MASTER THESIS
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A universally designed and usable method for data visualization

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Preface:

This thesis is submitted in partial fulfillment of the requirements for Norwegian Masters Degree in Universal Design of ICT (Information Communication and Technology) at Oslo and Akershus University College of Applied Sciences. It is based upon the current research and development conducted by Norwegian Computing Center. A mobile application called RevmaRApp is currently in the process of development for people with rheumatoid arthritis. Although RevmaRApp has different features, this thesis is only focused on the data visualization feature.

The goal of this thesis is to design and develop a new universally designed prototype for the data visualization which is to be used in RevmaRApp application. Therefore, special focus is delivered to create an accessible data visualization which can be used by the target user group as well as a larger audience. An intriguing part about this thesis topic was the flexibility to apply creative ideas to create a data visualization prototype which adhered to the Universal Design standards. Since I have had experience of working in the medical technology and electronic medical records systems for almost four years before I got admission into this study program at HIOA, I was eager to further my experience of design and development of applications which is specifically combined medical and technological aspects. Therefore, this particular thesis project seemed a good opportunity to utilize my past experiences from my work and my present experience from my study course. The combinations of these experiences would ultimately provide me with a good set of skills to understand the challenges and advantages of using Universal Design principles in developing mobile applications in general as well as those specific for medical purposes as well.

Another important aspect is that the thesis was focused on creating a new data visualization prototype. The challenge of creating a data visualization prototype which also adhered to Universal Design standards was a compelling factor for me to select this thesis. The thesis was started with a literature review of relevant articles in the second semester of the course. This process provided valuable information regarding current status of data visualization and Universal Design especially in mobile applications. It helped to point out the gaps in previous researches and understand the need of this thesis. Hopefully, some of the findings from this thesis can be useful to understand these issues and fulfill these gaps. The design and development aspect was a daunting task since I had never actually materialized the knowledge I had gained in my study course. This thesis gave me an opportunity to combine theoretical and practical knowledge together to create a tangible product (prototype).

Another important factor which also attracted me towards this thesis was the evaluation phase of the thesis. This thesis topic was a bit different from other thesis topics since it consisted of two parts: 1) Design and Development and 2) Evaluation. This evaluation phase of the thesis was an integral part to understand and assess the use of Universal Design standards in any development project. Writing this particular thesis was a daunting task for me, however, in the process of this thesis; I have learned and understood the practical necessities of Universal Design. Through this process, I have also been able to gain empathy towards users with different impairments. I have certainly understood the need of a study course like Universal Design of ICT which can help to generate efficient and qualified manpower in the field of design, development and assessment for different types of design and development activities. This thesis has made me realize the large amount of people with impairments who are excluded from ICT and mobile devices. Therefore, I will utilize the knowledge that I have gained from this thesis and the entire masters' course to create accessible applications in future.

I would like to thank some of the individuals who have been the pillars of success for this thesis. First of all, I would like to thank my supervisor, Dr. Pietro Murano PhD, who has been extremely supportive and a beacon of light throughout this thesis providing me with guidance whenever I required it. I would also like to thank Dr. Kristin Skeide Fuglerud PhD. From Norwegian Computing Center who has been supportive and provided initial input into this thesis. Trenton Schulz from Norwegian Computing Center was also extremely helpful and supportive throughout this thesis and especially during the design and development phase.

His valuable suggestions as well as past experiences while working on RevmaRApp project helped to develop a good overview and understanding for this thesis. Another important aspect he helped was to during the evaluation phase by sharing his test flight version of RevmaRApp prototype which was very important during the conduction of experiments at the late stage of this thesis. I am extremely indebted to these individuals who have been directly involved in this thesis.

I would like to extend my deep appreciation to Asst. Professor Siri Kessel at HIOA, who has been directly and indirectly involved in different aspects and different phases of this thesis. Her valuable inputs in the first and second phase of this thesis provided a path to achieve the goal of this thesis. Her critical reviews have guided this thesis to become more supportive of universal design standards.

I would also like to thank my friends Mr. Sijan Gurung and my sister Mrs. Pratibha Shrestha for being extremely supportive throughout this process and helping me to proof read my thesis and providing moral support. I would like to take this opportunity to thank my girlfriend, Dr. Soni Shrestha who also provided valuable medical inputs for this thesis since this was a thesis which dealt with rheumatoid arthritis patients. She has been very supportive throughout this thesis and also helped to proof read it.

I would like to thank anyone who might have been directly or indirectly involved in this thesis. Finally, I hope that this thesis can provide some valuable input in the field of Universal Design, data visualization and evaluation processes of mobile applications.

Oslo, 15 May 2015 ....

Department of Computer Science Suraj Shrestha (237415)

A universally designed and usable method for data visualization.

Summary:

The goal of this thesis in general was to create a data visualization prototype for a mobile application called RevmaRApp which is targeted towards the use by people with rheumatoid arthritis conditions. The issues of accessibility of mobile applications and especially mHealth [sic](Jovanov, 2006) are raised in this thesis to represent a large section of the population who have impairments. The thesis targets the use of universal design techniques and standards to create accessible mobile applications. The literature review has suggested that there is very small amount of research in the field of accessible design and development of mobile applications. Therefore, this thesis focused on the efficiency of customization options such as change of user interface elements in terms of color, size etc. to make a mobile application more accessible. Another important aspect is the applicability and availability of data sorting mechanism in the mobile application and its effects on accessibility and universal design as well as usability.

This thesis consisted of a prototype development phase and evaluation phase. These two phases were iterative in nature since the main development methodology was two-step methodology (unified methodology) (Billi et al., 2010) which was combined with iterative cycles such as Scrum. The evaluation strategy was also included in the initial phase of the thesis. Heuristic evaluation methods (Vetere, Howard, Pedell, & Balbo, 2003) were utilized to provide expert opinions combined with user testing information provided by the Norwegian Computing Center. An experiment was also conducted at the later stage of the thesis to understand the benefits and drawbacks of both prototypes and utilize this knowledge for future improvements.

The first deliverable of this thesis was a universally designed prototype for data visualization. The second deliverable of this thesis was the results from the evaluations and experiment. The results showed that the new prototype was more accessible and easy to understand as well as use than old prototype. The data visualization technique used in the new prototype was easier to extract

required data and review them as well. An experiment was conducted using Cambridge simulation gloves to simulate the affects of arthritis on hands and wrists using eighteen participants. The results from the experiment showed that for a majority of tasks for the new prototype was discovered to be significantly better than the old prototype. A semi-structured interview conducted after the experiment also reinforced the finding of the experiment through explanations and descriptions from the participants which shed some light on their preference for new prototype over the old one. However, there are still some improvements which are necessary to create a more accessible prototype. There are still some screen reader compatibility issues for the new prototype which needs further improvements, there are several issues regarding the multimodal means of communication such as speech input, use of tactile keyboard etc. Although the results from the experiment showed that the new prototype had significant benefits over the old one, it is still felt necessary that the use of real users along with a larger number of participants can provide more concrete evidence.

Chapter 1

1.1 Introduction

The use of mobile devices has steadily increased among all user groups. In 2015, The GSMA Intelligence reported in the report "The Mobile Economy" that there are almost 3.6 billion mobile phone users all around the world which is almost half of the world's population(Intelligence, 2015). Although the penetration amount of mobile phones is quite high, the amount of smart-phone users is still quite low. According to a survey done by "eMarketer" published on January 16, 2014: The number of smart-phone users has grown from 1 billion to almost 1.75 billion in 2014 (eMarketer, 2014). Although, this growth in the number of smart-phone users is optimistic, we must bear in mind that most of these are young people. However, one study by "Deloitte" predicted that in 2014, the ownership of smart-phones for the people over the age of 55 will increase by almost two times to about 45 to 50 percent in comparison to 2013 where the ownership of smart-phones was only about 25 percent.

One of the studies suggested that the reason behind the popularity of mobile phones is the ease of access to information and constant connectivity(C. Ling, Hwang, & Salvendy, 2006). Mobile devices especially smart-phones are used for a variety of purposes due to the availability of different types of mobile applications. However, there is a difference between the purposes of use of mobile technologies for different age groups. While younger users are concerned with social interaction aspects, the users who are adult or elderly have purposes which vary from job-related issues to security, safety and personal independence (Abascal & Civit, 2001).

Along with different types of mobile devices, there are also different types of mobile applications which can be downloaded into smart phones which serve a variety of purposes. Similarly, mobile applications which are developed for health related issues are also increasing (Klasnja & Pratt, 2012). This sharp increase is related to the affordability and availability of mobile devices and smart-phones which have higher processing capacities. Most healthcare information systems are designed for health professionals to enter, receive and exchange information about patients(Lorenz & Oppermann, 2009). These healthcare information systems range from mobile devices to personal computers and servers located in health institutions. However, there are several issues related to usability and accessibility of these systems. These issues become extremely difficult when designing them for the use by the elderly and people with disabilities, due to restricted perceptual competence and lack of familiarity with different devices as well as learning curve (Lorenz & Oppermann, 2009).

As mentioned above, the use of mobile applications has steadily increased and with this increase, the penetration rate of mobile devices to people of different demographics is certain. The GSMA Intelligence report called “The Mobile Economy, 2015” reported that the penetration rate for adoption of smart-phones will reach 70 to 80 percent ceiling which is considered as the highest level of penetration. This suggests that the use of smart-phones has peaked and mobile applications of different types including those for health issues are developed for a variety of users with different types of impairments. Therefore, these mobile applications must be developed so that they are made accessible according to the standards specified for “Universal Design”.

In this thesis, a mobile application called “RevmaRApp” is the main focus. RevmaRApp is a mobile application which is developed by the “Norwegian Computing Center”. This mobile application is specifically targeted towards users with rheumatoid arthritis. It consists of several features; however, our thesis is only focused on the data visualization part of RevmaRApp.

At first I have evaluated the data visualization currently available in RevmaRApp through heuristic evaluation method. This evaluation is then tallied against the user testing information provided by the Norwegian Computing Center. The results thus obtained are used to recommend and create a new prototype for the data visualization adhering to the universal design standards which are discussed further below. At the end, an experiment is conducted for both the old and new prototypes, and a heuristic evaluation is done on the new prototype to understand scopes for future improvements.

In the first chapter, I discuss about various important terminologies relevant for this thesis, and provide an overview of the different features available in RevmaRApp including data visualization. In addition to this I also discuss problem statements in the first chapter.

In the next chapter, I discuss some relevant literature in 5 different aspects: In the first part, the current context of usage of mobile devices is discussed since RevmaRApp is a mobile application, followed by a brief description of some of the mobile applications which have similarities with RevmaRApp in terms of features and motivation where I have specifically focused on patient monitoring systems. In the third part of this chapter, I discuss about the feasibility factors influencing development of mobile applications and their relationships to universal design standards. The fourth part addresses the need to follow universal design principles according to the various national and international legislatures, which are designed to ensure and recommend the use of universal design standards. Finally, in the last part, different types of data visualizations are discussed to provide an overview on various types of data and techniques to visualize them.

Since, this is a thesis which consists of two parts, evaluation and prototype development, the next chapter is about the use of personas in the development of the prototype and the software engineering technique used in the development phase. Following the prototype development, I conducted an experiment to get statistical evidence. The process of the experiment is discussed in detail in the following chapter. The results obtained from the experiment as well as the prototype development are summarized in the later part of the thesis. In this structure, this thesis document is organized. So in the following section, I discuss some of the terminologies relevant to this thesis.

1.2 Terminologies:

1.2.1 Universal Design:

Universal design is a design concept that recognizes respects, values and attempts to accommodate the broadest possible spectrum of human ability in the design of all products, environments and information systems. It goes beyond the approach of accessible, adaptable and barrier-free design concepts of the past. It helps to eliminate the need for special features and spaces, which for some people are often stigmatizing, embarrassing, different looking and usually more expensive

(NorthCarolinaStateUniversity, n.d.-b).

It is a design process that has an intention to simplify design of products, through which the product can be usable by the maximum amount of people of all ages and with varying degree of abilities.

1.2.2 Data Visualization

Data visualization is a relatively new term which is also related to information visualization. Unlike graphical presentations, it is not just a method to visualize data in graphical forms. Its main purpose is to provide complete information to the readers or users about the information and structure behind the data in order to give them an insight of the information(Chen, Härdle, & Unwin, 2007).

1.2.3 Rheumatoid Arthritis

(Rheumatic Arthritis) RA is defined as an auto-immune disease which is of chronic nature. ACR (American College of Rheumatology), describes rheumatoid arthritis as a chronic inflammatory disease which is characterized by joint tenderness, swelling, and destruction of synovial joints, pertaining to severe disability and premature mortality (Aletaha et al., 2010). It begins from the small joints of the hands and feet and spreads to the larger ones in later stages. In prolonged stages, the joint deformity erupts which leads to physical disability. According to a Global Burden of Disease (GBD) 2000 study, which was published in World Health Report 2002, RA is the 31st leading cause of Years Lived with Disability (YLD) worldwide. A 2010 extension study of the GBD suggests a global prevalence of RA to be 0.24% and approximately two times higher in females than males. The findings from this study suggest that RA is a global burden and its affects are increasing among the global population. Almost 1 percent of the population of the world is suffering from rheumatoid arthritis (Symmons, Mathers, & Pfleger, 2003).

1.2 Motivation

"A picture is worth a thousand words"

-Frederick R. Barnard

RevmaRApp is a mobile application developed to monitor and evaluate daily activities of rheumatoid arthritis patients. Further details about this mobile application are provided below in section 1.3. This particular thesis work will only focus on the data visualization feature of RevmaRApp, which is explained below in section 1.4. The present data visualization is first analyzed using standards such as WCAG 2.0 for mobile accessibility, WAI-ARIA and ETSI – EG 202 116.

The motivation behind this particular thesis is to make optimal use of universal design techniques and provide an accessible and easily understandable data visualization. The data visualization developed for this thesis must be compliant for mobile devices such as cell-phones and tablets. The visualization thus developed must be available for cross-platform usage which means the mobile application is developed to be used with different mobile operating platforms; however a majority of the focus will be on Apple based devices such as iPhones and iPads but this data visualization will be available for Android devices as well. Therefore, the new prototype is designed to be platform independent.

Visualization of data is an important method of conveying information to readers. Unlike graphical presentations, data visualization is the method used to convey complete information to users even in the absence of textual contents. In order to evaluate and explore, people normally use their different senses. However, different senses have different abilities to take in information. These differences are shown in the figure below:

	Visual/Aural	Tactile	Kinesthetic
Physical mechanism	light/sound waves	surface texture	force, length, velocity
Causality	one way (passive) information flow	one way (passive) information flow	two way (active) energy flow
Organs	retina/ear drum	skin sensors: pacinian, corpuscles, etc.	muscle and muscle spindles
Perceptual organization	global, spatially mapped	spatially focused, body mapped	spatially focused, body mapped
Information bandwidth [1]	$10^6/10^4$ (bits/sec)	$10^1 - 10^2$ (bits/sec)	20-30 Hz

Figure 1: Different perceptions and their properties

From this table, it can be deducted that visual perception has the highest bandwidth for presentation of information. Therefore, for easier and faster comprehension, visual graphs and charts are used as the means of visualization (Tufte & Graves-Morris, 1983).

1.3 Overview of RevmaRApp:

In the following section, a brief overview of the current mobile application called RevmaRApp is shown. This overview is intended to familiarize the readers about the existing RevmaRApp mobile application and its different features.

This section shows the screenshot images of different user interfaces within RevmaRApp. The users have to interact with all of these user interfaces to store their daily activities in the mobile application. The overview consists of screenshot images of the RevmaRApp application user interfaces and a short description of what it is intended for. The screenshot consists of Norwegian language therefore, a short description is also provided for corresponding screenshots to help the readers understand about each user interface and its functions.

The overview shows the process of information exchange and interaction between the users and the mobile application. It will provide you with an insight into the inner workings of the mobile application, its different functions and user interaction capabilities. It will help the readers to understand the context of use of the different features within the mobile application. The screenshots which are shown below are used to show the interaction designs of user interfaces, information delivery systems and user input fields:

a.

Figure 2, shows the home screen which consists of five different categories.

1. Info
2. Activity Registration
3. Overview
4. Reflection
5. Goal

The user can select any of these categories. These categories are mostly for information sharing purpose only.

Figure 2: Home Screen

Retrieved: 10/9/2015 From: RevmaRApp-skisser, 07-04-2015, *RevmaRApp,* Unpublished manuscript, Norsk Regnesentral, Norway

b.

Figure 3, shows the Information page.

This page normally is designed to provide information to the users about the application. This page informs the users about various features within the application and how these different features interact and function.

Figure 3: Information Page

Retrieved: 10/9/2015 From:RevmaRApp-skisser, 07-04-2015, *RevmaRApp,* Unpublished manuscript, Norsk Regnesentral, Norway

c.

Det finnes en liste med aktiviteter i appen som du kan velge fra, men disse kan gjerne endres og suppleres slik at de passer din hverdag.

For hver aktivitet kan du angi tidspunkt, varighet, i i hvilken grad aktiviteten er viktig for deg, om du kun følte plikt eller om den også var lystbetont, og hvor mye energi du brukte på aktiviteten.

Du kan også merke hver aktivitet med egendefinerte stikkord/merkelapper (tagger).

Denne informasjonen brukes til å få oversikt over aktivitetene.

Figure 4: Activity Information Page

Retrieved: 10/9/2015 From:RevmaRApp-skisser, 07-04-2015, *RevmaRApp,* Unpublished manuscript, Norsk Regnesentral, Norway

Figure 4 shows, an information page which describes about one of the five categories listed in the home screen which is called “Activity Registration”.

This information page informs the user about a default list of activities which can be customized according to the needs of the user. It also informs that each activity has three attributes:

1. Importance
2. Energy
3. Duty/Pleasure

It also describes that the user can determine these attributes according to their experiences after doing the activities and they can review or compare them at a later date.

d.

Aktivitetene blir vist i en oversikt hvor de … grønne og …. røde.

De mørkest røde er aktiviteter som var lite viktig og som kun utføres av plikt.

De mørkest grønne er aktiviteter er de viktigste aktivitetene som også er lystbetonte.

Figure 5: Description of Graphical Visualization

Figure 5, shows the information about the graphical visualization that is currently used in the application.

It provides a short introduction about the visualization and describes the use of different colors to visualize the three attributes of Energy, Importance and Duty/Pleasure.

Retrieved: 10/9/2015 From:RevmaRApp-skisser, 07-04-2015, *RevmaRApp,* Unpublished manuscript, Norsk Regnesentral, Norway

e.

Figure 6, shows the “Reflection Overview”.

This overview, suggests the user on how to interpret the visualization and reflect upon their activities depending on the three attributes.

It informs the user about the objective of the mobile application, which is to find a balance between rest and activity, duty and desire, consumption and replenishment.

Figure 6: Reflection Overview

Retrieved: 10/9/2015 From:RevmaRApp-skisser, 07-04-2015, *RevmaRApp,* Unpublished manuscript, Norsk Regnesentral, Norway

f.

Figure 7, shows a default activity list which can be customized by the users according to their needs.

The user can tap on the plus symbol and create a new activity.

Figure 7: Activity List

Retrieved: 03/05/2016 From: RevmaRApp, *RevmaRApp,* Unpublished mobile application, Norwegian Computing Center, Norway

g.

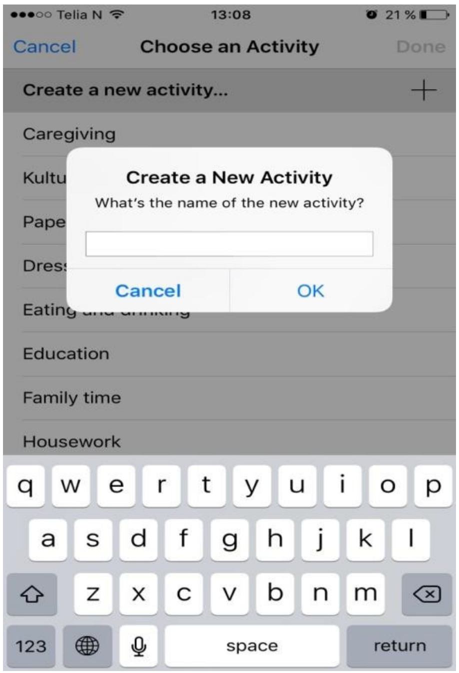

Figure 8, shows the new activity registration page.

New activity can be inserted into the list of activities as required by the user.

