
- Diagnosis and screening – Two of the three interviewees agreed that temperature, breathing rate and oxygen saturation can be useful. Two interviewees added that the heart rate is important and one of them suggested for sepsis. The other one also added monitoring breathing sounds for diagnosis especially for conditions such as asthma. One of the interviewees suggested blood sugar levels (for diabetic patients), heart electric activity [1], sleep quality, brain activity and urine composition. The interviewee highlighted how oxygen saturation, sleep quality and brain activity can be utilised in the Intensive Care Unit for monitoring patients.
- Treatment of diseases – All the three interviewees acknowledged the importance of temperature, breathing rate and oxygen saturation. Then two of the interviewee included the heart rate. One of the interviewees added breathing sounds. One of the interviewees suggested blood sugar levels (for diabetic patients), heart electric activity, sleep quality, brain activity and urine composition. The interviewee highlighted how oxygen saturation, sleep quality and brain activity can be utilised in the Intensive Care Unit for monitoring patients.
- Rehabilitation – One of the interviewee suggested that chronic lower respiratory conditions can be monitored by temperature, breathing rate and oxygen saturation.

[1] Also known as electrocardiogram (ECG)

None of the interviewees saw the relevance of monitoring physiological signs for wellness care.

Choose the intended user who will benefit from the data collected:
All the interviewees agreed that the patients and all the healthcare providers will benefit from this information. One of the interviewees stressed that if it is for childcare it is for level 1 and level 2 care.

The general comments from the interviewees:

- Some of the interviewees suggested that asthma is a chronic condition that can benefit from long-term monitoring of oxygen saturation for treatment, diagnosis and screening as well as rehabilitation purposes.
- One of the interviewees suggested that infected neonatal babies in intensive care unit would benefit tremendously from non-invasive monitoring of vital signs.

C.1.2 HIV/AIDS

Two of the interviewees agreed that for this condition that it is necessary to identify the stage [1] that the physiological signs can be monitored. They suggested that opportunist infections can be monitored using physiological signs. One of the interviewees also implied that side effects from the drugs can be monitored using physiological signs. Then two of the other interviewees suggested that CD4 count can be used as point-of-care diagnostic method, but did not see the relevance of wearable technology for this application. One of the interviewees expressed concerns over the capabilities of wearable technology because HIV has the the ability to suppress immune response [2]. This makes it difficult to detect the presence of opportunist infections.

Despite having reservations on the application of wearable sensors four of the interviewees provided their input regarding the important physiological signs.

Choose the physiological signs and their respective stage of care:

- Preventative care – Two of the interviewees agreed on the relevance of monitoring heart rate, temperature, breathing rate and oxygen saturation. Only one of the interviewees suggested that there is need to monitor user's activity levels, blood pressure, blood sugar levels, sleep quality, brain activity(for opportunistic conditions such as TB meningitis and other stage three infections) and urine composition.
- Diagnosis and screening – Three of the five interviewees agreed that heart rate, temperature, breathing rate, oxygen saturation and brain activity can be used for monitoring. Two interviewees added that activity, blood pressure, blood sugar levels and urine composition are important. One of the interviewees stated that motion, sleep quality, blood volume pulse and body water levels (in the form of trans-epidermal water loss[3] and bio-impedance [4] for dehydration).

[1]HIV/AIDS has four distinguishable stages namely: acute primary infection, asymptomatic stage (suppressed immune response), symptomatic HIV infection (opportunistic infections) and AIDS (Avert, 2017).

[2]Immune response is how the body recognises and defends itself against bacteria, viruses, and any foreign substances. The body response by showing signs and symptoms to indicate the presence of an infection or illness.