Figure 8: New Activity

Retrieved: 03/05/2016 From: RevmaRApp, *RevmaRApp,* Unpublished mobile application, Norwegian Computing Center, Norway

h.

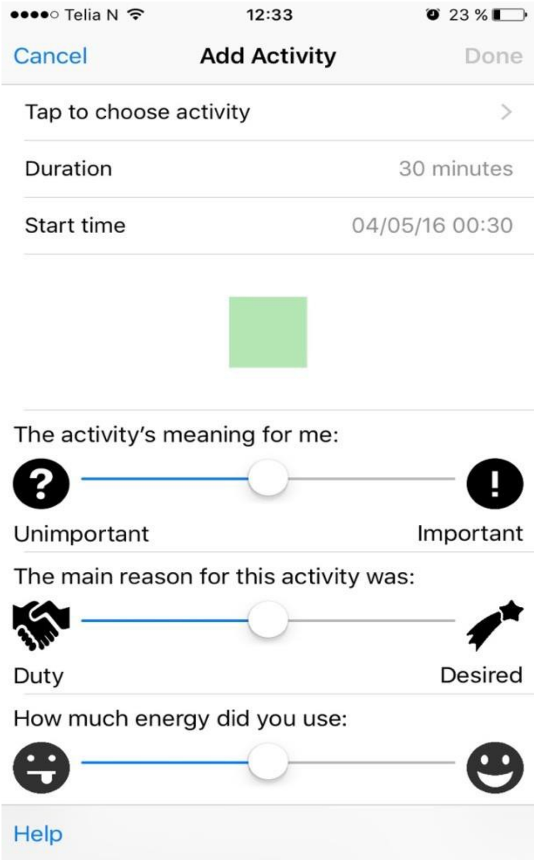

Figure 9, shows the "Register Activity" page.

The user can define the values for three attributes:

1. Importance
2. Energy
3. Motive

The user can use the slider to define the values by sliding it.

Importance has two extremes:

1. Unimportant
2. Important

Similarly, Energy has two extremes:

1. More
2. Little

Lastly, Motive has two extremes:

1. Duty
2. Pleasure

Figure 9: Register Activity

Retrieved: 03/05/2016 From: RevmaRApp, *RevmaRApp,* Unpublished mobile application, Norwegian Computing Center, Norway

i.

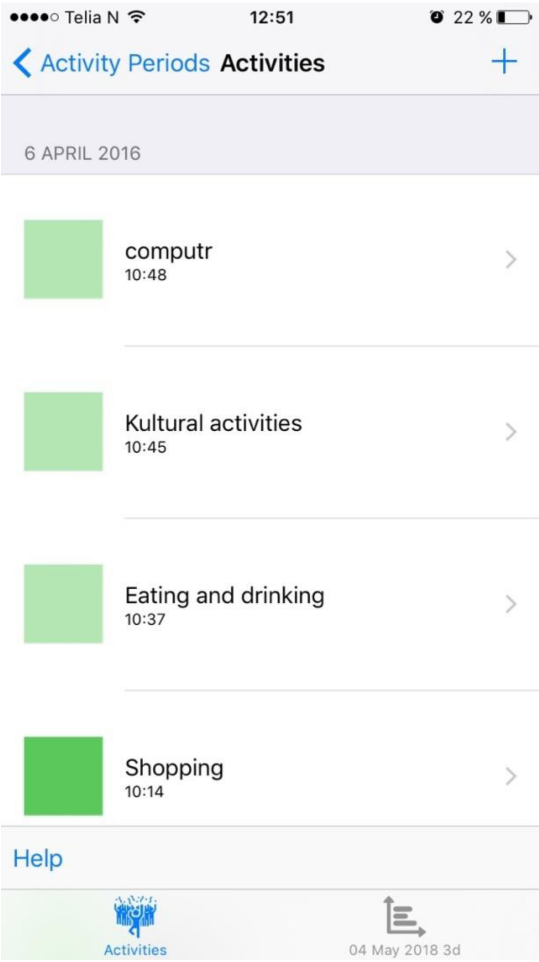

Figure 9, shows the "Activity Registration" log for one particular day.

It shows the list of activities which were registered by the user on a particular day including the time of registration.

The color palette defines the three different attributes of activity as either red or green activities.

Figure 10: Daily Activity Overview

Retrieved: 03/05/2016 From: RevmaRApp, *RevmaRApp,* Unpublished mobile application, Norwegian Computing Center, Norway

j.

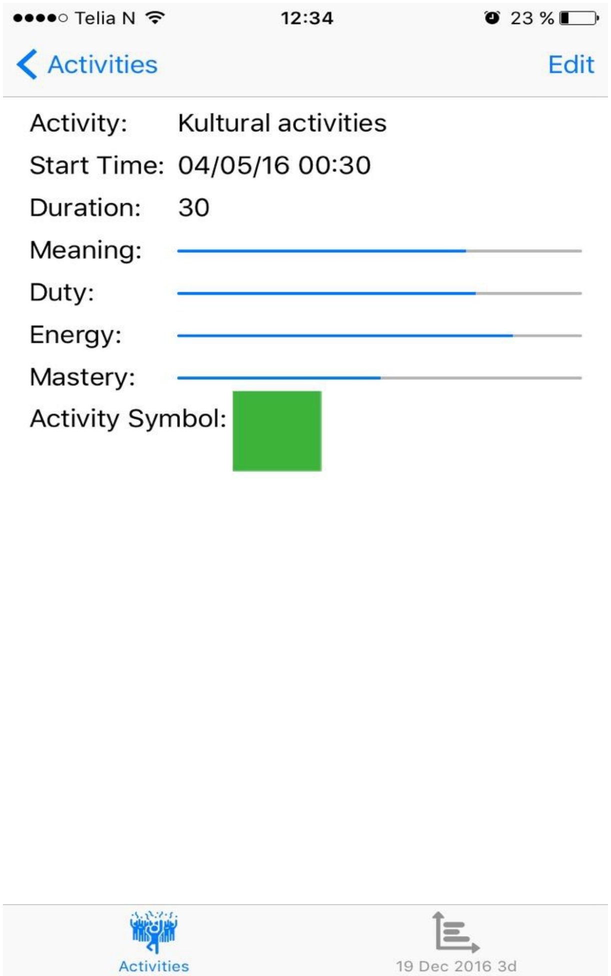

Figure 11, shows the details of activity such as name of activity, start time, duration of activity, meaning, duty, energy and mastery. The color of the symbol also represents the energy level.

Figure 11: Details of Activity,

Retrieved: 03/05/2016 From: RevmaRApp, *RevmaRApp,* Unpublished mobile application, Norwegian Computing Center, Norway

1.4 Overview of current data visualization available in RevmaRApp:

“RevmaRApp” developed by “The Norwegian Computing Center” is targeted towards the people diagnosed with rheumatoid arthritis. The application is developed to create a record of activities carried out within a certain period of time. Each activity consists of three attributes namely:

a. Importance
b. Energy
c. Duty/Pleasure

These three attributes are determined by the users, depending upon their experiences while doing the activities. After completing their activities, the users can record their feedbacks in the application for the three attributes. Thus the application will record the feedbacks from users for these three attributes. Users as well as healthcare personnel can reflect upon these activities and healthcare professionals can provide further recommendations to their patients based upon the data. This understanding provides a certain degree of independence of analysis of their activities to improve their quality of life.

1. Activity has 4 major attributes:
   a. Name
   b. Time Started
   c. Time Ended
   d. Duration

These attributes are assessed as per three categories:

1. Duty
2. Energy
3. Importance

These categories are assessed using a continuous slider visualization which allocates a decimal value between 0 and 1. This value is registered by the user of the application as per their experiences.

1.4.1 Explanation of Visualization:

The data is represented via a graph which consists of 4 quadrants.

1. Quadrant I: Activities which were desired and important
2. Quadrant II: Unimportant activities that are required
3. Quadrant III: Important required activities
4. Quadrant IV: Unimportant, desired activities

Usage of Colors and their meanings:

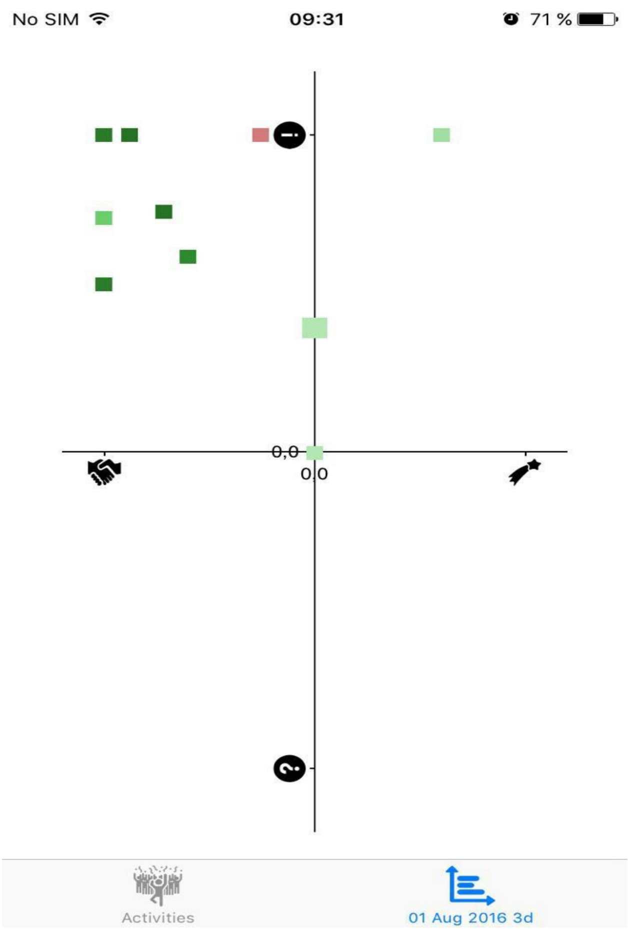

Figure 12: Current visualization

This is the current visualization of available on RevmaRApp (Retrieved: 2015/10, from: RevmaRApp, 2015 – 04, Unpublished manuscript)

1. a. Dark Red (Importance is 0,0 and Duty is 0,0)
   b. Light Red (Importance is 0.49 and Duty is 0.49)

2 a. Dark Green (Importance is 0.50 and Duty is 0.50)

   b. Light Green (Importance is 0.99 and Duty is 0.99)

3. Other combinations of values of “Importance” and “Duty” give grey color.

Quadrant Segmentation:

1. Dark Red to Light Red is plotted in quadrant 3(QIII) in the lower left hand corner

2. Dark Green to Light Green is plotted in quadrant 2(QII) in the upper right hand corner
3. Other combinations are plotted in quadrant 1(QI) and quadrant 4 (QIV)

Value Visualization (0 to 1)

1. Values between 0 and 1 are shifted to -0.5 to 0.5. (The distance from the Origin(O) is calculated in order to represent the intensity of color)
2. Value of Energy is a major contributing factor to the size of the object which is represented as squares.

There is a substantial growth in the usage of mobile technologies. The growth of mobile devices and their increasing demand in usage has provided further opportunities in the field of medicine and medical sciences as well. In the recent years, there has been a growing trend towards development of various healthcare and health-monitoring systems catering to the mobile users. In this similar quest, the Norwegian Computing Center has developed a mobile application for rheumatoid arthritis patients called “RevmaRApp”.

This application is designed to record routine activities of people diagnosed with rheumatoid arthritis which means that a large amount of data will be recorded in the database. As the amount of data increases it becomes difficult for the users to obtain specific data and reflect upon it, therefore there must be a means to visualize it. In RevmaRApp, data visualization is already present, which is the main focus of this thesis. This current data visualization is analyzed and a new prototype is designed in this thesis to develop an accessible and universally designed data visualization which can be incorporated into the RevmaRApp mobile application in future.

Problem Statements:

The use of written form of language is not sufficient to relay various kinds of information to diverse groups of users in terms of abilities therefore; different visualization methods are required to create graphical representations of data (Hienert, Zapilko, Schaer, & Mathiak, 2011; Pedersen, 1988; Skog, Ljungblad, & Holmquist, 2003; Ware, 2012). Visual displays provide the highest bandwidth of transmission of information where we acquire more information from visual information than all other senses combined (Cohn, 2004). Therefore, techniques to visualize information such as data visualizations must be accessible in design to include different groups of users despite of impairments(Jacobson, 2002).In our context, the existing data visualization in RevmaRApp consists of several accessibility problems such as its dependence of colors as the sole means of conveying information and lack of screen-reader support to name a few. According to the World report on Disability, produced by WHO and World Bank almost one billion people in the world are struggling with some form of disability (Organization, 2011). Among these different disabilities, rheumatoid arthritis is the 31st leading cause of years lived with disability (YLD) and almost one percent of the total population of the world suffers from this rheumatoid arthritis (Symmons et al., 2003). It is extremely important to narrow the digital divide which is increasing with the advent of internet, mobile devices and new technologies where static textual contents are gradually replaced by dynamic, interactive and multi-media contents (Wadell, 1999). There has been little or no research specifically targeted towards data visualization for mobile devices (Chittaro, 2006). However, some of the common challenges regarding data visualization with all types of mobile devices are design of visualizations which are not only impressive to look at but also conveys the intended information in an accurate manner; another common problem is the difficulty to use data visualization in the small screens of mobile devices (Chittaro, 2006).

Therefore, there needs to be a more focused research on how to use Universal Design principles and standards to create accessible data visualization for mobile devices (Chittaro, 2006; Kane, Jayant, Wobbrock, & Ladner, 2009). This thesis addresses some of the problems related to creating accessible data visualization. In this thesis I intend to understand how to use Universal Design standards to develop accessible data visualization by providing customization options for users so that they can customize user interface elements according to their needs which can make the data visualization accessible for people with different types of impairments. Another approach is to use multi-modal means of relaying the information to users which can help them to adapt the information according to their needs(Jacobson, 2002). In this context, I intend to develop the system to be compliant with screen – readers so that data visualization can be navigated by screen reader users as well. Therefore, I hope to decrease the digital divide as mentioned above through the means of use of Universal design standards.

Is there sufficient evidence to suggest that a data visualization which lets a user to select the type of data from a list of categories that s/he wants to see is faster than a data visualization which shows all the data in one chart?

Is there sufficient evidence to suggest that the customization features, to change graphical attributes of contents such as color and size make it more accessible?

Goal of thesis:

In this thesis, the main goal is to evaluate the old data visualization available in RevmaRApp and based upon the findings, develop a new prototype for data visualization. The old data visualization which is described in section 1.4 consists of a quadrant graph where each quadrant consists of small square objects which represent activities. They are color-coded and the colors range from green to red which represents energy levels of each activity. According to universal design, colors should not be used as the only means of conveying information(Lidwell, Holden, & Butler, 2010).

In the data visualization used in RevmaRApp, the application depends upon colors to represent the energy levels of activities. Further information regarding the usage of colors is described in section 1.4. Another problem is related to congestion and interaction with different elements on the data visualization. As the squares become numerous the data visualization becomes congested and users cannot get a clear understanding of their activities. They need to do multiple interactions to view the details regarding their activities. Touch screen devices are manipulated using fingers however, lack of precision makes touch screen interactions difficult, prone to errors and fatigue (Benko, Wilson, & Baudisch, 2006). As shown in figure 12, the square icons which represent activities are scattered on the graph and some are positioned higher on the graph while some are located lower but it is not clear to a user as to how that positioning is achieved and what exactly is it based upon.

In order to better understand the problem, it is important to understand the context of use of the mobile application as well. There are basically two user groups:

1. Arthritis Patients: The mobile application is developed for patients who have

arthritis that affects mobility of hands, fingers and joints. Impairments of hands and fingers cause problems when interacting with devices with small screens such as smart-phones and especially when the touch target areas are smaller in size.

2. Healthcare personnel: Another particular user group for the application is the health personnel. They can access the information provided by their patients and analyze the data to provide medical suggestions.

The aim of this thesis is to understand how the data which is recorded using RevmaRApp can be visualized in the best possible way so that the arthritis patients as well as the healthcare personnel can easily interact with the data and obtain relevant information for further analysis. The current data visualization in RevmaRApp is evaluated using WCAG 2.0 guidelines on mobile accessibility. Based upon this evaluation new data visualization is developed which follows the optimum amount of universal design approaches and principles. Therefore, this thesis will produce an effective and simple data visualization prototype or a concept which can be used to display data in a graphical format such as graphs or charts and it must be able to accommodate the variety of data that the application will generate. It will adhere to WCAG 2.0 guidelines on mobile accessibility and recommendations will also be provided as per other standards such as ETSI EG 202 116, BS8878 which can provide suggestions regarding the current legislative, management and international issues.

Conclusion of Chapter 1:

In the first chapter, I have provided a brief introduction of RevmaRApp in terms of its area of application, features and the data visualization currently available in RevmaRApp. This chapter provided an overview of RevmaRApp to make the reader familiarize with the different functionalities and features of the mobile application as well as terminologies.

Chapter 2

Background

Outline of Chapter 2:

In this section, I discuss various aspects related to development of mobile applications (i.e. data visualization in our application) and their relationship to universal design and accessibility. In the first part, I will provide a brief overview regarding the current context of use of mobile devices with respect to different user groups. This will be followed by a brief description of some of the mobile applications which have similarities with RevmaRApp in terms of users and usage arena which are mostly focused upon patient monitoring systems. In the third part of this section, I will discuss about some of the feasibility factors which have to be considered according to the universal design principles. The fourth part consists of a brief look on different types of data as well as various representation methods used to visualize these varieties of data. Finally, the last part consists of various national and international legislatures which ensure and recommend the use of universal design approach.

2.1 Current Context on usage of Mobile phones by different user-groups:

The use of mobile devices is constantly growing which reflects the huge increase in users of some sort of mobile phone in the world. However, in developed nations the increase of new mobile phone users is nominal since the new penetration rate has reached close to saturation(Intelligence, 2015). This suggests a positive signal towards increasing penetration of smart-phones in all user groups despite of age differences. However, there remains disparity among the penetration rates for users of different age groups with the highest of 70 percent penetration rate for smart-phone users for age groups between 18 and 54 years(Deloitte, 2014).

Smart-phone usage in developed nations is also at its peak according to the GSMA Intelligence Report called “The Mobile Economy” published in 2015; however this increase is mostly accredited to the young users of the smart-phones. The use of smart-phones and mobile technologies in general, depends upon motivation or purpose of use. This can be either intrinsic or extrinsic motivations and it can also vary in terms of importance, either utilitarian or hedonic (Conci, Pianesi, & Zancanaro, 2009). There are several other factors which are associated with use of mobile phones which applies to all users irrespective of age or gender. These factors are accessibility to information, display characteristics, arranging appointments, and safety(R. Ling & Haddon, 2003). One study suggested the use of mobile phones by older people in Finland was highly influenced by security and communication factors (Oksman, 2010). Another study suggested that the purpose of use of mobile phones by the elderly was highly motivated by social integration and independent living (Kurniawan, 2007).

Similarly, the use of mobile devices in health sector is increasing sharply. This sharp increase is related to the affordability and availability of mobile devices and smart-phones which have higher processing capacities. Most healthcare information systems are designed for health professionals to enter, receive and exchange information about patients(Lorenz & Oppermann, 2009). These healthcare information systems range from mobile devices to personal computers and servers located in health institutions. There are several issues related to usability and accessibility of these systems. These issues become extremely difficult when designing them for the use by the elderly and people with impairments due to restricted perceptual competence and lack of familiarity with different devices as well as learning curve (Lorenz & Oppermann, 2009). Therefore, the mobile applications which are targeted to be used in the health care sector must be developed and designed according to the universal design standards.

2.2 Previous work on similar mobile applications:

A term called mHealth (Jovanov, 2006) apps is coined, which is used to represent the up surge of mobile health applications available in the market. RevmaRApp is a mobile application which is targeted towards people with rheumatoid arthritis. In this section, I will discuss further about various mobile applications which have similarities to RevmaRApp. In addition to this, I will also discuss about some of the mobile applications which have interesting features which can be incorporated into RevmaRApp to make it more accessible.

Some of the mobile applications which bear similarity to RevmaRApp are discussed below to illustrate the current context of usage of mobile applications in health industry. The features contained in these applications as well as some of their complexities pertaining to their use are also addressed in this part. The applications are not completely related to rheumatoid arthritis but most of them have similarities in terms of their use to monitor musculoskeletal and non – communicable diseases or impairments. Throughout this literature survey, I have not found much of literature and research specific to mobile applications related to rheumatoid arthritis.

An application called "Candoo" [sic], using Google Voice Recognition and synthesis engine for web navigation, pill reminder including weather information notification was developed to help patients with dementia or Alzheimer's disease. These patients seem to respond to multimedia interactions such as music and photographs (Yamagata, Kowtko, Coppola, & Joyce, 2013). A mobile application similar to this one, consisting of a voice recognition system can be beneficial for patients with arthritis since typing can be difficult for people with rheumatoid arthritis. It can also include pain tracking system as an added feature.

Several mHealth apps have already been developed targeting arthritis patients, one such app is called "PInGO" (Kazi & Deters, 2013).It was developed in order to examine and assess muscle improvement in juvenile arthritis patients who were undergoing a training program for a period of 6 weeks (Kazi & Deters, 2013). The app consisted of a questionnaire for before and after exercise, which had to be completed by the patients. This provided valuable assessment of the exercises and their effects on patients which in turn helped the medical professionals to generate an effective fitness regimen for their patients. "PInGO"[sic] is available as an android mobile app as well as a web-based version is also available via Google Chrome. It has similarities with RevmaRApp in terms of features and functionalities as both of these applications act a medical application consisting of electronic diary feature and the target user group is also people diagnose with arthritis for both of them. However, PinGo[sic], does not provide a data visualization which makes it difficult to assess the data while RevmaRApp consists of a data visualization feature.

In the article, "MyWalk: a mobile app for gait asymmetry rehabilitation in the community", (How, Chee, Wan, & Mihailidis, 2013), a system called "MyWalk" [sic] is discussed which is relevant in current context as there is an increase in usage of wearable technologies and mobile devices. MyWalk is also an android application developed to help in the rehabilitation process of the Gait patients, which is a disorder in locomotion caused by diseases such as Parkinson's disease. Unlike "PInGO" (Kazi & Deters, 2013) where data is recorded by patients manually, MyWalk records real time data to assess Step-Time Asymmetry (STA), which records consecutive uneven heel strikes. Patients can gather data on their own movements and forward it to the healthcare professionals to get a better understanding of their conditions. MyWalk incorporates telerehabilitation techniques using pervasive computing systems. It records real time data and analyzes it to provide a visualization of the data. However, MyWalk has some issues related to accuracy of data and visualization. Unlike PinGo [sic], MyWalk consists of data visualization feature which helps the users to understand the data. However, MyWalk uses a line chart to visualize the data which has several issues. One of such issues is related to the size of line charts and its correlation with accuracy. In terms of normal line charts, the optimal chart height was found to be 24 pixels (6.8 mm on 14.1" 1024 X 768 pixel display) (Heer, Kong, & Agrawala, 2009). This suggests that line charts are not suitable for mobile devices with smaller screen sizes due to loss of accuracy of information and interaction capabilities. Therefore, in RevmaRApp, a different data visualization technique is implemented.

In another research paper, by Pereira and Moreira (Pereira, Moreira, & Simões, 2010), suggested that in real time monitoring systems, there are issues surrounding simultaneous monitoring of multiple patients and storage of data in the database. Their solution included a network of wireless sensors which can be used to monitor vital signs of patients. Data from the sensors are stored in central repository which can be accessed locally using Ethernet or Wi-Fi connections and remotely through the use of internet. Integration of such technology into a system for arthritis patients can be extremely useful in order to obtain real time data due to the increase in wearable technologies. RevmaRApp acts as an electronic diary for rheumatoid arthritis patients where data is not collected in real time. Therefore, there are possibilities of errors during data entry from patients. In order to reduce such errors, a real-time sensor-based data collection method can be implemented in future. However, sensor-based networks generate large amount of data and the authors suggested that complex visualization is not the best solution because of the processing requirements of the client system. The application must also be made scalable to cope with the increase in users for future.

These relevant technologies discussed above are gaining mass audience due to increase in the use of mobile devices and wearable technologies. Such devices gather a large amount of different types of data ranging from real time transfer of data to locally stored data by the applications which are of personal nature therefore, a safe and easy method of data visualization is necessary.

To cater to such diverse types of data, there are various related work in the field of data visualization such as IBM Many Eyes, Data360, StatCrunch, Socrata etc (Hienert et al., 2011). These visualization tools can be used by the users to upload data and create visualizations which are suitable according to the needs of the users. These different approaches towards data visualization provide a new concept of using online or web based data visualization approaches which are designed to support cloud computing communities.

In one article, called “Interactive Information Visualization to Explore and Query Electronic Health Records”(Rind et al., 2011), it is suggested that medical decision making is a complicated process where a large amount of data is stored in EHR (Electronic Health Record) systems. In this article the authors have surveyed and reviewed the data visualization and interaction techniques found in 14 EHR systems. The authors have attempted to divide the data types into categorical and numerical data, where they suggest that the most common method to visualize categorical data is by placing icons(for point events), and line segments (for events with duration) on a horizontal time line. This can be further differentiated using color codes. While numerical data can be visualized using line plots however use of point plots or bar charts is also accepted. But in systems which visualize both categorical and numerical data, dual visualization technique such as WBIVS (Web Based Information Visualization System) (Rind et al., 2011) is used, which uses line charts for numerical data and a matrix view for categorical data. The authors have concluded that medical information is complex and difficult to interpret and this problem can be solved by using appropriate data visualization techniques. However, in all 14 applications that they surveyed, they discovered varying degrees of problems related to visualization of different types of medical data.

SOVAT (Spatial OLAP Visualization and Analysis Tool) is another tool used to make community health decisions. This tool can be used to handle large amounts of data and visualize the information in numerical and spatial views. It consists of two technologies: 1. Online Analytical Processing(OLAP) and Geospatial Information System(GIS)(Scotch & Parmanto, 2005). This article suggested that there is a need for a powerful multidimensional data storage and manipulation system especially concerning spatial data. SOVAT [sic] is an example of an application which combines OLAP [sic] and GIS [sic] and consists of abilities such as: storage of data sets, statistical analysis, exploration of data, visualization of data using charts and spatial objects and perform spatial analysis. However, the system still lacked the ease of use and the complexity of usage makes it difficult to adopt technologies like SOVAT [sic]. Therefore, specific concerns regarding usefulness and ease of use of systems must also be addressed during developing such systems.

HealthMap is an event based monitoring system for infectious diseases. Data from various sources is collected through RSS (Rich Site Summary) on the backend whereas on the frontend Google Maps public API is used to create mappings (Freifeld, Mandl, Reis, & Brownstein, 2008). HealthMap [sic] organizes and visualizes data according to three categories: date, location and disease. The developers allowed the system to adapt to the needs of the users where customization options were created to adapt the system to expert users as well as novice ones. The data showed in the visualization changed according to the selection of categories by the user. Users had the ability to zoom into the specific maps of countries and track for any alerts for diseases which were ordered by reverse chronological order. Therefore, HealthMap [sic] allowed the users to visualize the data according to their selection of categories. However, due to complexity of this application the frontend still needs to improve to provide better user experience and automation capabilities.

2.3 Feasibility factors in application development process

This part will discuss different feasibility factors including security of data and issues related to different hardware and software platforms which will provide an overview of which factors must be considered to select a good data visualization using the corresponding seven principles of Universal Design.

There are seven principles of universal design which were developed in 1997 by a team led by late Ronald Mace in North Carolina State University:

1. Principle 1: Equitable Use
2. Principle 2: Flexibility in Use
3. Principle 3: Simple and Intuitive Use
4. Principle 4: Perceptible Information
5. Principle 5: Tolerance for Error
6. Principle 6: Low Physical Effort
7. Principle 7: Size and Space for Approach and Use

Among these seven principles, I have chosen to explain two principles which are very important for our data visualization. These two guidelines and their correspondence to our project are discussed further below:

2.3.1 Equitable Use and Security:

In most applications which are developed for medical purposes security of data and accuracy in exchange of information have become vital factors for success. In the paper by (Li, Lou, & Ren, 2010), the authors have stressed on security and privacy concerns regarding the personal data collected through sensor networks or Wide Body Area Networks (WBAN). Such data must be stored and transmitted securely. The United States of America has (HIPAA) Health Insurance Portability and Accountability Act of 1996, which ensures privacy concerns for security of data however, with the use of WBAN [sic], one compromising node in the WBAN [sic], can be the source of leakage of data. Issues such as threats from dynamic networks, confidentiality, dynamic integrity assurance, dependability have been raised by the authors in the paper. There is also an underlying technical inverse proportionality between security and efficiency of the system. Therefore, with the use of wearable and WBAN, it becomes extremely important to secure personal data collected using these devices without compromising the performance of the device and the network as well. While designing data visualization, it is imperative to understand such challenges in order to extract necessary data from the database and provide limitations to the interaction of such data. One particular example is the use of selective data visualization using "Snap" which can be used to select particular databases and generate visualizations while another way of visualization is use of separate visualizations to show different dimensions such as time, topic and location using "VisGets"(Hienert et al., 2011). The seven principles of Universal Design developed in 1997, by a team led by late Ronald Mace in the North Carolina State University states seven principles for Universal Design approach. In the first principle called "Equitable Use", guideline number 1c. states that provisions for privacy, security and safety should be equally available for all users(Story, 1998).

2.3.2 Flexibility of use (Hardware/ Software Independence)

With the rapid increase in different types of technologies and the affordability of hardware and software systems including various mobile platforms such as Apple IOS, Android, Windows etc. a large number of possibilities are available for application development. However, a study done by Joorabchi, Mesbah and Kruchten (Joorabchi, Mesbah, & Kruchten, 2013), suggests that; while developing applications, one particular problem is the development of applications which is operable in different mobile devices with different hardware and software capacities which also run on different platforms. For example, Android consists of various versions and browsers among which some have issues relating to HTML5. Such fragmentation across platforms becomes an important issue for success or failure of the application. Along with this, data intensive apps need to have an offline backend caching which has its own share of problems.

To understand different visualization techniques for these different types of data, produced by a variety of mobile operating system platforms; it is imperative to understand how these operating systems provide various supporting features for development of applications and processing of data within their structures. Applications development using Apple computer's mobile operating system iOS and Google's open source mobile operating system Android differ in almost every aspect. In this part, I discuss about Android and iOS platforms for application development, since the prototype developed for this thesis is targeted towards these two mobile platforms.

2.3.4 Android OS

Applications made in Android platform are packaged as apk files. Such .APK package consists of .DEX files. .APK can be considered the highest compressed version of Android packaging thus shows that the deployment time is dependent on this packaging. Android provides a neat feature for communication with any server when required by any application, using a connection object which acts as a transceiver. Android uses Java as the primary programming language which is one of the most used programming languages in portable technologies. From a hardware perspective, Android provides the flexibility of using its development environment and other services on any hardware platform. Android has provided a range of SDKs; however, Eclipse still remains a dependable SDK. Interface development is generally through XML files including layout and elements in Eclipse which uses a WYSIWYG editor. In terms of documentation support, Android has no specific handbook however; a large amount of documentation is available on various topics regarding Android through various Android communities. Android being an open-source project, the communities have greater access to any documentation. Android has a completely different approach in comparison to its iOS counterpart; it consists of three parts: Manifest file (AndroidManifest.xml) containing the details of internal organization, resources containing images and supporting files, are stored under /res/layout/main.xml and Activity is stored with its class files.

2.3.5 iOS

Applications made in Apple iPhone platform are packaged as .ipa files or .plist. The entire application can be compressed using ARM architecture which does not provide any flexibility since the package can only be used for iOS devices. The expansion or unzipping of .ipa files can be done by changing the extension to .zip thus forth, it can be unzipped using any unzip application. Similarly, Apple uses objective C as the base language for development. Delegates is used in classes to reference objects which implement particular protocols and thus delegates comes into action whenever object gets called for a response. Apple does not provide hardware platform independence, thus the developer requires a Macintosh device with Mac OS X running on it. XCode has been a stable IDE for iOS. Interface development occurs in iOS, using a graphical editor which stores these elements in .xib files which can be graphically connected to code via outlets. iOS, although not an open source Operating System (OS), still has not provided any formal documentation, however, various technical documents are provided free of cost. Application development as per the Model View Controller (MVC) approach consists of a user interface (view) under .xib file. View Controller is represented as header (.h) and implementation (.m) file, which communicates between view and the model. Finally a property list (.plist) file bundles the app.

2.4 Different types of data and data representation methods:

In this section, I discuss several types of data visualization and their corresponding usage for different types of data and provide justifications for using bars as data visualization in my prototype based on the type of data collected in RevmaRApp.

The term InfoVis [sic] techniques has been coined to represent data visualization techniques. It is extremely important to understand the need of data visualization in different mobile applications since the needs of these applications are dynamic in nature. This dynamic nature of mobile applications means that different kinds of data have to be visualized using different types of data visualizations. The selection of the appropriate form of the data visualization is important for a successful mobile application. The elements of the graph such as the color combinations, symbols, legends and range must also be in accordance to the need of the entire visualization process which must be customized as per the needs of the users as well as the types of data which are stored and manipulated by the users.

Classification of data is a big issue(Ware, 2012). In 1977, Bertin (Bertin, 1981) suggested that there are two fundamental forms of data: data values and data structures. In this context, data can be divided into entities and relationships. Entities are objects which need to be visualized and relationships are structures or patterns which relate entities with each other. Both entities as well as relationships can have attributes. An attribute is a property which is linked to an entity and which has no identity of its own. In our application, an activity is an entity which consists of attributes such as: 1. Importance (Variations: Unimportant and important), 2. Motive (Variations: Duty and Pleasure), 3. Energy (Variations: Lost or Gained). An attribute of an entity can have multiple dimensions(Ware, 2012). Dimensions can be 1D (1 Dimensional), 2D (2 Dimensional) , 3D(3 Dimensional) and so on.

According to a statistician named Stevens (Stevens, 1946), there are four levels of measurement:

1. Nominal

2. Ordinal

3. Interval

4. Ratio

Data can be normally divided into two groups: categorical and quantitative.

Categorical data is described as the discrete data which represents different sets of categories which are not continuous. Unlike quantitative data which has some form of continuity, categorical data are discrete in nature. Such discrete nature of categorical data makes it difficult to visualize(Bendi, Kosara, & Hauser, 2005). Categorical data are normally considered nominal in nature while quantitative data are ordinal. These different types of categorical data have no relation to each other which makes it difficult to design a common visualization which can accommodate all the data. Therefore, there is no silver bullet.

These different types of data have created a need for a new field of research into different types of data visualization techniques. The visualization of categorical data is affected by the fact that whether the data is independent or not. In case of independent data, different methods such as bar graphs, dot charts or pie charts can be used(Friendly, 2000). However, if the data is dependent with each other then, such methods are not suitable.

To visualize such data with relationships, other techniques such as Sieve diagrams or Mosaic displays are used.

a. Sieve Diagram:

Sieve diagram was proposed by Riedwyl and Schupbach (1983) which was later on named as parquet diagram in 1994. It is used to plot two way frequency tables(Friendly, 1992). In this diagram, the larger boxes are rectangle in shape which consists of smaller boxes which are square in shape. The rectangle box represents the expected frequency whereas the square ones represent the observed frequency. Sieve diagrams plots two way frequency tables where the rows and columns are independent of each other. There can be difference between observed and expected frequencies which is given the term departure from independence(Friendly, 1992). The departure from independence can be either positive or negative.

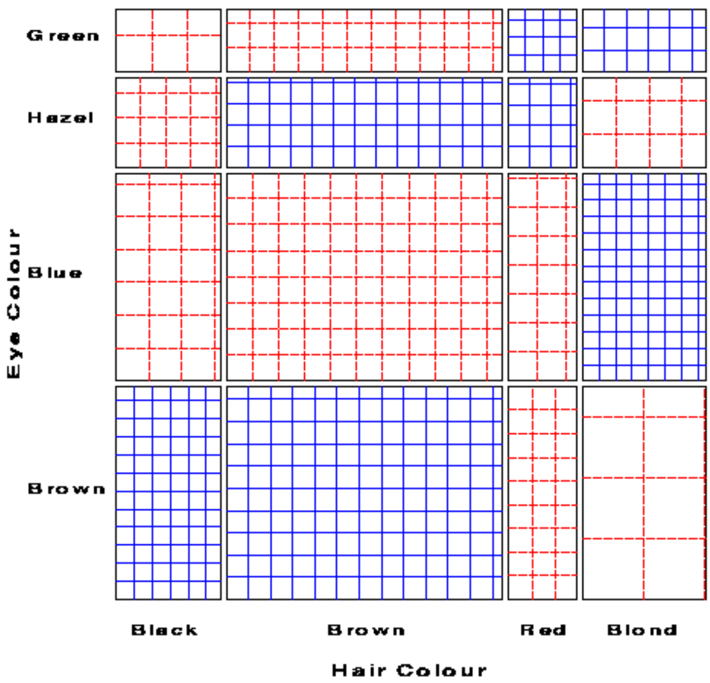

Figure 13: Sieve Diagram

This is an example of Sieve Diagram (Retrieved: 2015/10, from http://www.datavis.ca/papers/koln/)

b. Mosaic Display:

Hartigan and Kleiner in 1981, proposed mosaic display. Mosaic display consists of tiles and the area of these tiles is proportional to the cell frequency represented in a table. Condensed mosaic display has similarities to a bar chart in term so width of the columns in the chart is proportional to the marginal frequencies of one data set and the height of each tile is determined by conditional probabilities of another data set in each column. Enhanced mosaic display uses color and reordering of rows and columns to associate patterns and displays observed frequencies as well as deviations from a specific model.

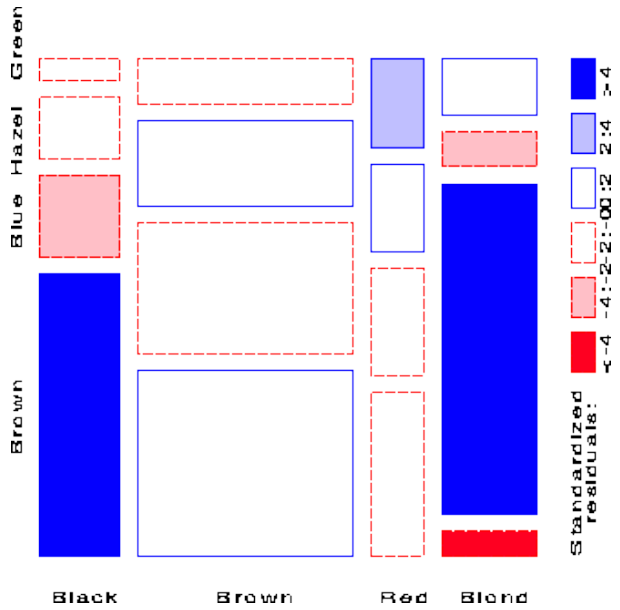

Figure 14: Mosaic Display

This is an example of Mosaic Display (Retrieved: 2015/10, from: http://www.datavis.ca/online/mosaics/about.html, Friendly, M. (2000). *Visualizing categorical data*. Cary, NC: SAS Institute)

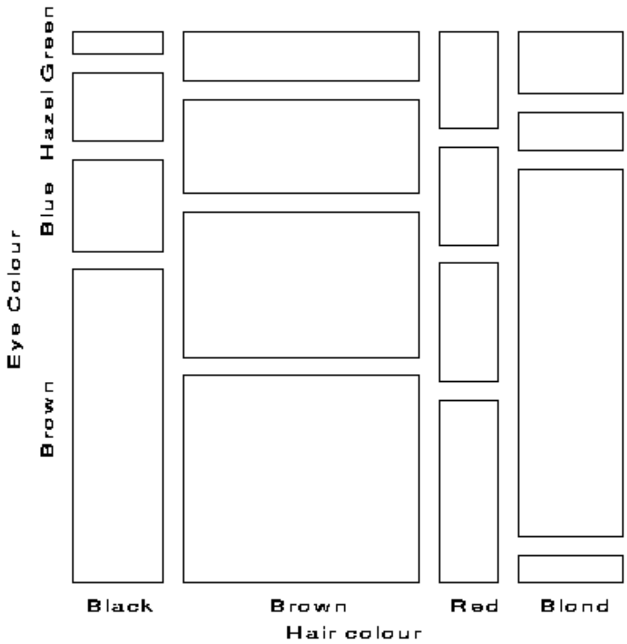

Figure 15:: Condensed Mosaic Diagram

Figure 1: This is an example of Condensed-Mosaic Diagram (Retrieved: 2015/10, from http://www.datavis.ca/papers/koln/, Friendly, M. (2000). *Visualizing categorical data*. Cary, NC: SAS Institute)

However, to represent independent data which have no relationships with other data, Bar graphs and scatter plots are used. Bar Graphs depend on continuity of data and do not necessarily represent categorical data but quantitative data. Scatter plots represents two or more variables and depends on continuity factor as well(Bendi et al., 2005). We will discuss further regarding the benefits and the drawbacks of these different techniques.

a. Bar graphs:

A bar graph might be one of the easiest methods of data visualization. According to Meyer, whenever there is uncertainty regarding which graph to use to represent a particular set of data, the easiest answer is to use a bar graph (Meyer, 1997). However, there is a limit to what kind of data can be represented using such graphs and how to make the best application of such graphs. For example use of 3D bar graphs to represent data might give ineffective results and provide false information due to distortion of data which can cause data ambiguity and distraction from what the data might try to convey through that graph. Such graphs can cause cognitive overload for the reader in order to separate each section of the bar and then compare it against other bars(Few, 2004). The choice of colors to represent data in these graphs can be crucial as well as the text alignment and location can also play a vital role to convey the message. Placement of legends used to define axis labels must be of concern too in order for the reader to easily grasp the indicators provided through the legend. A flat bar graph conveys more accuracy of information than a three dimensional bar. Different shades of same color varying in shades of hue from dark to light shades can be much more beneficial to convey the information rather than using different colors(Harris, 1999).