[3] Trans-epidermal water loss defined as the constitutive steady state water vapour loss from the skin surface, theoretically excluding desorption and sweat gland activity (Mohamad *et al.*, 2012)

[4]Bio-impedance can be used to express the hydration of the soft tissue by solely considering impedance components (i.e. resistance and reactants) independently of regression predictions of fluid volumes or assumptions about the constant chemical composition of the fat-free body (Gatterer *et al.*, 2014)

- Treatment of diseases – Four of the interviewees highlighted the use of heart rate, temperature and breathing rate for the treatment of HIV. Then three interviewees agreed that oxygen saturation and brain activity can be used to monitor this condition. Two of the interviewees saw the relevance of monitoring activity, blood pressure, blood sugar levels and urine composition. One of the interviewees suggested that motion, sleep quality, blood volume pulse and body water levels for monitoring.

Choose the intended user who will benefit from the data collected:
All the interviewees agreed that the patients and all the healthcare providers will benefit from this information. One of the interviewees stated that the patients will benefit from the information and the healthcare providers will most likely use the information.

C.1.3 Diarrhoeal diseases

The diarrhoeal diseases that are prominent in SSA are cholera, typhoid and salmonella. These were the ones that were highlighted during the interview by the interviewee.

Choose the physiological signs and their respective stage of care:

- Preventative care – One of the interviewees suggested the relevance of monitoring the heart rate, temperature, oxygen saturation, blood pressure, blood sugar levels, urine composition and body water levels [1]. The wearable device can play a significant role to prevent the spread of diarrhoeal diseases especially in the surge season especially when it is the wet and humid[2].
- Diagnosis and screening – Four of the five interviewees agreed that breathing rate, urine composition and body water levels can be used for diagnostic purposes. Three interviewees added that heart rate, temperature, oxygen saturation, blood pressure and blood sugar levels. One of the interviewees highlighted that motion (severe cases), activity(severe cases), sleep quality (severe cases), body water levels, pressure levels and galvanic skin response [3] are also important for diagnostic purposes.
- Treatment of diseases – The same physiological signs identified for diagnosis and screening were highlighted for treatment of diseases.

Choose the intended user who will benefit from the data collected:
All the interviewees agreed that the patients and all the healthcare providers will benefit from this information. One of the interviewees stated that the patients will benefit from the information and the healthcare providers will most likely use the information.

C.1.4 Malaria

Choose the physiological signs and their respective stage of care:

- Diagnosis and screening – Three of the five interviewees agreed that heart rate, temperature, oxygen saturation, blood pressure and blood sugar levels can be used to diagnose malaria infected people. Two interviewees agreed that the breathing rate and urine composition (for the haemoglobininuria [4] and protein levels) can be utilised. Only one of the interviewees stipulated the importance of motion, activity, heart electrical activity, brain activity, blood volume pulse and haemoglobin(suggested separately but can be measured from the urine composition).

[1]One of the interviewees suggested body water levels can be determined using bio-impedance or fluid trans-epidermal water loss techniques.

[2]The wet seasons are: Below tropic of Capricorn in SSA - wet winters; The equatorial region is wet throughout the year and areas between the tropics experience wet summers.

[3]Galvanic skin response is used to detect emotional arousal

[4]The presence of haemoglobin in the urine and this occurs in the event of severe malaria and haemolytic anaemia.

- Treatment of diseases – All of the interviewees agreed that heart rate and temperature can be important to monitor the treatment of the malaria. Then three interviewees highlighted that oxygen saturation, blood pressure and blood sugar levels. For physiological signs such as motion (severe cases), breathing rate, activity (severe cases especially when experiencing limb joints which affects movements) and urine composition, two interviewees stated them. One of the interviewees suggested the importance of heart electrical activity, brain activity (cerebral malaria), blood volume pulse and haemoglobin.
- Rehabilitation – One of the interviewees suggested that activity and motion can be used for rehabilitation especially if the patient suffered from severe malaria.