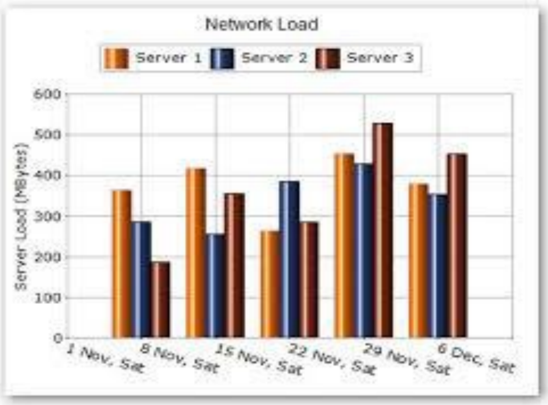

Figure 16: An Example of Bar Graph

This is an example of an inappropriate use of bar graph for data visualization. (Retrieved: 2015/05, from http:// https://www.syncfusion.com/products/windows-forms/chart)

b. Scatter Plot:

Scatter plot can represent two variables and show the relationship between them. The collection of points on a vertical (Y) and horizontal (X) planes along with the positive or negative direction for these values represent the data. Such a plot can provide a detailed view of the variables. Similar to bar graph, scatter plots have the same problems as to visualization of data where it also has to deal with problems such as data ambiguity and distortion as well as visual distractions. A better use of scatter plot can be made with the use of tabular presentation of the data it might represent which means a use of table to represent the data to provide a more in-depth understanding of the data and the plot can be used to demonstrate the overview of that dataset. According to the Guideline 1.4 Distinguishable under Perceivable principle of WCAG 2.0, it is important to use different colors to represent the data through the fills or dots and the background of the plot so that the users can easily notice the dots which represent the data, from the background. Similarly, to make the distinction between the two variables, it is practical to use two different symbols to represent them(Harris, 1999).

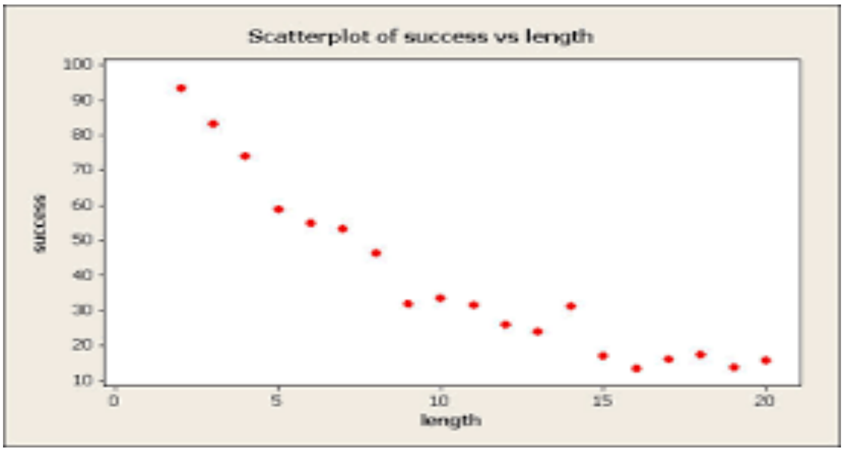

Figure 17: An example of Scatter Plot

Retrieved from: http://sites.stat.psu.edu/~lsimon/stat501wc/sp05/minitab/graphics/ScatterplotA_success_vs_len.gif)

In this chapter, I have discussed some relevant literatures, which provide an overview of the current scenario in mobile health application development according to the universal design principles. It also provides information about the use of different types of data in these applications which is one of the most important factors to be considered when developing data visualization. In RevmaRApp, the application uses bars to visualize the data which is based upon the fact that the data is independent. As mentioned before, simple and easy to use data visualization is necessary for RevmaRApp. Bar graph is considered as one of the simplest and easiest data visualizations to understand as well.

There are some conventional diagrams and charts which are used as popular means of data visualizations and such images must be an “efficient depiction of meaningful and unambiguous data” (Klass, 2001). Data visualization must be visual and provide a summarized view to the reader so that the reader can grasp the idea provided by the data immediately by viewing the visualization. Another factor is that the data visualizations must be accurate and reflective of the data. In order to make visualization more accessible by different sets of users, it is necessary to understand the needs of the users. Furthermore, it is also helpful to create various customization options so that users can customize the visualization according to their needs such as changing of colors, language, size of fonts etc.

In the next part, some relevant international legislations, laws and accessibility principles will be discussed which describes the need to make these applications as Universal in design as possible. This section focuses on the laws which govern "Universal Design" approach to design and development of technologies.

2.5 International and national legislatures and recommendations for Universal Design Approach:

In a number of countries, the need to address issues regarding universal design and accessibility are enshrined in legislations (Keates & Clarkson, 2003). Various guidelines, principles and laws are created to enforce and recommend equality for all despite of any kinds of impairments. Most of these legislations are punitive such as 1995 UK Disability crimination Act, Sect. 504 of US 1973 Rehabilitation Act, 1990 US Americans with Disabilities Act (Keates & Clarkson, 2003). Some of these relevant guidelines and legislations are explained further below:

2.5.1 ETSI (European Telecommunication Standard Institute)

There are several procurement guidelines which demand the use of accessible technologies, especially for institutions which directly deal with public such as various government institutions. ETSI EG 202 116, defines "Design for all" as design of products to be usable by all people, to the greatest extent possible, without the need for specialized adaption. Usability is defined by ETSI EG 202 116, as extent to which a product can be used by specific users to achieve specific goals with effectiveness, efficiency and satisfaction in a specified context of use. These two factors give rise to the "usability gap" factor, which is the gap created by the users' needs and the set of functionalities provided by the technology. This gap needs to be as minimal as possible in order to establish a strong universal design approach for the technology, which we intend to achieve in our project as well. As mentioned in the handbook for "Design for All" by the Center for Universal Design, there are seven principles (Story, 1998).

1. Equitable Use: Design must be inclusive of all its user groups.
2. Flexible in use: Design must be able to provide varying features to address the needs of the users on an individual level according to their preferences and abilities.
3. Simple and intuitive to use: It must be easily understandable, regardless of the user's experience, knowledge or skills.
4. Perceivable information: The design must provide sufficient information to the user through multiple methods of perception in order to counter any sensory or cognitive impairment in the users.
5. Tolerance of error: There must be able to cope with any unintended errors and mitigate such mistakes without effecting the entire process and system.
6. Low physical effort: Design must be able to contribute to minimize fatigue
7. Size and space for approach and use: Appropriate size and space must be allocated to interact with the systems regardless of the user's body size, posture or mobility.

One major issue that comes into play when we are talking about data-centric applications is related to privacy. This issue is as vulnerable a topic as ever, due to the fact that privacy has become an unattainable fact when it comes to the virtual world. In the realm of internet, we can certainly say that privacy is a luxury that not all of us can have. There are various strategies which one can embrace in order to attain a certain level of privacy in the virtual world such as verbal behaviors, non-verbal behaviors, and environmental mechanisms, cultural mechanisms (Neustaedter and Greenberg 2003). Some important environmental aspects of privacy issues which can be controlled by the individual are video fidelity, capture angle, camera state and audio link (Neustaedter and Greenberg 2003). The seven principles of Universal Design developed in 1997, by a team led by late Ronald Mace in the North Carolina State University states seven principles for Universal Design approach. In the first principle called "Equitable Use", guideline number 1c. states that provisions for privacy, security and safety should be equally available for all users(Story, 1998).

2.5.2 U.N. Convention on right of persons with disabilities

Another important legislature, which has recently come into concern is related to access for all. A concept where information technology and all its aspects from user interface of systems to the hardware devices must be accessible by people with disability as well as those of old age. According to the United Nations (U.N.), convention on the right of persons with disabilities, it is imperative for a person with a disability to have the same ease of access to physical, social, economic and cultural environment, to health and education and to information and communication in order to fully enjoy all human rights and fundamental freedoms (Assembly 2006). This basic principle is to be adhered to in order to provide a system which is accessible by any person with or without disability as well as any age related barriers. The notion of "One size fits all" is quite vague and very difficult to attain thus there will be a need for some assistive technology besides the universal design approach for some individuals due to the severity of their disabilities(Clarkson, Coleman, Keates, & Lebbon, 2013). "One size fits all' is not a term that is used in conjunction with "Universal Design". Therefore, the data visualization which I have designed for this project consists of various customization settings. The users can use different customization settings to change various features such as color, contrast, size of text etc.

2.5.3 ISO and IEC

International Organization for Standardization (ISO) and International Electro-technical Commission (IEC), have issued a policy statement in June 2000 stating "Addressing the needs of older persons and people with disabilities in standardization work". According to the ISO/IEC Guide 71(ETSI 2002), human abilities have been divided into 4 major categories such as Sensory, Physical, Cognitive and Allergy which are to be considered in order to allow the concept of access for all or universal design. The standard explicitly states that, in order for a system to be accessible by people with disabilities it is important to make the system accessible by two or more sensory abilities where all the inputs and outputs are conveyed using an alternative method which will be useful to circumvent the disability of the person. For example, for a person with an auditory disability, visual signals such as flashing lights or other sensory stimuli can be used. Therefore, this project has designed an approach to develop a highly customizable system which allows flexibility for users to change the appearance and interfaces.

2.5.4 Rehabilitation act (United States of America)

While European nations and Europe as a whole has been working towards a "Design for All" approach, the United States has remained a strong pioneer on this subject with Rehabilitation Act 1973 which stated that, a person with disability as per the definition in section 705(20) shall not be excluded from an opportunity to participate in, be denied of, or discriminated against under any program or activity which receives Federal financial assistance, Executive agency or U.S. Postal Service(Richards, 1985). Another important act is Telecommunications Accessibility Enhancement Act of 1988 which ensures the full accessibility of all Federal telecommunication systems to individuals with hearing and speech disabilities. While "Tech" act of 1988, which was amended in 1998 as "Assistive Technology Act of 1998" which stated that the accessibility to assistive technology for all those disabled would be provided through comprehensive statewide programs to provide technological alternatives to various disabled people of all ages which will help those disabled through funding, training and ease of access(ETSI, 2002).

2.5.5 EC Mandate (CEN/CENELEC) - Europe

Recent legislative efforts such as EC mandate 283, which also consists of a European version called CEN/CENELEC Guide 6, has been published to guide standards to become more inclusive using "design for all" approach. ANEC (European Association for Co-ordination of Consumer Visualization in Standards) has also issued its policy statements which addresses the issue of barrier free standardization. Although, European legislative efforts have started to bear fruit in the field of universal design approach, United States of America has been in the forefront with its Rehabilitation act of 1973 with subsequent amendments along with Telecommunications Accessibility Enhancement Act of 1988 and Technology – Related Assistance to Individuals with Disabilities ("Tech") Act (1988). Americans with Disabilities Act (ADA) in 1991 was considered a milestone which guaranteed civil rights of people with disabilities.

2.5.6 British Standard – 8878 – United Kingdom

Another standard which has been developed for accessibility issues is BS8878:2010, which has been designed to provide recommendations in the design and development process of accessible web products. BS8878 has defined web products as any website, web-service or web-based workplace application which includes web-based virtual learning environments, Rich Internet Applications (RIA), "Software as a Service"/Cloud computing services provided through a browser; as well as internet – enabled "widgets". According to BS8878, there is a need to make web products accessible due to three particular reasons:

1. Legal reasons
2. Commercial reasons
3. Ethical reasons

The legal reasons provide a basis to make web products accessible as per the grounds provided through Equality Act 2010 and the Disability Discrimination Act 1995. People with disability occupy a substantial percentage in the world which according to a joint document by World Health Organization (WHO) and World Bank, suggests to around one billion. Along with this, the number of people aged 60 and above has been projected to go beyond 2 billion people by 2050 by the World Health Organization (WHO). These figures show that commercially there is a huge market for accessible web products. From an ethical standpoint, it is important to understand that web products should be easily accessible for everyone who wants to interact with such products. Web products must be able to ensure equality for all the users despite their disabilities or old age, which has been reinforced by the United Nations Convention on the Rights of Persons with Disabilities which includes obligatory procedures for member countries to promote "Universal Design" of products.

BS8878 has been designed for different types of organizations ranging from public to private, non-profit and non-governmental organizations (NGOs), government organizations, local bodies, academic institutions as well as the corporate sector.

2.5.7 World Wide Web Consortium (w3c)

There are many considerations to be made while designing a data visualization according to the universal design approach. According to the W3C (World Wide Web Consortium) (Sullivan & Matson, 2000), several standards have been developed to ensure accessibility issues surrounding the entire process of design, development and usage of web technologies as well as hardware assets. To give an introduction, there are 4 major principles called Perceivable, Operable, Understandable and Robust under which WCAG 2.0 (Web Content Accessibility Guidelines) has been developed. WCAG 2.0 is developed for web content developers, accessibility assessment specialists and authoring tool developers. Another important standard is ATAG (Authoring Tool Accessibility Guidelines) which has been developed to make development tools accessible subsequently making the products developed using those tools accessible as well. UAAG (User Agent Accessibility Guidelines) has been focused on accessibility issues pertaining to contents which are triggered through events, rendering of such content, inclusion of assistive technologies and user interface management. WAI-ARIA (Accessible Rich Internet Applications) is responsible for addressing accessibility issues surrounding dynamic content including various development technologies such as Ajax, HTML, and JavaScript etc.

WCAG 2.0

World Wide Web Consortium [W3C] and Web Accessibility Initiative [WAI] in collaboration with many partners produced Web Content Accessibility Guidelines [WCAG]. WCAG [sic] can be accessed and used by anyone who wants to make web contents accessible. As mentioned above, WCAG [sic] consists of four principles and under these principles there are many guidelines which have relevant success criteria and techniques to implement them.

Principles: There are four principles in WCAG [sic] 2.0 which are described in brief below:

- Perceivable: This is the first principle of WCAG [sic] 2.0. It suggests that the website must present the information in multiple perceivable methods engaging different senses so that the information can be transferred to the users with any impairment.

- Operable: Web interfaces and navigation services must be easily operable by users.

- Understandable: The information displayed on the web as well as the use of web services and interfaces must be clearly understandable.

- Robust: The system must be designed and developed keeping in mind various other technologies which might interact with it including assistive technologies and it must also be compliant with new technologies as they evolve.

Guidelines: There are 12 guidelines in WCAG [sic] which are to be followed by developers and designers to develop accessible web contents. The guidelines are divided within the four principles to make them easily understandable by the developers and designers.

Success Criteria: Every guideline consists of certain success criteria. These success criteria are the parameters which confirm that the web contents are in compliance to the guidelines in WCAG 2.0.

The legislations and guidelines mentioned above in section 2.5 are developed to assess and govern the inclusion of accessibility features. They help to ensure equal participation for all the users irrespective of any disabilities or age factors. In this project, the data visualization is developed adhering to these standards and legislations.

Conclusion of Chapter 2:

In this chapter, various literatures relevant in the context of this thesis and universal design were discussed. Some of the previous researches in the field of mobile application development especially mHealth [sic] apps and their several feasibility factors related to seven principles of universal design were also discussed. Finally, the guidelines, principles and legislations related to universal design which affect the design and development of our data visualization were also briefly discussed in this section.

Chapter 3

Methodology

Universal access “refers to the global requirement of coping with diversity in: (1) the characteristics of the target user population (including people with disabilities); (2) the scope and nature of tasks; and (3) the different contexts of user and the effects of their proliferation into business and social endeavors”(Stephanidis & Savidis, 2001).

User interaction design in the context of mobile devices is still a difficult issue to address(de Sá & Carriço, 2008), especially when it comes to ubiquitous nature and small screens of such devices. Another issue comes from the design and development process where important stages such as prototyping and evaluation are overlooked. The authors of this article have tried to highlight some of the issues which they discovered when developing a psychotherapy application for mobile devices. They used common UCD (User Centered Design) methodologies. They especially discovered errors with the design teams in every stage of the project particularly affecting the analysis and requirements gathering, prototyping and evaluation stages. In the requirements gathering stage, user centered methodologies such as ethnographic sessions, user observation and interviews were used. However, when designing pervasive mobile systems, these methodologies were found insufficient(de Sá & Carriço, 2006). Due to ethical issues such as privacy of information, methodologies such as contextual inquiries and ethnographic sessions were difficult to apply. These issues had implications on the design process, especially using scenario-based simulations in which a set of activities were performed under different conditions. However, this process was incomplete and too artificial. Therefore, the process did not provide important information.

During the prototyping process, the use of simple cards or paper were found to be inaccurate in terms of measurement of screen sizes of mobile devices as well as the user interface components. There were also issues regarding the deterioration of paper based prototypes. In terms of evaluation of systems, it is preferred to perform evaluations with a working software prototype however, it is also true that it takes some time to create working software prototypes(de Sá & Carriço, 2006). Testing with low-fidelity prototypes can be inaccurate and mislead the results, therefore, prototyping with a running software prototype can be beneficial.

Another issue related to evaluation and prototyping is the lack of software prototyping frameworks for mobile devices(de Sá & Carriço, 2006). Some automated testing and data collection tools have been designed. MyExperience(Froehlich, Chen, Consolvo, Harrison, & Landay, 2007) is one of those tools. However, there are still several issues concerning user experiences. Some of these issues highlighted in the paper are related to disruption of calls caused by surveys triggered automatically, phone calls getting abruptly halted, CPU overhead leading to delays in key presses and stuttering ring tones. Therefore, automated testing systems are far from perfect. MyExperience [sic] lacked a visualization technique to help researchers visualize event streams of qualitative and quantitative datasets for analysis and since MyExperience[sic] did not possess a front-end tool, researchers need to learn XML to use it.

Other approaches such as trans-generational design (Miller, 1996) and rehabilitation design (Hewer & Kingsland, 1995) are specific to design for elderly and specific impairment types respectively. Both of these approaches only target specific population groups or impairment types (Keates & Clarkson, 2003).

From the literature survey and a comprehensive study of other researches, two-step methodology (unified methodology) is selected to develop and evaluate the new prototype. While requirements gathering process is very important, several issues have been raised in literatures while conducting this process. In order to curb some of these issues, I have used two approaches for requirements gathering; first approach was to use the results of the preliminary usability testing conducted by the Norwegian Computing Center, the second approach was the mixed usage of personas and user stories. This was also done in combination with a heuristic evaluation (Kjeldskov et al., 2005) of the previous data visualization which provided valuable information regarding the features and performance abilities of the application in general. After the requirements gathering process was concluded, the results were used to design and develop a running mobile version of the prototype.

As mentioned in above literatures(de Sá & Carriço, 2006, 2008), it is recommended to use a running and functional prototype for testing therefore, I have designed a running prototype for specific testing purposes. An experiment involving 18 participants and the running versions of old and new prototypes was conducted at the final stage of the evaluation. This was done to involve the users throughout the design and development process. In our design and development process, users have been directly and indirectly involved since the beginning and until the final prototype is delivered.

Cognitive walkthrough is another methodology which is continuously used in the engineering and development community(Polson, Lewis, Rieman, & Wharton, 1992). It is a review process which focuses on ease of learning. It is especially targeted for development of such systems which must be explored by users to learn about its various features. Cognitive walkthrough has same basic organization and rationale as other kinds of design walkthroughs, such as architecture walkthroughs, functional requirements walkthroughs, document walkthroughs and code walkthroughs(Fagan, 2002; Polson et al., 1992).

One particular fallacy of methodologies related to ease of learning is that they are performed late at the end of the design and development process which means that solutions for serious problems can cause extensive delays due to revision and improvements on the entire application. However, Cognitive walkthrough can be implemented at any point of the design and development process. One particular challenge is the use of cognitive theory to design real systems. Many theoretically-based design methodologies have issues when it comes to transferring that methodology for practical use in design and development. Similarly, cognitive walkthrough is also a less tested theory when it comes to practical use and numerous unsuccessful attempts have been made to apply cognitive theory in designing usable systems(Bennett, 1984; John M Carroll & Campbell, 1987; John Millar Carroll & Kellogg, 1989; Polson et al., 1992). Among these attempts the well known and quite controversial ones are GOMS model (Card, Newell, & Moran, 1983) and CCT (Cognitive Complex Theory) (D. Kieras & Polson, 1999; D. E. Kieras, 1988). They can make quantitative predictions of performance time and CCT can especially predict training time as well, but they are not capable of substituting the cognitive walkthrough since they cannot reveal problems which might be caused by errors of judgments or conceptions.

ORIENT (Antona, Mourouzis, & Stephanidis, 2007) is a universal access evaluation framework based on conceptual and evaluation framework which has been designed for design and delivery of interactive systems. It employs the walkthrough inspection method through form-based instrument.

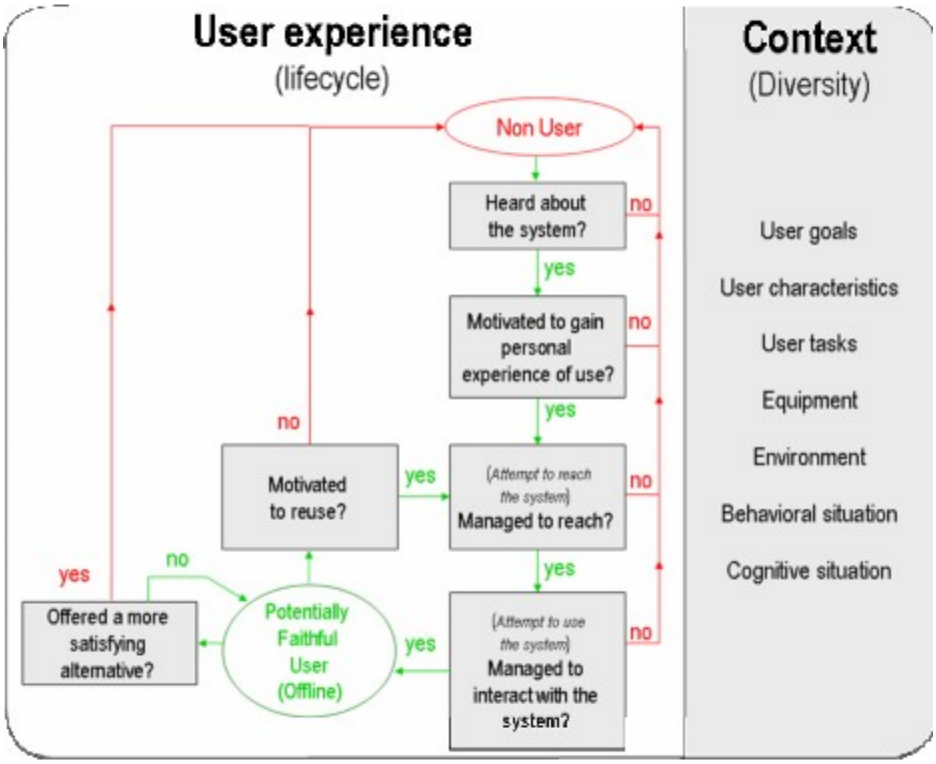

Figure 18: Evaluation Framework "ORIENT"

Retrieved from: Antona, Mourouzis, & Stephanidis (2007), *Towards a Walkthrough Method for Universal Access Evaluation,* Foundation for Research and Technology – Hellas (FORTH), Institute of Computer Science, Heraklion, GR-70013, Greece 2 University of Crete, Department of Computer Science

ORIENT (User Orientation inspection) is an evaluation framework instrument designed to assess the usability and accessibility of various systems throughout the user experience lifecycle as demonstrated above in Figure 17. It depends upon the cognitive walkthrough methodology as well. However, it was developed as a manual tool and caused problems related to redundancy. When multiple inspectors use ORIENT to inspect a common system, the issue of redundancy is generated. This issue can be addressed by creating an online tool support to conduct assessment experiments (Antona et al., 2007). Another issue is the lack of user involvement.

Although this framework is capable of assessing usability and accessibility issues, it lacks in terms of user involvement.

There are various challenges when it comes to application of universal access concepts into mobile computing such as: small screen size, limited input capabilities, limited and relatively expensive bandwidth, limited connectivity, limited computational resources, limited power (batteries), and a variety of devices(Billi et al., 2010). Other issues related to context and interaction such as: variable context, type of interaction, interruptions, privacy and security, intimacy and availability are also present(Billi et al., 2010).

According to Fordist (Billi et al., 2010) and Taylorist (Billi et al., 2010) models of human activity, human behavior can be broken down into structured tasks. HCI (Human Computer Interaction) depends on this idea. Evaluation methods in HCI often rely on measurements of task performance and task efficiency (Billi et al., 2010). However, such measurements might have issues related to universal applicability as the evolution of computers from desktops to ubiquitous computing.

In this context, unified methodology (two-step methodology) seems to be a viable option to use. It has two steps: Accessibility evaluation conducted since the beginning of the project followed by usability evaluations. This is done to avoid overlap of two different evaluations. Accessibility evaluation is conducted to assess the accessibility issues for specific user group. The assessments are made over the tasks. Heuristic evaluation is one of the widely applied techniques for evaluation purposes (Bertini, Gabrielli, & Kimani, 2006). However, it becomes especially difficult for mobile devices, therefore, new concepts of heuristics are developed such as ambient heuristics (Mankoff et al., 2003) andgroupware heuristics(Baker, Greenberg, & Gutwin, 2001). As suggested by Vetere et al., “Mobile Heuristic Walkthrough” is used in the evaluation process in this thesis(Vetere et al., 2003). This is a hybrid evaluation technique which combines Heuristic evaluation and Cognitive Walkthrough. Such tailored heuristic is used to reduce any “cosmetic noise” that is often prevalent in expert evaluations such as heuristic evaluations (Kjeldskov et al., 2005).

Therefore, an important aspect of developing accessible applications is an early assessment of the design and development process to direct it towards universal design concepts. Accessibility features must be incorporated into the application development process from the beginning, and not after the completion of the development process. This can be achieved through guided inspection conducted with selected users and integrated by an expert evaluation performed using an adaptation of the Web Accessibility Initiative guidelines (Billi et al., 2010). Two step methodology (Billi et al., 2010) is focused on incorporating universal access in the entire design and development process from conception to conclusion. The unified methodology consists of two phases. First, the accessibility evaluation is conducted on an unrefined product with users performing specific tasks which are integrated with an expert evaluation such as Heuristic evaluation. Second, a secondary usability assessment is made on a more refined product using heuristic evaluation.

The two step methodology:

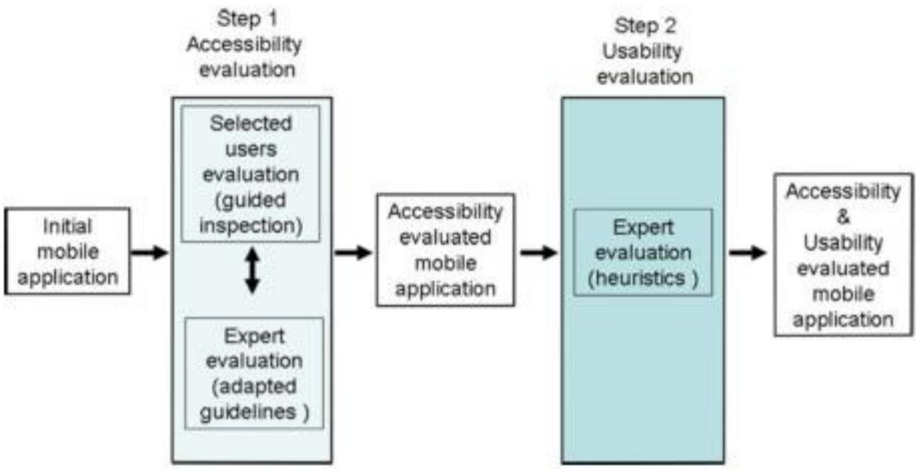

Figure 19: Two Step Methodology

Retrieved from: A unified methodology for the evaluation of accessibility and usability of mobile applications, M Billi, L Burzagli, T Catarci, G Santucci… - Universal Access in the …, 2010 – Springer

This two step methodology is used to develop our data visualization where the accessibility evaluation through testing of the application with potential user group as well as a heuristic evaluation was followed by a usability evaluation through heuristics evaluation process at the end. The users were the four participants involved in the user testing for Norwegian Computing Center. The user testing information collected by the Norwegian Computing Center was used to create personas to involve users since the initial stage. A comprehensive user testing was not done in this thesis at the beginning since the users were not made available. Therefore, the secondary data from previous user testing was used to create personas to follow user centered design approach.

Finally, an experiment is conducted among users to compare the two prototypes. At the end, a heuristic evaluation is done on the new prototype and improvements are made over the issues that are discovered before the final prototype is delivered.

The accessibility issues of the mobile application can be addressed in two ways.
1. Technological Standards:
The first way to address accessibility issues is from the technical and technological standpoint to find out accessibility issues within the application and solve those issues to make the application more inclusive. For example: WCAG 2.0 guidelines on mobile accessibility, WAI-ARIA
2. Management and Logistical Standards:
The second way is to find out the management and logistical procedure that need to be followed in order to deliver an accessible product based on standards as mentioned above such as ETSI (European Telecommunications Standards Institute). The current data visualization can be improved by adhering to the standards set by W3C for accessibility.
An evaluation study is the preliminary phase that will provide us with some relevant improvement procedures which is followed to design a new concept for data visualization. The new data visualization prototype must also be designed according to the Universal Design standards.

In this part, we will investigate how the contents of the mobile application can become more accessible for its users. We want to investigate the possible solution to the data visualization problem in the RevmaRApp [sic] mobile application. RevmaRApp [sic] is a mobile application which is used by arthritis patients to record their daily activities. It is not a sensor-based automated system therefore; the users need to enter their data themselves. Through this application it is possible for the medical personnel to track activity details and find any links between activities and affects of such activities on the patients. Therefore, here we will investigate what the developer can do when developing web applications like this to make it more accessible for all its stakeholders.

Based on the suggestions obtained from this investigation, a list of possible improvements, required on the existing data visualization is established. These suggestions will be important to complete the main objective of designing the new concept of data visualization. The focus will be on users that are diagnosed with rheumatoid arthritis varying on the degree of severity.

Everyday more and more information gets published on the web, this is a positive trend. “The right of access to information and ideas is vital for any society” (Vijayakumar & Vijayakumar, 2004). Therefore, it is important to contribute to the amount of research that makes information more accessible. We will do this by looking at the various guidelines provided by WCAG 2.0 guidelines on mobile accessibility. Other standards such as ETSI – EG 202 116(ETSI, 2002) and British Standard: BS8878 (British Standard) will also be used to evaluate the process of procurement and implementation. By creating standards, guidelines and legislations like these, the web becomes more accessible. This means that more users including people with disabilities can take part in the ever growing use of the web.

In current context, WCAG 2.0 on mobile accessibility and WAI – ARIA are relevant standards which can be used to create a new prototype. However, all the guidelines mentioned in these standards are not relevant for evaluation of the old data visualization in RevmaRApp [sic]. Therefore some of the relevant guidelines are listed below which can be used to assess the existing visualization and these guidelines must be considered while designing new data visualization as well:

a. WCAG 2.0 on Mobile Accessibility:

WCAG 2.0 has 4 principles and 12 guidelines. These principles and guidelines are the foundations to establish on design and development of various applications.

The following are the four principles:

1. **Perceivable:**
    a. **Small Screen Size:**

Small screen size makes it difficult for people to view entire information at a glance especially when magnification or zoom-in feature is used.

Techniques:

- Minimize the amount of information that is put on each page.
- A dedicated mobile version which can be customized
- A responsive design which can be used to render contents depending on viewport width.
- Provide a reasonable default size for contents and touch control elements to minimize the use of zoom in/out features by users with visual impairments.

b. Zoom/Magnification

Zoom/Magnification is available in two forms.

i. Operating System-level
   - Set default text size

ii. Browser-level
   - Set default text size of text rendered in the browser's viewport
   - Magnify browser's viewport

WCAG 2.0 success criteria that is most related to zoom/magnification is:

WCAG 2.0 Success criteria:

- 1.4.4 – Resize Text (AA) states "text can be resized without assistive technology up to 200 percent without loss of content or functionality"

  Techniques:

- Ensure that the browser pinch zoom is not blocked by the page's viewport meta element so that it can be used to zoom the page to 200%.
- Support for system fonts that follow platform level user preferences for text size

c. Color and contrast

Older users have decreased color and contrast perception capabilities. Since mobile devices are used under different situations such as outdoor, indoor and in motion, people especially with low vision have issues to access contents with poor contrast.

WCAG 2.0 success criteria:

- 1.4.1 – Use of color (A) states that color is not to be used as the only means to convey information
- 1.4.3 – Contrast (Minimum) (AA) requires contrast ratio of at least 4:5:1 for texts and images
- 1.4.6 – Contrast (Enhanced) (AAA) requires contrast of at least 7:1.

Techniques

- G18: Ensure a contrast ratio of at least 4:5:1 exists between text and background
- G14: Ensure the information conveyed from color differences is available in text
- G183: Use contrast ratio of 3:1 with surrounding text and distinguishable visual cues for links and controls
- For mobile platforms, use of text that is 1.5 times the default size on mobile devices does not guarantee that the text will be readable by persons with visual impairments. Under such cases, they may need to use built-in assistive technologies such as magnification, zoom in/out or audio output.

2. Operable

a. Keyboard Control for touch-screen devices:

Mobile devices consist of different interfaces ranging from physical keypads to on-screen and touch-sensitive keyboard interface. These different keyboard interfaces are useful for people with different disabilities including visual, dexterity and mobility.

WCAG 2.0 success criteria that are related to Keyboard Control for touch-screen devices are:

2.1.1 Keyboard (Level A)

2.1.2 No Keyboard Trap (Level A)

2.1.3 Focus Order (Level A)

2.1.4 Focus Visible (Level AA)

b. Touch target size and spacing:

Many interactive elements can be shown on a small screen, however, these elements must be big enough and have enough distance from each other so that they can easily and distinctly target each one of them.

Techniques:

- Ensure that touch targets are at least 9 mm high by 9 mm wide.
- Ensure that touch targets close to the minimum size are surrounded by a small amount of inactive space.

c. Touch-screen Gestures:

Many mobile devices are designed to be primarily operated via gestures made on a touch-screen. Therefore, gestures must be simple and easy to use and learn.

Techniques:

- Gestures in apps should be easy enough to replace touch interactions with screen reader interactions using a two-step process of focusing and activating elements.
- Do not use multi-touch gestures, rather use simple gestures which are easier to perform for people who rely on head pointers or a stylus.
- Activate elements via mouseup or touchend event. This means the element can only be accessed via touch trigger events such as: the user has lifted the finger off the screen, the last position of the finger is inside the actionable element, and the last position of the finger equals the position at touchstart.
- Use touchscreen gesture instructions and suggestions.

d. Placing buttons where they are easy to access:

Mobile application should position interactive elements where they are easily accessible if the device is held in different positions.

Techniques:

- Design applications for one hand use.
- Design for left or right-handed use.
- Implement work around means to allow users to shift the display in multiple ways to facilitate one-handed operations.

3. **Understandable**

   a. **Changing Screen Orientation (Portrait/Landscape)**

   Mobile application must be able to change orientations so that it can be used with assistive technologies.

   Techniques:

   - Make it easy to change the orientation to return to a point at which their device orientation is supported
   - Make changes in orientation automatically detectable by assistive technologies using programmatically exposed means.

   b. **Consistent Layout**

   In responsive designs, component arrangements depend on device size and screen orientations including consistency in placement of repeated components and navigational elements. However, under WCAG 2.0, consistency of components is not a requirement.

   WCAG 2.0 success criteria related to Consistent Layout are:

   3.2.3 Consistent Navigation (Level AA)

   3.2.4 Consistent Identification (Level AA)

   Techniques:

   - Place page elements including navigation components in consistent order relative to the page and screen size
   - Components remain visible even in different screen sizes and orientations and does not collapse into a single button or appear in different orders.

   c. **Position page elements before the page scroll:**

The small screen size on mobile devices limits the amount of content which can be displayed without scrolling.

Techniques:

- Place important elements before the page scroll so that users who use screen magnifiers can locate important information easily.
- Consistent and predictable location of elements especially for users with cognitive impairments or low vision.

d. **Grouping operable elements that perform the same action:**

Multiple elements which perform the same action or direct to the same direction should be contained within same actionable element.

WCAG 2.0 success criteria that is most related to grouping of actionable element are:

1.4.4 Link Purpose (In Context) (Level A)

1.4.5 Link Purpose (Link Only) (Level AA)

e. **Provide clear indication that elements are actionable**

Elements that trigger changes should be sufficiently distinct to be clearly distinguishable from non-actionable elements. Interactive elements must also be detectable using assistive technologies such as screen readers.

WCAG 2.0 success criteria that are most related to grouping of actionable element are:

3.2.3 Labels or Instructions (Level A)

3.2.4 Help (Level AAA)

4. **Robust**

a. **Set the virtual keyboard according to the type of data that needs to be entered:**

Standard keyboard can be customized according to the settings of the device.

Techniques:

- **Provide different virtual keyboards depending on type of data entry.**

- **Provide settings to install custom keyboards.**

b. **Provide easy methods for data entry:**

Users can enter information on mobile devices using multiple ways;

Techniques:

- Use of different modes of input such as on-screen keyboard, Bluetooth keyboard, touch and speech.
- Reduce the amount of text entry needed by providing select menus, radio buttons, check boxes or by automatically entering known information (e.g. date, time, location)

WAI – ARIA:

WAI – ARIA focuses on additional accessibility challenges created by DHTML (Dynamic Hyper Text Markup Language), Ajax and related technologies which are event driven. Such event driven technologies might not be easily available for people with cognitive and sensory disabilities. WAI – ARIA helps to develop accessible web contents and user interfaces which are interoperable in nature along with compatible features for various assistive technologies. In WAI – ARIA 1.1, core accessibility issues is discussed which defines support for multiple content technologies to provide accessibility using keyboard navigation and various WAI – ARIA features. In the current data visualization, there is no usage of WAI-ARIA features to make it compatible with assistive technologies such as screen readers.

4.3 ETSI – EG 202 116

As stated above, this section of the document will address the accessibility issues in the aforementioned two methods. The universal design approaches in terms of technical guidelines is provided in the previous part. In this part, the issues of logistics and procurement of accessible technologies are discussed. To ensure equal participation of all the individuals despite of their age or disability European Telecommunication Standards Institute (ETSI) can provide a basis for procurement and development of an accessible environment. The standards can be maintained as per the policy statements published under ANEC (European Association for the Co-Ordination of Consumer Visualization in Standards), which states that “Products and

Services should be designed barrier free. A barrier free design of consumer products and services is not (or should not be) separate from standard mass market design." According to this, the intended users and the services provided to these users must be explicitly defined. User characteristics vary for every application in terms of:

a. Sensory abilities
b. Cognitive abilities
c. Physical abilities

The legal regulation provided under EU Directive 90/270 on the minimum safety and health requirements for work with display screen equipment has provided an opportunity to adopt Human Centered Design approach for all ICT (Information Communication Technology) equipment.

In a Human Centered Design approach it is important to address the following activities:

1. Defining the context of use
2. Specifying user and organizational requirements
3. Producing prototypes
4. Evaluation of designs

1. Defining the context of use

This can be broken down into four branches:

1.1. Description of users

Our user group consists of two different groups in general. First group is the patients with arthritis which can be further broken down into different groups according to the demographical characteristics such as age, gender etc. as well as medical diagnosis and severity of impairments.