C.1.5 Pre-term Birth Complications

Choose the physiological signs and their respective stage of care:

- Preventative and wellness care – One of the interviewees highlighted that heart rate, temperature, motion, activity, blood pressure, blood sugar levels, heart electrical activity and urine composition for preventative and wellness care.
- Diagnosis and screening – The physiological signs that can be utilised for diagnosis as highlighted by four of the five interviewees are heart rate, temperature, oxygen saturation, blood pressure, blood sugar levels and urine composition(presence of protein). Three of the interviewees highlighted the importance of monitoring motion, breathing rate, activity and heart electrical activity. Two interviewees stated that brain activity can be used to monitor premmies. Only one interviewees saw the relevance of the following physiological signs: sleep quality, blood volume pulse, body water levels (for oedema) and pressure levels. One of the interviewees suggested the monitoring of the blood perfusion (which can be measured non-invasively using pulse CO-Oximetry).
- Treatment of diseases – Four of the interviewees identified heart rate, temperature and blood sugar levels to be important. The other physiological signs that were identified by three of the interviewees were motion, breathing rate, activity, oxygen saturation, blood pressure, heart electrical activity and urine composition. Then two interviewees agreed upon brain activity being important. Finally, only one interviewee stated sleep quality, blood volume pulse, body water levels and pressure levels.

C.1.6 Tuberculosis

Choose the physiological signs and their respective stage of care:

- Preventative care – One of the interviewees highlighted that heart rate, temperature, breathing rate and sleep quality(night sweats) can be utilised for preventative care.
- Wellness care – one of the interviewees identified heart rate, temperature, breathing rate, oxygen saturation and blood sugar levels.
- Diagnosis and screening – Four of the interviewees agreed that heart and breathing rate are important for diagnosis. Then three of the interviewees highlighted temperature and oxygen saturation as physiological signs that can be used for monitoring tuberculosis. One of the interviewees stated that motion, activity, blood pressure, blood sugar levels, sleep quality, brain activity(TB Meningitis for seizures, drowsiness and delirium), urine composition, body water levels and cough count.
- Treatment of diseases – The physiological signs identified for diagnosis and screening were identified for treatment.
- Rehabilitation – One of the interviewees identified heart rate, temperature, breathing rate, oxygen saturation and blood sugar levels for monitoring patients that are in rehabilitation.

C.1.7 Neonatal sepsis and infections

Choose the physiological signs and their respective stage of care:

- Preventative care – One of the interviewees highlighted that heart rate variability is important to prevent sepsis.
- Wellness care – One of the interviewees identified heart rate, temperature and breathing rate.
- Diagnosis and screening – All of the interviewees agreed that heart rate, temperature and breathing rate are important for diagnosis especially for premmies. Then four of the interviewees highlighted motion and blood sugar levels as physiological signs that can be used for monitoring neonatal sepsis. Three of the interviewees stated that activity, oxygen saturation, blood pressure and heart electrical activity are important for monitoring. Then two of the interviewees highlighted that brain activity and urine composition can be monitored for diagnosis. One interviewee stated that sleep quality, blood volume pulse and body water levels can be used for diagnosis.
- Treatment of diseases – Four respondents had similar physiological signs for treatment of neonatal sepsis. These are heart rate, temperature and breathing rate. Three interviewees agreed that motion, oxygen saturation, blood pressure, blood sugar levels and heart electrical activities(for infective endocarditis or rheumatoid arthritis) play a role in treating neonatal sepsis. The physiological signs that were identified by two interviewees for treating sepsis were activity and urine composition. Only one interviewee identified sleep quality, brain activity, blood volume pulse.

C.1.8 Stroke

Two of the interviewees highlighted that there are two different types of strokes namely ischaemic stroke and haemorrhagic stroke. Ischaemic stroke is characterised by the sudden loss of blood circulation to an area of the brain, resulting in a corresponding loss of neurological function. Then for haemorrhagic stroke, bleeding occurs directly into the brain parenchyma. However, it is difficult to distinguish the two unless a computerised axial tomography (CAT) scan is performed.

Choose the physiological signs and their respective stage of care:

- Preventative care – All the interviewees highlighted the importance of blood pressure as an important physiological sign to be monitored to prevent a stroke especially for hypertensive patients. Four of the interviewees also agreed that brain activity will be essential as well to monitor. Three interviewees agreed that motion, breathing rate, activity and heart electrical activity (for atrial fibrillation resulting in multiple strokes). Two interviewees identified the following physiological signs are heart rate, blood sugar levels (for diabetic patients hypoglycaemia can mimic stroke) and blood sugar levels. One of the interviewees highlighted temperature, sleep activity (patients who suffer from sleep apnoea), urine composition, picture monitoring (cholesterol under the eye) and body water levels.
- Wellness care – Three of the interviewees stated that blood pressure can be used for wellness. Two of the interviewees agreed that breathing rate, blood sugar levels, heart electrical activity and brain activity can be used for wellness and motivate a healthy lifestyle. Only one interviewee suggested the following physiological signs heart rate, temperature, motion, activity, urine composition, blood volume pulse and body water levels.
- Diagnosis and screening – Five respondents agreed that blood pressure is important. Four of the interviewees agreed on motion and brain activity should be monitored for diagnostic purposes. Three interviewees highlighted that heart rate, breathing rate, activity, blood sugar levels, heart electrical activity and blood volume pulse. Then one interviewee identified temperature, sleep quality, urine composition, picture monitoring and body water levels.
- Treatment of diseases – Two respondents identified heart rate, motion, breathing rate, activity, blood pressure, blood sugar levels, heart electrical activity and brain activity. Then only one

interviewee identified temperature, sleep activity, urine composition, blood volume pulse and body water levels.

- Rehabilitation – Three of the interviewees suggested that monitoring motion, activity, blood pressure and brain activity would be essential for monitoring a patient after a stroke. Two interviewees agreed that breathing rate, blood sugar levels, heart electrical activity and blood volume pulse. Only one interviewee identified heart rate, sleep activity, urine composition, body water levels and pressure levels (gait analysis).

C.1.9 Ischaemic heart disease

Choose the physiological signs and their respective stage of care:

- Preventative care – All the interviewees highlighted the importance of monitoring the heart rate for at risk users. Four of the interviewees agreed that blood pressure will be essential as well to monitor. Three interviewees agreed that motion, breathing rate, activity, oxygen saturation, blood sugar levels(in certain cases where the patient is diabetic) and heart electrical activity. Two interviewees identified the following physiological signs are temperature, sleeping activity, urine composition (for diabetic patients) and blood volume pulse. One of the interviewees mentioned body water levels [1].
- Wellness care – Four of the interviewees said that monitoring the heart rate can be used for wellness purposes. Three of the interviewees agreed that blood pressure monitoring can be used for wellness care and motivate a healthy lifestyle. Two interviewees suggested the following physiological signs motion, activity,breathing rate, oxygen saturation, blood sugar levels and heart electrical activity. Then one interviewee identified temperature, sleep activity, urine composition and blood volume pulse for wellness purposes.
- Diagnosis and screening – Five respondents agreed that heart rate and blood pressure is important. Four of the interviewees agreed on heart electrical activity should be monitored for diagnostic purposes. Three interviewees indicated motion, oxygen saturation and blood sugar levels can be used for diagnosis. Then two interviewee identified temperature, breathing rate, activity, sleep activity, urine composition and blood volume pulse. One of the interviewee suggested monitoring body water levels.
- Treatment of diseases – Four respondents identified heart rate, blood pressure and heart electrical activity. Three interviewees suggested using oxygen saturation and blood sugar levels for monitoring ischaemic heart disease. Two interviewees identified temperature, motion, breathing rate, activity, sleep activity, urine composition and blood volume pulse. One of the interviewees suggested monitoring body water levels.
- Rehabilitation – Four of the interviewees suggested that monitoring heart rate and blood pressure when recovering from heart attack. Three interviewees agreed that motion, breathing rate, activity, oxygen saturation, blood sugar levels and heart electrical activity can be monitored during rehabilitation. Then two interviewees indicated temperature, sleep activity, urine composition and blood volume pulse. Only one interviewee identified body water levels for monitoring a patient in recovery.