Prevalence of RA varies between 0.3 and 1 percent, while in Oslo, Norway from 1991-94, there were 437 RA patients per 100,000 aged between 18 to 79 (Symmons et al., 2003).

In the user testing that was conducted by Norwegian computing center, there were four participants in total who were recruited from the Norwegian Rheumatoid Association.

Second group consists of the medical personnel who interact with the patients and the mobile application.

1.1 Description of tasks

In order to understand the different types of tasks to encounter, we must be able to understand the user groups in detail.

In the application, the activities have been divided as:

1. Activity Regulation
2. Activity Balancing
3. Mapping and Regulation of Activities
4. Surveying daily activity
5. Activity Registration and balancing
6. Equilibrium

   Under these different activity groups, there are several individual activity lists. These lists consist of more individual activities such as eating, drinking, gardening, household chores etc. Information regarding such activities can be provided by answering further questions about the activity and through reflection of the task. This input of information is the origin of data for the application which needs to be secured and stored. Such data can then be represented using the data visualization technique which is addressed further in this document.

1.2 Description of equipment

As per the regulations, the equipment in use must be described. In our context, the hardware system consists of Apple mobile devices including cell phones and iPad compatibility. Similarly, the application is compatible with Apple's operating system for the mobile devices.

The new visualization prototype is developed to be compliant with Android devices as well.

1.3 Description of environments

A detailed description for the environment can be addressed later in this document. Under current circumstances, the mobile application is to be used by patients while at home, work or travel in order to record data on daily activities performed by them. The daily activities can be household duties or tasks related to the employment of users. This data can be forwarded to the health personnel who can make an assessment regarding the data by reviewing them.

2.1 Specifying user and organizational requirements

ISO13407 states that relevant user and organizational requirements must be considered.

a. Health and Safety issues must be addressed as per the relevant legislative requirements
b. Co-operation and communication between patients, health personnel, programmers, designers, testers must be established
c. The new system or mobile application must meet the operational and financial objectives
d. Performance testing must be observed and logged
e. Training and necessary documentation must be provided for all user groups
f. Human computer interface and interaction must be substantially incorporated

3.0 Producing prototypes:

Prototyping is the crucial part of the entire development and design process. The prototype in this thesis consists of a mobile application for data visualization which is designed iteratively. A user testing is done for some parts of the mobile application. During this development phase of the prototype it might be helpful to use personas or role-play to simulate the necessary steps required to complete the tasks. Such simulations can be cost effective than user testing strategies in the development phase. However, in the final evaluation user testing can be implemented as well.

4.1 Evaluation of designs

In ETSI, a usability checklist was created in January 1995 to assist evaluation of technologies for people with special needs. According to this list, the users with various impairments are categorized under different groups. However, as per our study they fall under “**people with reduced mobility and strength**” category.

4.2 Subjective Assessment:

A subjective assessment can be carried out for this project which can involve patients diagnosed with arthritis of different demographic varying in age, gender and severity of their impairments. Such subjective assessment can provide valuable information regarding the usability factors of the mobile application and human-centered design.

According to the concept of human-centered design, I will conduct these three assessments on both the data visualizations.

4.2.1 Heuristic evaluation:

The visualization which is already available in RevmaRApp is first evaluated by the heuristic evaluation method. This method is selected because it is suitable for early design and development process for iterative designs. The results obtained from this heuristic evaluation is analyzed and based upon these results a new data visualization is created.

4.2.2 Usability testing:

The usability testing can provide details regarding the performance and the preferences of the users. It is viable in terms of its validity on a sample user group for a sample amount of tasks which can be analyzed.

For our particular project, a method using experiments can be beneficial since it relates to the tests being observed in a real environment where the patients can provide information regarding the mobile application through their personal experiences in different real life situations. It also provides a suitable format to test the hypotheses mentioned in section 5.1.2.

4.2.3 Semi – structured interviews:

A semi-structured interview of the participants is conducted after the experiments are completed. The interviews are conducted to provide further in-depth analysis of their experiences using the two data visualizations. The participants can provide further explanations about their user experiences while using both data visualizations.

b. Design issues to consider:

These technical suggestions provided by ETSI, WCAG 2.0 etc. that are discussed below are followed to solve some of the issues regarding design and data visualization processes:

a. **Color**

Recommendations:

1. Avoid using colors from opposite ends of the spectrum. For example: Red and blue
2. No more than five colors must be used
3. Existing color conventions must be understood and adhered. For example red for danger, blue for cold.
4. Shades of colors such as blue, green and violet must not be used, because elderly population have difficulties to understand and interpret them.
5. Contrasting background and foreground combinations must be used to make them distinct form one another.
6. Extremely dark and extremely light colors must not be used.
7. Glossy design of colors must be avoided rather use a matted version of colors to avoid reflective illusion errors.
8. Especially for users with visual impairments, it is necessary to use contrasting background and foreground combinations which must be simple color combinations without the use of gradients. For example: White on black or blue background.

b. **Graphical user interface(GUI)**

Recommendations:

1. A meaningful visualization medium must be selected to be used as a metaphor describing user's tasks.
2. Visual elements and icons must represent specific things on screen and must not be redundant.
3. Immediate feedback of actions must be provided as results of such actions to ensure direct manipulative control on the GUI elements.

4. Destructive actions such as deletion of data must only be performed with a secondary confirmation mechanism.
5. Actions performed using GUI elements must be reversible.
6. It is important to provide Help information on elements to allow the user to understand their intended actions once such elements are activated.
7. Consistency of the GUI elements must be established to ensure conformity throughout the application.

c. Form fill-in dialogues:

Recommendations:

1. It must only be used when a large amount of data entry is required.
2. It is applicable for different kinds of users varying in experience and frequency.
3. Logical grouping of related fields is necessary for convenience and to avoid cognitive overload, which can be achieved by grouping related fields adjacent and a space should be used to separate groups from each other.
4. Layout must be aesthetically pleasing and clear.
5. Uniform distribution of fields must be used rather than cramming one part of the display with all the fields and leaving remaining parts vacant.
6. A maximum number of characters to be entered into the fields must be indicated to avoid any excess of input.
7. Fields must be categorized as mandatory and optional and a distinction of such must be indicated for the users.
8. Any field which requires the data to be entered in a specific format must be indicated and a sample of the required input format must be provided. For example: An input field which requires a specific date format.
9. In case of time-stamp input, it is important to use AM/PM format to avoid confusion.

10. Titles used to represent the fields must be clear and concise.
11. Consistency of fields is another important factor to address, in order to avoid any miscommunication.
12. If required, default values can be provided in the form fields to save the time of the users while filling the forms.
13. Measurement units such as Kg. or Km. can be pre-defined to specific fields to avoid any miscommunication of quantitative values.

d. Output

Recommendations:

1. Selection of appropriate output medium as per the requirement of the task is necessary.
2. Provisions for alternative output mediums must be established to compensate for any disabilities.
3. Output design must meet with technical standards set forth by various documents for example WCAG 2.0.
4. Compatibility with alternative output technologies such as assistive technologies must be maintained as well.
5. Graphical elements must be of high quality which has a rapid display rate to show digitized visual images.

e. Visual Display output for small screens:

Recommendations:

1. Flat panel display must conform to ISO 9241-3(ETSI, 2002).
2. Sufficient display space must be allocated to avoid any miscommunications and to provide ease of access.
3. In case of LCD (Liquid Crystal Display) devices, backlight must be used in a low ambient light setting.
4. Abide by the national language conventions, where uppercase is used at the beginning followed by lower case letters.
5. Error recovery display messages must be clear and concise for the users to understand.

6. Legibility and reading rates gets diminished directly in proportion to the amount of lines that can be displayed on screen. For example: Reading rates for 1 and 2 line displays can be slower than those for 20 line displays.

f. Graphics and textual contents in visual displays:

Recommendations:

1. For capital letters, character height may be calculated as subtending 20 to 22 minutes of arc at the reading distance as per requirement. An optimum range of 3,8 mm to 4,5 mm is suggested as letter height for easier legibility(ETSI, 2002).
2. The width of character should be 50% to 80% of character height and the stroke width must be 8% to 20% of the character height (ETSI, 2002).
3. To display numeric information, 7 or 9 segment displays are acceptable.
4. Ideally line spacing should be 1,5 to 2 times the space between words on a line.
5. Character and background contrast ratio must be 3:1 as a minimum (ETSI, 2002).
6. Use of familiar typefaces without any styling options such as italics, decorative fonts and designs is encouraged for use.
7. If the amount of text is more than the available screen space then a scroll option should be provided which can be controlled by the user.
8. Graphical elements such as animations are an easy means of grasping attention of users so they must be designed to be visually stimulating.
9. Symbols or graphical elements when used must adhere to international conventions as prescribed under ISO symbols ISO7000, ISO7001, IEC symbols for equipment(IEC 60417)(ETSI, 2002).

Conclusion of chapter 3:

In the first part of this chapter, I have discussed several methodologies which have been used to evaluate and develop universal designed systems with user centered approaches. From the literatures, it is shown that all of the methodologies have various features and they have different advantages and disadvantages. However, among these different methodologies, in this thesis two-step methodology (unified methodology) is suitable. The second part of this chapter discussed about various accessibility issues as well as various techniques to determine and evaluate accessibility issues. Relevant technical and logistical guidelines were also explained such as WCAG [sic] 2.0 for mobile accessibility and ETSI [sic] respectively. In the next chapter the details of the use of personas in this thesis as well as the user testing conducted by the Norwegian computing center are further discussed.

Chapter 4:

Requirements Collections Methods:

The Norwegian computing center had conducted a user testing which generated some important and interesting results. The details regarding user testing and the results from the testing as well as some relevant literature and procedures are described further in the first part of this chapter. In the second part of the chapter, personas are developed from the testing information for the four participants who were involved in the user testing conducted by Norwegian Computing Center. Therefore, the first step of requirements gathering process involving the users is explained in this chapter.

The first step towards design and development is to understand the users and usage context. Therefore, a set of requirements or specifications is gathered initially. However, the requirements can change as the development activities are continuous until the delivery of the final product. Normally general population is divided into demographics such as age, gender etc, however for design and development purposes, a different kind of partitioning is suggested by the nature of human-product interaction (Keates & Clarkson, 2003). The human-product interaction is divided into three distinct stages – perception, cognition and motor functions(Card et al., 1983). This method divides the population in terms of abilities to perform certain functions.

Although a product is normally designed for WHOLE POPULATION [sic] (Keates & Clarkson, 2003), in reality there will be certain limitations in terms of context of use, user-preferences, legislative and safety requirements etc (Keates & Clarkson, 2003). After removing those who have limitations as mentioned above, the resulting population is called IDEAL POPULATION [sic] (Keates & Clarkson, 2003). From this IDEAL POPULATION we can draw the requirements and design products. After the product or prototype is developed, its physical properties might be actually usable by a certain group of population referred as INCLUDED POPULATION [sic] (Keates & Clarkson, 2003). However, as mentioned above the requirements can change until the delivery of the final product. Therefore, as the requirements evolve the population changes as well. This population is referred as "NEGOTIABLE MAXIMUM

POPULATION” [sic] (Keates & Clarkson, 2003). These changes consequently affect the target population which makes it difficult to conceptualize target population without understanding who is defining the target population and what the definition is (Keates & Clarkson, 2003).

To summarize:

- WHOLE POPULATION – everyone
- IDEAL POPULATION – the maximum achievable
- NEGOTIABLE MAXIMUM POPULATION – everyone included by the specifications
- INCLUDED POPULATION – those who can actually use the product
- TARGET POPULATION – those who were intended to use the product. (Keates & Clarkson, 2003)

Figure 20: WINIT Scales

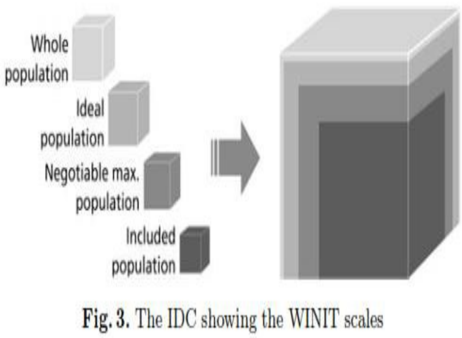

Figure 21: IDC (Inclusive Design Cube) showing WINIT scales

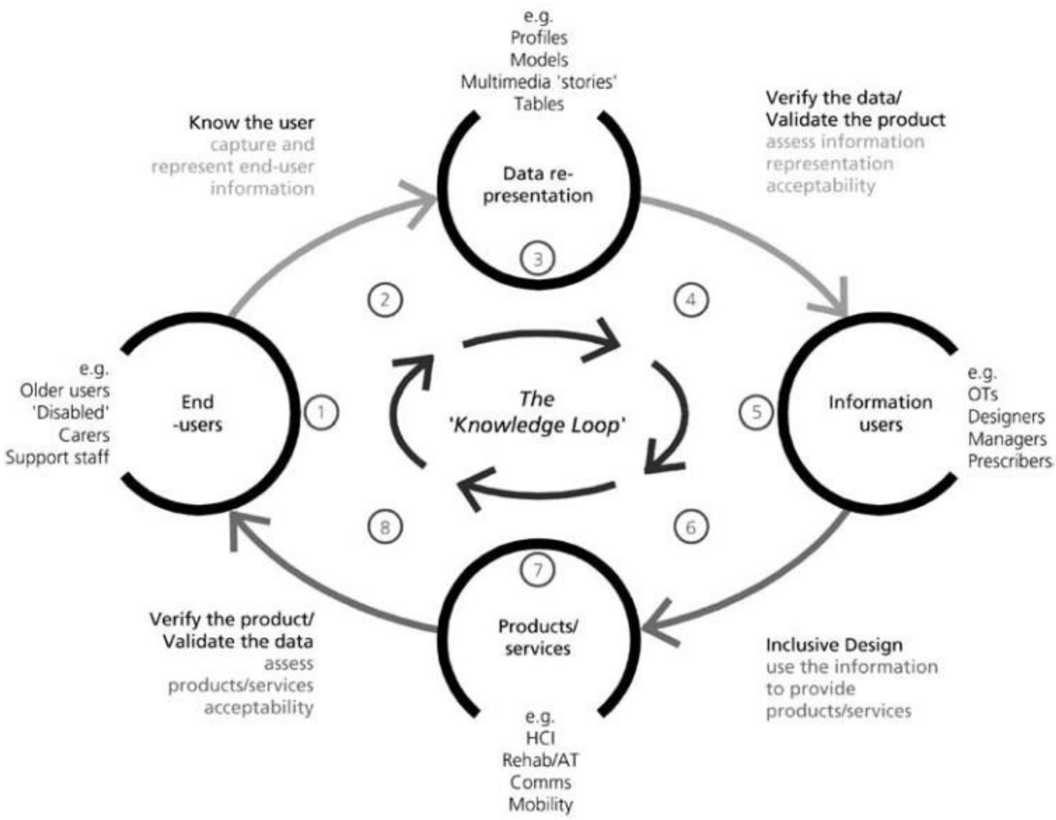

Figure 22: Inclusive design knowledge loop

The knowledge loop represents the flow of information and completion of activities to produce a inclusive designs. Besides focusing on the users who are elderly and those with disabilities, it looks at the broader prospect of end-users. Based on the perspective and requirement, the loop can be entered at any point. From the perspective of capturing data about the end-users the following steps can be taken:

1. Identify potential data capture techniques.
2. Apply the techniques to generate suitable data representations
3. Verification of the generated data
4. Data passed to Information User
5. Application of data to check validity and usability of data by the information user
6. Generate, prescribe products, services
7. Verify the data observed with the needs and validate data-capture methods.

4.1 Information obtained from User Testing from Norwegian Computing Center:

The Norwegian Computing Center had conducted a user workshop to conduct a user testing for RevmaRApp on October 8, 2015 from 15:00 – 17:00.

Following are the details and analysis of the user trial workshop:

There were two conductors of user trial workshops:

1. Kristin Skeide Fuglerud
2. Trenton W. Schulz

There were 4 participants in total, who were recruited via The Norwegian Rheumatism Association.

The user trial was conducted for the entire application and it tested all the functionalities within RevmaRApp. This trial was conducted using iPhones and iPads. However, for this thesis, we are more concerned about the data visualization therefore, only the results related to the data visualization is included further in this document.

Summary of results from the User Trial:

1. Some people had difficulty to interpret graphical visualization in RevmaRApp.
2. Textual labeling for the axes to explain what they stand for is needed.
3. Graphical icon at the bottom menu is grey in color which might be interpreted as inactive. This caused some confusions.
4. Overall difficulty to understand symbols and graphs.
5. Users were completely unable to understand the quadrant results.
6. The colors did not explain anything therefore a better explanation of what the colors represent is needed.
7. Further explanation about all aspects of graphical visualization is necessary.

4.2 Personas:

Development of software applications must be based upon the requirements of the users. The main goal of using personas is to understand the specific needs of end-users (Cooper, 1999). Personas are created with a seven step process. First of all, the characteristics of users must be identified which in our case was done by interviews and usability testing conducted by the Norwegian Computing Center which is described in above section. From such characteristics, behavioral variables are selected and a pattern of variables which have similarities are combined to form a group. In our case, the similarity was the presence of rheumatoid arthritis in all four participants. The initial characteristics of personas are created from the information derived from user testing conducted by the Norwegian Computing Center. For each persona, a goal is also created along with a narrative which consists of a short storyline.

Although personas are fictitious, their characteristics and goals are based on real end users, and these characteristics are collected and analyzed from various research and data collection techniques such as interviews, user testing and surveys. Similarly, in this thesis, personas are based upon the data obtained from the user testing which was carried out by Norwegian Computing Center as described in section 5.1.

Criterion	Procedure Definition		Product Formalization	
Steps of the Personas technique[8] / Characteristic	What?	How?	Product Content	Product Structure
Step 1: Identify Behavioural Variables	Semi-explicit	Semi-defined	Semi-defined	Semi-formal
Step 2: Map interview subjects to behavioural variables	Explicit	Undefined	Semi-defined	Informal
Step 3: Identify significant behaviour patterns	Semi-explicit	Semi-defined	Undefined	Informal
Step 4: Synthesize characteristics and relevant goals	Explicit	Semi-defined	Semi-defined	Informal
Step 5: Check for redundancy and completeness	Explicit	Semi-defined	N/A	N/A
Step 6: Expand the description of attributes and behaviours	Explicit	Defined	Defined	Semi-formal
Paso 7: Designate persona types	Explicit	Defined	Semi-defined	Informal

Figure 23: Seven step process of persona creation,

Retrieved from: Integrating the Personas Technique into the Requirements Analysis Activity, by J. W. Castro ; Dept. de Ing. Inf., Univ. Autonoma de Madrid, Madrid; S. T. Acuña; N. Juristo, Computer Science, 2008. ENC' …, 2008 - ieeexplore.ieee.org.

Anna:

Anna Thompson is a 62 year old woman. She worked as an accountant for 30 years before retiring a few years back. At the age of 62, she still likes to remain active throughout the day. She likes to work in her garden and kitchen. She lives alone at home. She likes to remain independent.

Anna has rheumatoid arthritis; she also has age-related macular degeneration. Throughout the years, her arthritis causes her pain during movement of joints and morning stiffness. She also has swelling of the joints on most of the days. Therefore, she cannot work in her garden as much as she would like to. Although her arthritis has gotten worse, her macular degeneration is also giving her trouble as the years have passed. She likes doing cross-word puzzles on her mobile phone which was given as a Christmas gift by her son. She needs to use the magnifier to see the words. The stiffness in her hands is becoming worse and she cannot use small devices such as mobile devices to type text message. She can only type short messages and cannot use the letters on the keypad properly.

She lives alone at home but she likes to remain in contact with her friends and family. She likes to talk to her son who lives in another city. She uses the mobile phone to call her son or message him. But she cannot easily use the dial pad or type text messages. Her doctor has asked her to use RevmaRApp, to monitor her daily activities for a period of 7 days. The doctor installs RevmaRApp into her mobile phone. She uses the registration of activities to register new activities but she does not find any instructions on how to do them. She looks at the graphical visualization in RevmaRApp to find an overview of her activities but she cannot interpret the information as she does not understand the meanings of symbols, colors and the graph since there are no descriptions or labels. It is frustrating for her to see that the smaller squares shown on the visualization are difficult to touch and interact and because of her arthritis complex touch gesture operations such as pinching and double tap is difficult.