[1] Water intake can reduce the risk of getting heart diseases (Jang *et al.*, 2016)

Table C.1: Illustration of the feedback from the interviewees

Disease	Stage of care	Heart rate	Temperature	Motion	Breathing rate	Activity	Oxygen saturation	Blood pressure	Blood sugar levels	Heart electrical activity	Sleep activity	Brain activity	Urine composition	Blood volume pulse	Body water levels	Pressure levels	Galvanic skin response	Breathing sound	Haemoglobin	Picture monitoring	Cough count
Lower Respiratory infections	Preventive care	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wellness care	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Diagnosis and screening	3	4	0	4	0	4	2	2	1	1	1	2	1	1	0	0	1	0	0	0
	Treatment of diseases	4	5	0	5	0	5	2	2	0	1	1	2	1	0	0	0	1	0	0	0
	Rehabilitation	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HIV/AIDS	Preventive care	2	2	0	2	1	2	1	1	0	1	1	1	0	0	0	0	0	0	0	0
	Wellness care	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Diagnosis and screening	3	3	1	3	2	3	2	2	0	1	3	2	1	1	0	0	0	0	0	0
	Treatment of diseases	4	4	1	4	2	3	2	2	0	1	3	2	1	1	0	0	0	0	0	0
	Rehabilitation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diarrhoeal diseases	Preventive care	1	1	0	0	0	1	1	1	0	0	0	1	0	1	0	0	0	0	0	0
	Wellness care	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Diagnosis and screening	3	3	1	4	1	3	3	3	0	1	0	4	1	4	1	1	0	0	0	0
	Treatment of diseases	3	3	1	4	1	3	3	3	0	1	0	4	1	4	1	1	0	0	0	0
	Rehabilitation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Malaria	Preventive care	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wellness care	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Diagnosis and screening	3	3	1	2	1	3	3	3	1	0	1	2	1	1	0	0	0	1	0	0
	Treatment of diseases	5	5	2	2	2	3	3	3	1	0	1	2	1	1	0	0	0	1	0	0
	Rehabilitation	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Preterm Birth Complications	Preventive care	1	1	1	0	1	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0
	Wellness care	1	1	1	0	1	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0
	Diagnosis and screening	4	4	3	3	3	4	4	4	3	1	2	4	1	1	1	0	0	0	0	0
	Treatment of diseases	4	4	3	3	3	3	3	4	3	1	2	3	1	1	1	0	0	0	0	0

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Table C.1 – *Continued from previous page*

Disease	Stage of care	Heart rate	Temperature	Motion	Breathing rate	Activity	Oxygen saturation	Blood pressure	Blood sugar levels	Heart electrical activity	Sleep activity	Brain activity	Urine composition	Blood volume pulse	Body water levels	Pressure levels	Galvanic skin response	Breathing sound	Haemoglobin	Picture monitoring	Cough count
	Rehabilitation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tuberculosis	**Preventive care**	1	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
	Wellness care	1	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
	Diagnosis and screening	4	3	1	4	1	3	1	1	0	1	1	1	0	1	0	0	0	0	0	1
	Treatment of diseases	4	3	1	4	1	3	1	1	0	1	1	1	0	1	0	0	0	0	0	1
	Rehabilitation	1	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Neonatal Sepsis and infections	**Preventive care**	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wellness care	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Diagnosis and screening	5	5	4	5	3	3	3	4	3	1	2	2	1	1	0	0	0	0	0	0
	Treatment of diseases	4	4	3	4	2	3	3	3	3	1	1	2	1	1	0	0	0	0	0	0
	Rehabilitation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stroke	**Preventive care**	2	1	3	3	3	0	5	2	3	1	4	1	2	1	0	0	0	0	1	0
	Wellness care	1	1	1	2	1	0	3	2	2	0	2	1	1	1	0	0	0	0	0	0
	Diagnosis and screening	3	1	4	3	3	0	5	3	3	1	4	1	3	1	1	0	0	0	1	0
	Treatment of diseases	2	1	2	2	2	0	2	2	2	1	2	1	1	1	1	0	0	0	1	0
	Rehabilitation	1	0	3	2	3	0	3	2	2	1	3	1	2	1	1	0	0	0	1	0
Ischaemic heart diseases	**Preventive care**	5	2	3	3	3	3	4	3	3	2	0	2	2	1	0	0	0	0	0	0
	Wellness care	4	1	2	2	2	2	3	2	2	1	0	1	1	0	0	0	0	0	0	0
	Diagnosis and screening	5	2	3	2	2	3	5	3	4	2	0	2	2	1	0	0	0	0	0	0
	Treatment of diseases	4	2	2	2	2	3	4	3	4	2	0	2	2	1	0	0	0	0	0	0
	Rehabilitation	4	2	3	3	3	3	4	3	3	2	0	2	2	1	0	0	0	0	0	0

APPENDIX D

CRITERIA SELECTION

The appendix contain mainly data on the number of criteria that were identified from previous studies. The studies reviewed are illustrated in Table 5.1.

D.1 The criteria identified from previous studies

The data collected from the literature review is provided in Table D.1. The table provides the total number of criteria identified.

Table D.1: The criteria that have been identified in previous studies for priority setting.

Number	**Criteria**	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	**Total**
1	Cost-effectiveness	1		1	1		1	1		1	**6**
2	Expected outcome of treatment	1	1	1						1	**4**
3	Costs of treatment	1	1	1			1		1		**5**
4	Safety		1		1		1				**3**
5	Alternatives		1	1	1		1		1		**5**
6	Potential clinical benefit over existing treatment								1		**1**
7	Improvement of patient-reported outcomes		1		1		1			1	**4**
8	Size of population affected by disease (Target group)				1	1	1	1		1	**5**
9	Potential to detect a condition which, if treated early, averts costs in the future						1				**1**
10	Public health interest				1		1				**2**
11	Integration into health system		1				1				**2**
12	Type of medical service				1		1				**2**
13	Rare diseases		1								**1**
14	Long term impact						1				**1**
15	Clinical guidelines				1						**1**
16	Sustainable		1				1				**2**
17	Burden of disease		1	1			1	1	1		**5**
18	Effectiveness of treatment	1	1		1	1	1				**5**
19	Severity of the condition	1	1		1	1		1		1	**6**
20	Quality of evidence on effectiveness	1	1						1		**3**
21	Urgency of need of care	1	1			1	1				**4**
22	Age	1	1			1		1		1	**5**
23	Gender	1	1								**2**
24	Race	1	1								**2**
25	Technology requirements						1				**1**
26	Religion	1									**1**
27	Social status	1	1					1			**3**
28	Health expenditure		1								**1**
29	Budget impact		1	1	1	1		1	1		**6**
30	Responsibilities	1									**1**
31	Mental (or) capabilities	1	1								**2**

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Table D.1 – *Continued from previous page*

Number	**Criteria**	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	**Total**
32	Physical Capabilities	1	1								**2**
33	Area of residence	1	1								**2**
34	Time on waiting lists	1									**1**
35	Political views	1	1								**2**
36	Community's views	1									**1**
37	Timeless of the technology or Novelty			1			1		1		**3**
38	Expected level of interest			1							**1**
39	Cultural views		1								**1**
40	Number of people benefiting	1	1		1	1					**4**
41	Ethical and legal issues		1	1					1		**3**
42	Genetic background and sexual orientation	1									**1**
43	Patient's lifestyle responsible for cause of disease	1									**1**
	TOTAL	**22**	**26**	**9**	**12**	**7**	**17**	**7**	**8**	**6**	

APPENDIX E

MORE RESULTS FOR PRIORITISATION

This appendix provides the detailed description of the wearable sensors efficacy. The efficacy assessment is based on the accuracy, specificity and sensitivity of the wearable sensors as shown in Table E.1.