Table 1: Daily tasks for Anna

Personas Table 1: Daily tasks performed by Anna for a period of 7 days					
List of Tasks	Importance	Energy	Motive	(how many times a week)Frequency	Time
Personal Hygiene	Very Important	High	Duty	7	7:00 AM
Prepare and Eat Breakfast	Very Important	High	Duty	7	8:00 AM
Reading Newspaper	Mild Important	Normal	Pleasure	5	9:00 AM
Cooking Meal	Very Important	High	Duty	7	10:30 AM
Working in Garden	Very Important	Low	Pleasure	3	1:00 PM
Watching Television	Not Important	Low	Pleasure	7	3:00 PM
Listening to Music	Mild Important	Low	Pleasure	7	4:00 PM
Cooking and Eating Dinner	Very Important	High	Duty	7	5:00 PM
Going out for a walk	Mild Important	Low	Pleasure	5	7:00 PM
Driving a car to go shopping	Very Important	Low	Duty	5	Varies

Henry:

Henry is a 55 year old man. He lives at his house with his wife. He has been suffering from rheumatoid arthritis for a period of almost 10 years. His arthritis has also affected his eye and he has a condition called Uveitis which is a disease causing swelling and irritation of uvea of the eye. He has strong sensitivity to light, severe pain at random including blurry vision. He uses steroid and non-steroid eye drops, which provides some relief. He also speaks and understands, only Norwegian language so he needs the mobile application to have Norwegian language settings as well.

Henry also works as a consultant for a sales company. He has to prepare reports for the company and design charts and graphs for them. Because of his arthritis, he has difficulty completing household chores as well as professional tasks at the office. He likes to clean the house and do some carpenter work to build furniture in his garage. When at office, he uses magnification tools with his computer and laptop to create reports, graphs and charts for his company.

He has symmetrical arthritis in both of his wrists and protruding bony nodules in his right hand fingers. After a visit to his doctor, he was asked to use the RevmaRApp to record his daily activities for a period of seven days. He is quite familiar with mobile phones and iPads so he installed RevmaRApp and started using it.

He understands that he needs to register his activities but he does not find any information on what details must be recorded. He also finds it difficult to delete activities once they are stored. He also discovers that the change of activities from red activities to green activities is not normally updated and this update only occurs after the user goes to the period overview. He also does not receive any overview regarding new period. The quadrants used in the visualization are not explained and therefore it is difficult for him to understand what the quadrants are supposed to represent. The icons are difficult to interact with because of their size. The color of the menu is also misleading since grey color is used to represent inactive buttons it becomes confusing for him sometimes.

Table 2: Daily tasks for Henry

Personas Table 2: Daily tasks performed by Henry for a period of 7 days					
List of Tasks	Importance	Energy	Motive	(how many times a week)Frequency	Time
Personal Hygiene	Very Important	High	Duty	7	7:00 AM
Prepare and Eat Breakfast	Very Important	High	Duty	7	8:00 AM
Reading Newspaper	Mild Important	Normal	Pleasure	3	Varie s
Driving a car	Very Important	High	Duty	7	09:00 AM
Doing Laundry	Very Important	Normal	Duty	4	Varie s
Watching Television	Not Important	Low	Pleasure	7	Varie s
Listening to Music	Mild Important	Low	Pleasure	7	Varie s
Cooking and Eating Dinner	Very Important	High	Duty	7	5:00 PM
Going out for a walk	Mild Important	Low	Pleasure	5	7:00 PM
Working on reports, presentations for work	Very Important	Medium	Duty	5	Varie s

Jackie:

Jackie is 58 year old woman. She was diagnosed with rheumatoid arthritis 8 years ago. She is also suffering from cataract which is a commonly seen in patient with rheumatoid arthritis. She works as a deputy manager in a company. She is familiar with computers and mobile devices as she has to use them to check her emails, prepare reports etc.

She has blurred and brownish tint to vision which creates difficulty for her to understand and interpret colors at times. This causes severe problems for her when creating charts or diagrams and she needs help from others to distinguish colors at times.

The joints of her wrist and MCP(metacarpal phalanges) become difficult to use. This does not affect her from doing non-strenuous household work or using computers for a short period of time or writing. She especially has trouble using her mobile phones or touchscreen devices which have small screens . She finds it difficult to interact with small icons such as radio buttons or checkboxes.

As a deputy manager, she has to use her mobile phone for various purposes including making calls, sending messages and surfing the internet. She enjoys using mobile devices but because of her condition she cannot use them for a long period of time. She is also using RevmaRApp which was recommended by her rheumatologist.

She uses RevmaRApp to record her activities every day. She has been using RevmaRApp for a month and she understands its different features. However, she finds it particularly difficult to understand the data visualization. The graph has four quadrants and axes are not well defined with only icons and no labels which make it difficult for her to understand what they mean. She also finds it easier to understand the data visualization according to time periods rather than by sorting the activities. Although she is familiar with some mobile applications, she has difficulty understanding some icons and symbols used in RevmaRApp. She thinks she needs more explanation of symbols and icons to make it easier to use RevmaRApp.

Table 3: Daily Tasks for Jackie

Personas Table 3: Daily tasks performed by Jackie for a period of 30 days					
List of Tasks	Importance	Energy	Motive	(how many times a week)Frequency	Time

Personas Table 3: Daily tasks performed by Jackie for a period of 30 days					
List of Tasks	Importance	Energy	Motive	(how many times a week)Frequency	Time
Personal Hygiene	Very Important	High	Duty	7	6:00 AM
Prepare and Eat Breakfast	Very Important	High	Duty	7	7:00 AM
Reading Newspaper	Mild Important	Normal	Pleasure	5	Varies
Driving a car	Very Important	High	Duty	7	08:00 AM
Working in Garden	Very Important	Low	Pleasure	3	Varies
Watching Television	Not Important	Low	Pleasure	7	Varies
Listening to Music	Mild Important	Low	Pleasure	7	Varies
Cooking and Eating Dinner	Very Important	High	Duty	7	5:00 PM
Going out for a walk	Mild Important	Low	Pleasure	5	7:00 PM
Working on reports, presentations for work	Very Important	Medium	Duty	5	Varies

Martin:

Martin is 59 years old and he works as an accountant. He has been working in accountancy field for more than 25 years. For his work he needs to use accounting software at work. He loves going outdoors and staying in the nature with his wife. He was diagnosed with rheumatoid arthritis almost six years back.

He also uses a hearing aid to help him with his diminished sense of sound. In the past six years his arthritis has been causing him pain and distress. His main problems are the stiffness in hands when he wakes up in the morning. He has to constantly move his hands to gain some control over them. His arthritis makes it difficult for him to use computers for a longer period of time. This makes it difficult for him to work continuously at office and home.

He also likes to do his household chores such as cooking and cleaning. He also likes to go out hiking and stay in nature but because of his arthritis he cannot walk very far. Sometimes he has to be helped to get out of chairs or baths and walk up the stairs. He was asked by his doctor to use RevmaRApp to monitor his daily activities for a period of 15 days.

While using RevmaRApp, he came across some challenges with the registration of activities, and registration of new period. He finds it difficult to add new activities to a certain period of time. He also wants to be able to add and delete activities easily and he finds it easier to list activities by date beginning with the recent activities.

Table 4: Daily tasks for Martin

Personas Table 4: Daily tasks performed by Martin for a period of 15 days					
List of Tasks	Importance	Energy	Motive	(how many times a week)Frequency	Time
Personal Hygiene	Very Important	High	Duty	7	7:00 AM
Prepare and Eat Breakfast	Very Important	High	Duty	7	8:00 AM
Reading Newspaper	Mild Important	Normal	Pleasure	5	9:00 AM
Cooking Meal	Very Important	High	Duty	7	10:30 AM
Working in Garden	Very Important	Low	Pleasure	3	1:00 PM
Watching	Not Important	Low	Pleasure	7	3:00

Personas Table 4: Daily tasks performed by Martin for a period of 15 days					
List of Tasks	Importance	Energy	Motive	(how many times a week)Frequency	Time
Television					PM
Listening to Music	Mild Important	Low	Pleasure	7	4:00 PM
Cooking and Eating Dinner	Very Important	High	Duty	7	5:00 PM
Going out for a walk	Mild Important	High	Pleasure	5	7:00 PM
Driving a car to go shopping	Very Important	Low	Duty	5	Varies

The personas above are generated from the initial user testing and interviews conducted by the Norwegian Computing center. With the help of the personas and the issues raised in the user testing, several issues which are categorized as usability, accessibility and universal design issues are discovered in the existing data visualization of RevmaRApp. Some of the universal design and usability issues which are discovered in this phase of the thesis are presented below:

4.3 Universal Design Issues of the current system developed by NR:

1. Color is considered to be the only means of conveying information. There must be alternative means of communication of information beyond color content such as use of voice over capabilities or at least the user must be provided with the opportunity to customize the visualization according to their needs.
2. The visualization must be made accessible through screen readers.
3. The user must be able to zoom in or out of the visualization without any difficulties for navigation purposes.
4. The user must be provided with ample amount of time to complete tasks since the users are mostly elderly and patients of rheumatoid arthritis.
5. Opening of new windows or pop-ups must be initiated only after the commands are given by the user. Another way of achieving this is that the user must be notified if

any changes are going to occur and a dialog box must provide an opportunity for the user to accept or cancel these changes.

6. The visualization must be compliant with standards such as WCAG 2.0, ETSI, ADA, section 508

4.4 Usability Issues of the current system developed by NR:

1. Learning Curve: The current visualization cannot be understood at a first glance. The user must become familiar with the entire application and its functionalities to understand the graphical visualization. The visualization consists of colors as the only means of conveying information. It uses different gradients of green and red colors to distinguish one element from another which makes it difficult for users to comprehend. Activities are represented by small squares or round structures which have no other information so distinction of activities is also difficult.

2. Efficiency: The amount of efficiency is considerably reduced due to a lack of understanding of the existing visualization. The tasks within the visualization are represented using square icons which vary in size from large to very small. These structures have no other information attached to them and simple interactions such as clicking on these structures become difficult due to the fact that a lot of our users will be patients suffering from Rheumatoid Arthritis which affects joints leading to pain and under prolonged and severe cases leads to deformity of bones and joints. Due to such deformities, it becomes extremely difficult to interact using tap and touch gestures, as there are problems with coordination caused by pain. Another challenge is the interaction with small squares which represent different tasks in current visualization.

3. Memorization: RevmaRApp is a dynamic mobile application which means that data is subjected to change. The data inserted by the users may vary according to their daily routines and experiences therefore; the visualization will also change subsequently. One particular usability factor is memorization of the system which means once a system is used then the user must be able to understand its specific features and re-use the system as necessary and independently.

4. Errors and effects: Another important aspect is the rate of errors made by the

users while using the system and their effects on the entire system or even parts of the system.

Conclusion of Chapter 4:

In this chapter, I have explained the details regarding the user testing conducted by the Norwegian computing center. Along with this, four different personas were developed from the user testing information as well as various literatures. This helped to generate various requirements and also pointed out several issues related to accessibility and usability. Since the goal of this thesis is to evaluate and create an accessible prototype, the next chapter discusses about the software development technique which is used for the development of the new prototype.

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Chapter 5:

In this chapter, the software engineering technique used in this thesis is explained. This thesis is a combination of an evaluation study as well as a prototype development. The results from the evaluation study are used to create a prototype. In our case, the prototype development process follows a technique known as “scrum”. This particular technique is explained further in this chapter.

Software Engineering Techniques:

In any project involving software development whether small or big, it is necessary to establish a method to develop software applications. In this regard, the project will be based upon AGILE concept of self – management. SCRUM is the ideal method for this project since it is suitable for both, updating existing system as well as designing new prototypes (Schwaber, 2004). It has incorporated the concepts behind waterfall model, spiral and iterative methodologies successfully and evolved as a standard for software development methods. I have chosen Scrum since it consists of iterative cycles which can be repeated until the maturity of product is obtained.

Its success is attributed to the fact, that it assumes every development process to have fallacies and pitfalls. Therefore, it provides flexibility by adding control mechanisms to the process (Schwaber, 2004). The first point of action in this context was the development of a Gantt chart to establish a standard time-frame from initialization to the completion of the project. The Gantt chart provides specific time periods for completion of tasks. Based on this time frame, a project SCRUM board has been designed in www.trello.com.

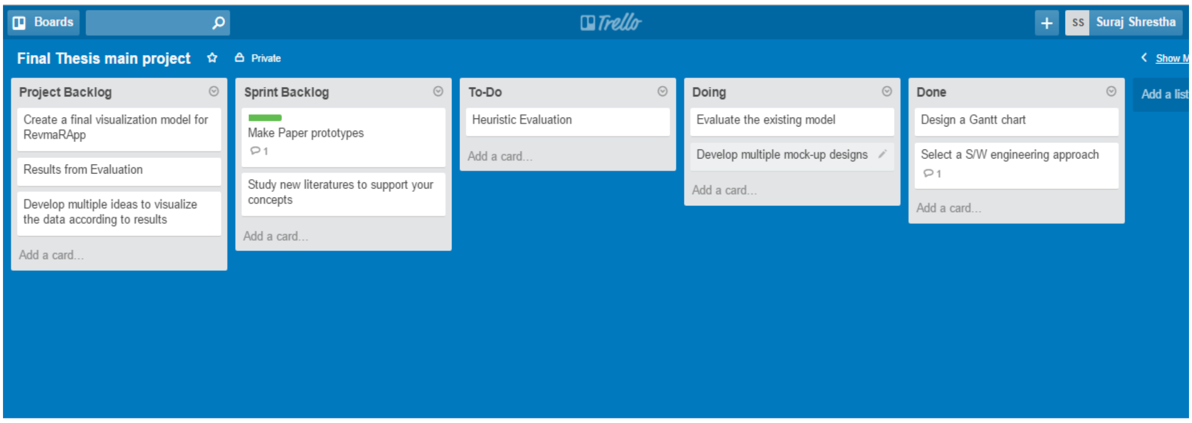

Figure 24: Trello board, Retrieved from: https://trello.com/b/8O4e91db/final-thesis-main-project, 02 May 2016

5.1 User Stories

User stories are created as a means to list the requirements of the system in regards to its practical use. Rather than just listing out the features required in the system, user stories lay down the foundation for the need of such features. In AGILE development, user stories are essential to understand the functionality requirements of the system.

In this project, I have used a story-driven approach. This approach is necessary to involve the different stakeholders of this project until the completion of the project. This allows active participation of all the stakeholders and the owners of the entire project (REVMARAPP) to become actively involved.

Another use of user stories is to make the entire process of requirement analysis and testing more comprehensive, visible and transparent. This helps to test the functionality achievements of the project. Each user story will add some degree of requirements to the project and increase functionality of the system. The development team or developer (individual) will try to understand these functionalities from user stories and design the software according to the requirements. This process of using user stories makes the entire process a testable component(Cohn, 2004).

List of User Stories:

1. As a project manager for the Norwegian Computing Center, I want a new or improved visualization technique and designs to develop a clear visualization for users.
2. As a lead developer of REVMARAPP, I want the visualization which is written in C#.NET, Java etc. using some backend logic so that current visualization can be replaced or improved to provide better services to the clients.
3. As a user, I need a new system which is designed according to universal design standards such as WCAG 2.0, ATAG, WAI-ARIA and UAAG.
4. As a CSR, I want the new system to be compliant to the ETSI (European Telecommunications Standards Institute) and Americans with Disability Act (ADA) so that the laws governing issues of procurement of accessible technologies are also incorporated into the new systems since we have a diverse clientele.
5. As a Project Manager, I want the prototype to have the capacity to sort the data to show specific selections of data because these are basic features used by our customers.
6. EPIC - As a Project Manager, I also want some immediate security features in the prototype.
7. As a Project Manager, I need the new system to avoid issues of concurrency to guarantee security.
8. As a Project Manager, I want the new system to safe guard the data and other medical history to affirm our customers' security while using the system.
9. As a Project Manager, I want the prototype to allow users to change settings of the application according to their needs.
10. As a Project Manager, I want the new system to provide customization options to change visualization features such as color, contrast etc according to the needs of the users.

The user stories as mentioned above are essential to understand the need of different functionalities within the project. These user stories are helpful to understand the needs of different stakeholders of the project. It also helps developers to list the requirements.

Based on these user stories a list of executable tasks is created.

SCRUM is essentially an AGILE methodology which is a combination of these tasks and requirements. In this section, I have discussed the practical use of SCRUM methodology for this project.

5.2 SCRUM Board:

The SCRUM board dissects the entire development process into 5 sections:

1. Project Backlog
2. Sprint Backlog
3. To-Do
4. Doing
5. Done

The project was first divided into two separate mini projects:

5.2.1 Documentation

5.2.2 Implementation

Both of these projects have SCRUM boards which are same in structure although the tasks which are listed in the above mentioned 5 sections are different for the two mini projects.

5.2.1. Documentation:

- Thesis Backlog:

  This is a collection of tasks which have to be completed to get the final documentation for the entire project. Thesis backlog is similar to project backlog but it differs in purpose. The tasks listed in thesis backlog must be completed in order to complete the documentation and dissertation. It consists of management level tasks such as meetings, reading of literatures, etc.
- Section Backlog:

  This is similar to Sprint backlog. Unlike sprint backlog which will consist of technical processes required to complete the design and development of project. This particular section backlog will address issues of completion of the documentation part. The section backlog consists of tasks which have to be completed to finish the entire process of writing the dissertation. For this purpose, the section backlog consists of different types of tasks such as writing different sections of dissertation from abstract and acknowledgement to the conclusion.

- Image Backlog:

An image backlog has been created to address the issues of references for future. In this backlog, all the images that have been used in the project from documentation to the development processes have been stored. Image backlog will be made available through a link to a database if it is felt necessary at the end of the project.

- Reference Backlog:

A separate reference backlog has been created since the initial stage of the documentation process to avoid issues of plagiarism. The reference backlog guarantees the authenticity of the documentation process and extensive steps have been taken to make the maximum use of reference backlog in every part of the document to make ample references to any textual, visual or multimedia contents used throughout the documentation and development processes.

5.2.2. Implementation

- Project Backlog:

A project backlog is generally a collection of all the tasks required to complete the entire project. The user stories were created to understand the different types of tasks that are necessary from the perspectives of users, project manager and developers. Based on the user stories and comprehensive study of the entire system, a list of tasks is created.

List of tasks in “Project Backlog”:

1. Create a final visualization for RevmaRApp
2. Conduct an evaluation
3. Collection of results from evaluation
4. Study (UD) Universal Design techniques necessary to design a new concept for visualization based upon the results from evaluation
5. Create a paper prototype
6. Create a CG (Computer Generated) Prototype
7. Selection of technologies to create CG Prototype

- Sprint Backlog:

A Sprint backlog is created from the Project backlog. A certain number of tasks in terms of importance and necessity of the project is selected and placed in sprint backlogs. These sprint backlog tasks are started after the allocation of necessary resources such as human resources, economic resources, technical resources such as equipments, logistical resources etc. Tasks listed in the project backlog are gradually added into sprint backlogs. Normally, a sprint is considered as a period of two weeks however, it may vary according to the decision of the team. In this case, the sprint would last for 3 weeks. This form of division of time into sprints made it possible to divide the project into smaller deliverables. After the completion of each sprint at least a new task would be added to the sprint backlog.

Conclusion of chapter 5:

In this chapter, the software development technique which is used for this thesis is explained. In our case, Scrum was selected because it is suitable for a new prototype development as well as updating existing systems. I have also discussed and explained several features related to scrum and its relevant aspects related to the thesis. In the next chapter, I discuss about the development of the new prototype and present different features which are included in the new prototype including accessibility features and the data visualization.

Chapter 6:

Prototype Development

In this chapter, the first part introduces the old data visualization and its different features. The second part then introduces the new prototype development process in detail including its different features such as the data visualization and various customization options. I also explain further regarding various accessibility features which are incorporated in this prototype to make it accessible.

The design and development of prototype is an integral part of this project. The final product is a prototype design along with the entire documentation. The design and development process of prototype for this project is divided into two parts. The first part is the design of a paper-based prototype and another is the CG (Computer generated) prototype.

Different types of paper-based designs for the prototype were created. These were tested against the data which they would represent. The most important part of the visualization process was to inform the user about the data. RevmaRApp consisted of 3 major categories of data:

- Importance
- Energy
- Duty/Pleasure

- Importance: The previous data visualization consisted of an axis which represented importance as the two extremes of axis:
    1. Important
    2. Unimportant

  However, the new visualization has divided this category of data into four variations:
    1. Very Important
    2. Mild Important
    3. Not Important
    4. None

This new variation has been designed to accommodate more data and to make the analysis of data easier. The practical reason behind the use of three variations of the data is linked to the use of the slider to enter the data in the application.