Table E.1: Brief description of the wearable sensors for each of the set of criteria

Wearable sensor	**Accuracy**	**Sensitivity**	**Specificity**
Accelerometer	The accuracy of accelerometers is 97 percent and can be applied for medical applications (Yang *et al.*, 2015). In previous studies the accuracy of accelerometers was improved through coupling them with pressure sensors or gyroscopes for a full range of motion.	The sensitivity ranges from 83 to 98.75 percent because there are certain motions that can not be accurately detected by the sensors such as falling.	The specificity is 92 percent which is good and can be utilised with a low chance of recording false positives.
Gyroscope	A gyroscope has an accuracy that ranges between 76 to 79 percent.Coupling with an accelerometer gyroscope increases the accuracy to as high as 95 percent.	The sensitivity of a gyroscope is 91 percent however studies shows that when an accelerometer is coupled with it the sensitivity will reduce to below 80 percent making it difficult to detect falls.	The specificity is 92 percent which can be improved by coupling with an accelerometers to approximately 99,38 percent.
Pedometer	The accuracy of the pedometers is affected by the positioning of the sensors. The pedometers worn around the waist provide more accurate results as the wrist ones can fail to detect small steps (Husted and Llewellyn, 2017). The accuracy is between 56 and 80 percent.	No studies have been conducted yet to determine the sensitivity	No studies have been performed on the specificity
Magnetic sensors	The accuracy is 48 - 71% relative to the positioning of the wearable sensor. The readings are more accurate around the leg (Kunze *et al.*, 2010).		
ECG electrodes	The accuracy ranges from 97% to 98 %. Accuracy is dependent on the type of electrodes whether metal or adhesive the latter being more accurate (Guo *et al.*, 2016).	The sensitivity ranges from 87.5% to 99.34% detects significant diseases using algorithms.	The specificity ranges from 91.67% to 99.37%.
Photoplesthmography	The accuracy of the PPG is 89 %. Challenges with PPG include cancelling the effects of ambient light and accommodating differences in skin colour and condition. Tattoos reduce the accuracy of PPGs and people of colour usually record less accurate results.	The sensitivity is approximated at 91%.	The specificity is approximated at 88%.

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Table E.1 – *Continued from previous page*

Wearable sensor	**Accuracy**	**Sensitivity**	**Specificity**
Blood pressure meter	The accuracy of blood pressure meters is low at 44 % and unreliable results will be produced.	The sensitivity is 80 %.	The specificity is 68%. This highlights that the sensor is not highly specific to the blood pressure and can read false positives.
Respiratory meter, force sensors, nasal pressure transducer	The accuracy of the pressure sensors range from 62 % to 88 % when measuring respiratory activities.	These sensors have a high sensitivity of 92 % therefore the signal output has less error.	The specificity is low at 72 % therefore it will be difficult to detect respiratory conditions and unusual breathing patterns.
Thermistor- negative temperature coefficient (NTC) sensor	These are deemed the most accurate temperature sensors that are commercially available with an accuracy of $\pm 0.2\,^{\circ}C$		
Infrared thermopile	The accuracy of the thermopile is low at $\pm 9.5\,^{\circ}C$ but has a long temperature range.		
Pulse Oximeter	The level of accuracy is high at 99.47 % measuring oxygen saturation efficiently.	The sensitivity is at a 100 %	The specificity is at 100 % showing that it can measure hypoxia effectively.
EEG electrodes	The accuracy of EEGs to measure brain activity is approximately 63 %.	The sensitivity of the EEGs is the 62 to 70 %. Although it was slightly more sensitive for focal seizures compared to generalized patterns, our reduced array has an unacceptably poor sensitivity for seizure detection.	The specificity of EEGs is 86 to 90 % which is high and can easily detect seizure and abnormal brain activities.
Biosensors or chemical sensor	The accuracy of the bio-sensors is 89 %.		