The placement of the slider as shown in figure 25, determines between the three variations of data. The positioning of the slider between the beginning and the middle will represent a lower value from “Not Important” to “Mild Important” while the positioning of the slider between the middle and the end of the slider will represent a higher value “Very Important”.

Similarly, in the previous visualization, energy was a category which had two variations. In the new visualization, energy has three variations:

1. High to Low
2. Low to High
3. None

This particular category of data is pivotal for the new visualization concept. The levels of energy will be entered by the user through the use of the sliders. The value from the beginning of the slider to the middle is considered “Low” and the value from the middle to the end of the slider is considered “High”. The activities in the new prototype will be randomly sorted out in the order the user selects from the three variations as mentioned above.

If the user selects “High to Low” then the activities with the highest energy will be sorted at the top and lowest one will be at the bottom.

If the user selects “Low to High”, then the activities with the lowest energy will be sorted at the top and highest one will be at the bottom.

In the previous visualization, there is no common name given to this third category of data which has two variations: Duty

1. Pleasure

In the new visualization, this third category is given a combined name called “Motive" as shown in figure 26. This category called motive has the three variations in the new data visualization prototype:

1. Duty

2. Pleasure
3. None

The user will slide the slider to determine whether the activity was considered a duty or a pleasurable act. If the slider is between the beginning and the middle then the activity is considered a duty while if it is between the middle to the end then it is considered a pleasure.

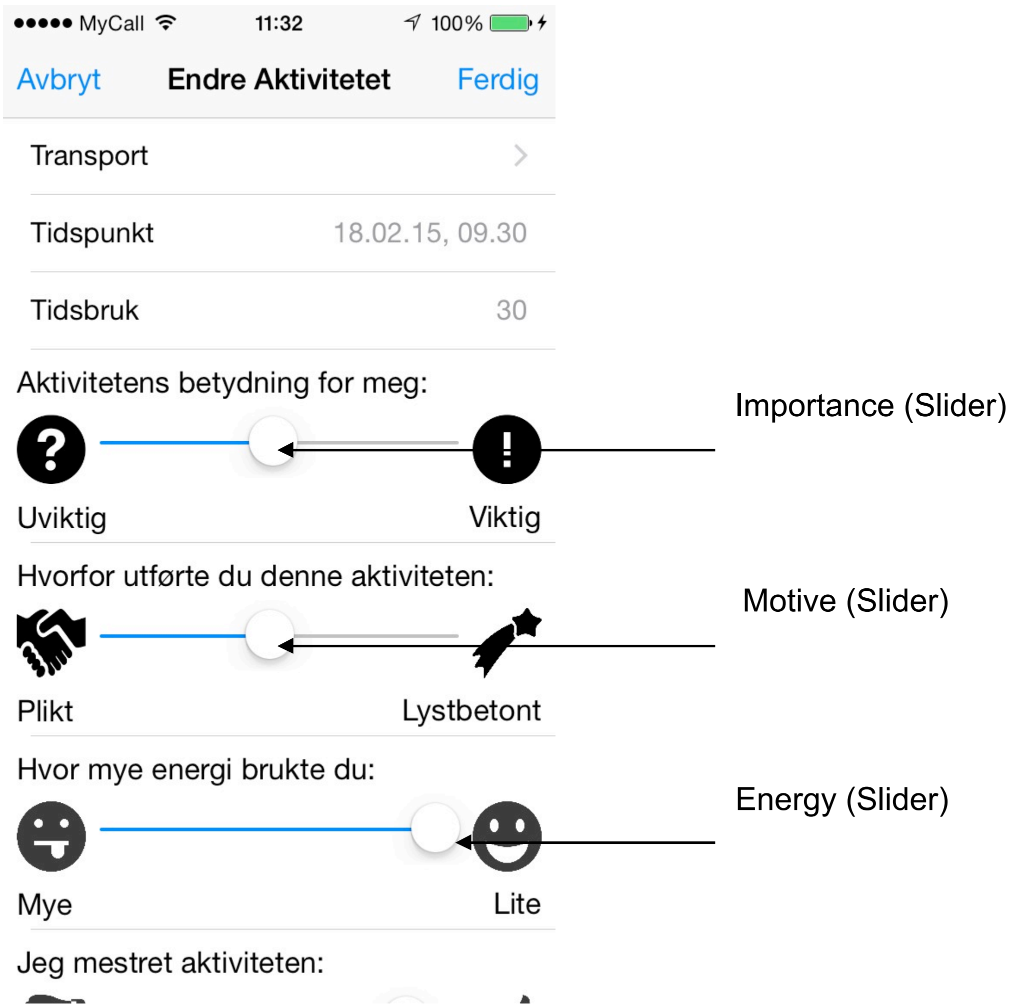

Figure 25: Activity Evaluation

Retrieved: 03/05/2016 From: RevmaRApp, *RevmaRApp,* Unpublished mobile application, Norwegian Computing Center, Norway

6.0 An overview of the New Prototype:

This is a short overview of the Prototype. This overview will describe the new user interface and a new data visualization technique. This overview will also show some of the steps users will use to interact with the prototype of the visualization.

The new visualization consists of the following features as shown in figure 26:

First level consists of a header.

Second level consists of a sub-header.

The first and second levels will auto show when scrolled down and they will auto hide when scrolled up.

Third level consists of three drop-down menus.

First drop-down menu consists of the first category called importance. When the user taps on the drop down menu, the list will appear which will show four variations:

1. Very Important
2. Mild Important
3. Not Important
4. None

Second drop-down menu consists of the second category called energy. When the user taps on the drop down menu, the three different variations will be shown as following:

1. High to Low
2. Low to High
3. None

Third drop-down menu consists of the third category called motive. When the user taps on the drop down menu, three different variations will be shown as following:

1. Duty
2. Pleasure
3. None

As mentioned above there are three drop-down menus on the third level of the application. These drop down menus act as filters for the data. The user has the option to select only one of the variations in any categories or the user can also select one option from each of the three drop down menus to get a customized and filtered data.

In other words, a user has the flexibility to choose only one option from one of the drop down boxes or one option for each of the three boxes.

After selection of the boxes, the user will be displayed a list of activities according to the selections the user makes on the drop down menus.

The list of activities will be visualized using bars almost similar to bars in the bar graphs and the length of these bars will be proportional or representative of the energy levels as well i.e. longer bars represent the higher energy levels. The bars will represent the activities and also the energy levels. However, the other two criteria namely “importance” and “motive” must also be shown in the visualization. To accommodate these data in the new visualization, symbols are used. These symbols are visualized as round figures containing the initial letter of every variation within the categories as listed here:

Table 5: List of Categories and respective abbreviations

S.No.	Categories	Variations	Symbols
1.	Importance	Very Important	VI
		Mild Important	MI
		Not Important	NI
		None	N
2.	Energy	High to Low	HL
		Low to High	LH
		None	N
3.	Motive	Duty	D
		Pleasure	P
		None	N

Future Considerations:

There are three categories in this application for data manipulation:

1. Importance
2. Energy
3. Motive

In future, if there is a need to add another category, then the application will automatically adjust its size to accommodate this feature. The screen will also automatically adjust the size of the area which shows the list of activities represented using bars. These bars will automatically adjust in size and length in proportion to the area available for each bar respective to the entire space. However, the clickable area for each bar will remain similar to avoid flexibility of use.

New Prototype Designs:

Step 1:

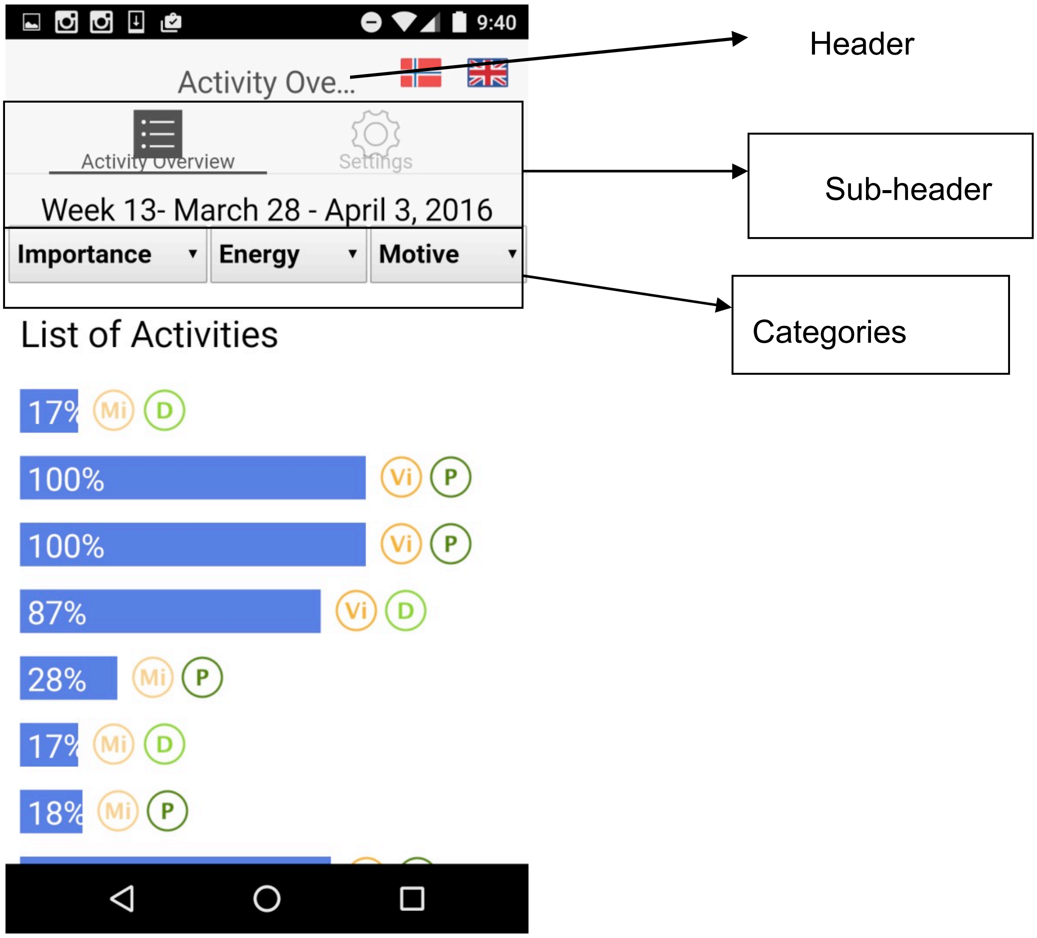

Figure 26: Prototype Home Screen

Figure 26 is the first step. This figure shows the header which consists of "Activity Overview" as text and two flags which can be tapped by the user to change the language. Below the header is the sub-header which shows two buttons for activity overview and settings and below the buttons is the time period.

The sub-header is followed by the three drop-down boxes which represent the three categories of data:

1. Importance
2. Duty
3. Motive

Finally it shows the list of activities. The default list of activities are shown to the user at first..

Step 2:

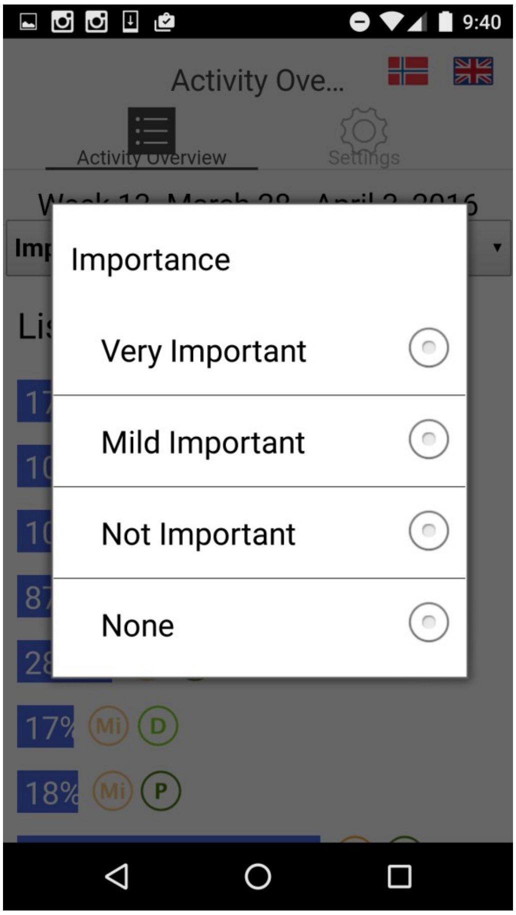

Figure 27: Importance Drop down menu

Figure 27 shows the second step. This prototype shows the drop down menu for a category called “Importance”. This drop down menu shows four variations of importance:

1. Very Important
2. Mild Important
3. Not Important
4. None

Step 3:

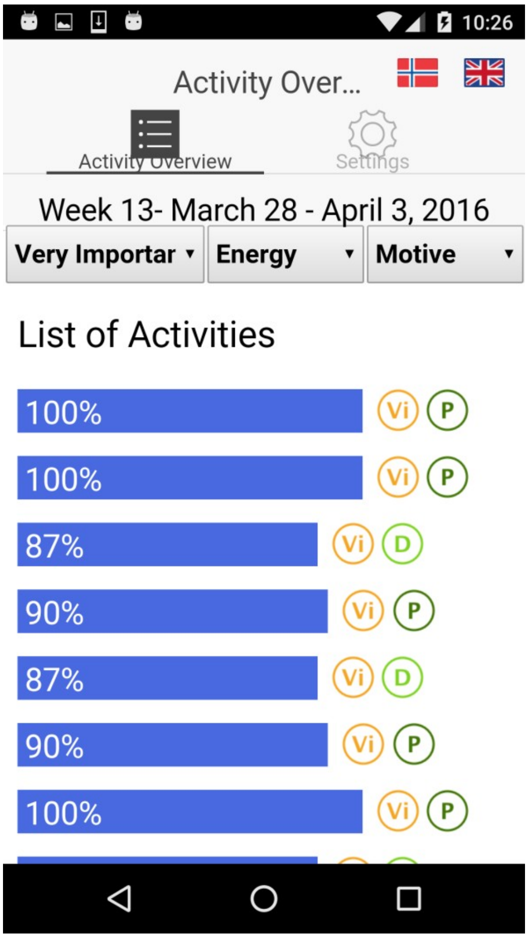

Figure 28: Selection of variation for first category

Figure 28 shows the third step. This step shows selection of “Very Important” variation of the “Importance” category. The selection of “Very Important” from the drop down menu adds first level of filter. Therefore, all the activities which have been entered as very important by the user is displayed.

Step 4:

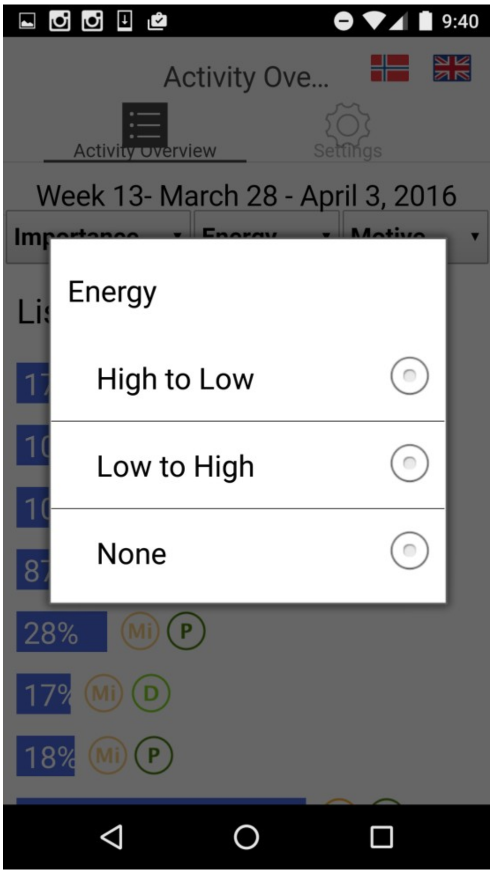

Figure 29: Drop down menu for Energy

Figure 29 shows the fourth step. When the user taps on the drop down menu for "Energy" the user is shown three variations of "Energy" category:

1. High to Low
2. Low to High
3. None

Once a user selects one of these variations the data is filtered according to the selection.

Step 5:

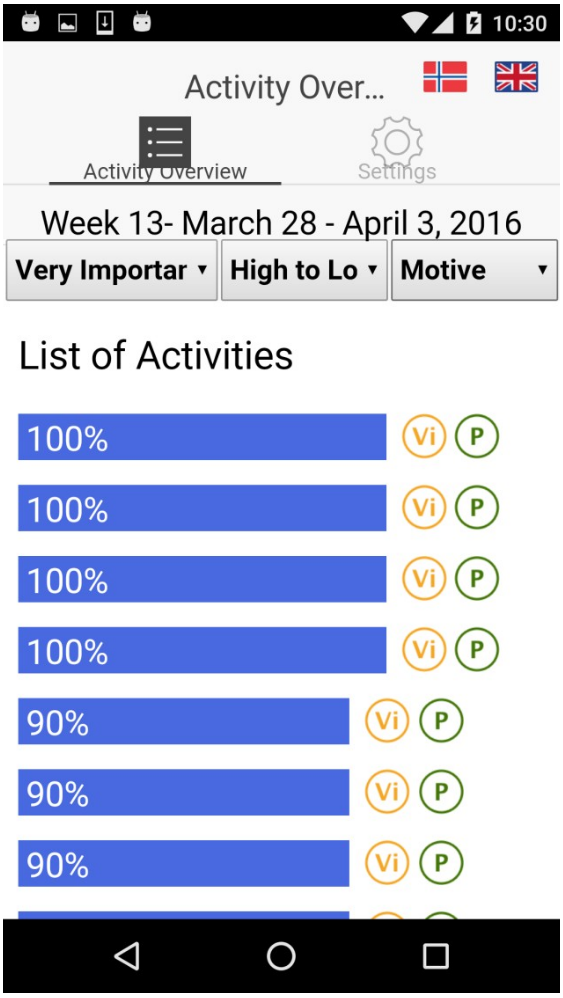

Figure 30: Selection of variation for second category

Figure 30 shows the fifth step. In this step, the user can tap on any of the three variations for "Energy" category to select it. In the third step, the user has already selected "Very Important" in the "Importance" category. In this step, the user has selected "High to Low" in the "Energy" category. After this selection, the data will be filtered for a second time for "High to Low" and the bars will be automatically adjusted from those having highest energy value to the bar showing lowest energy value.

Step 6:

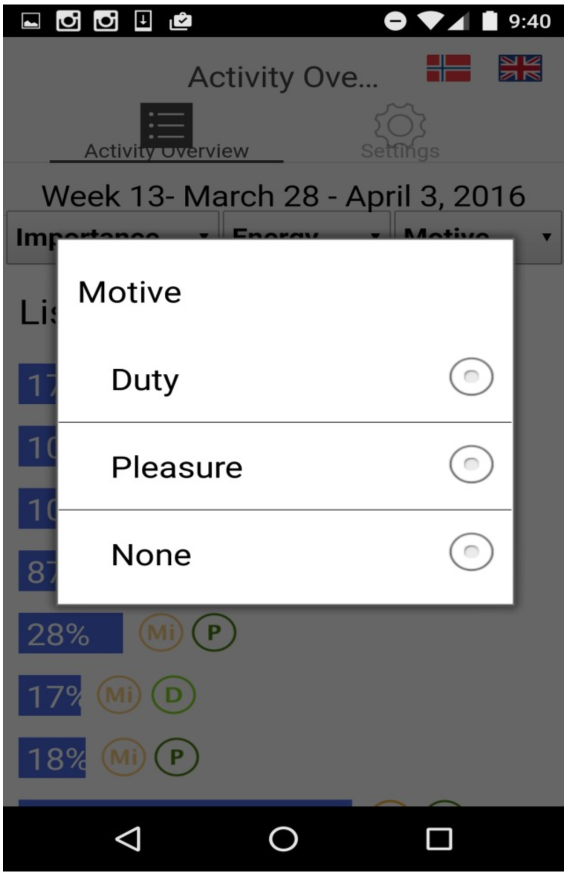

Figure 31 shows the sixth step. In this step, the user can tap on the drop down menu for “Motive” and the menu shows three variations “Duty”, “Pleasure” and “None”.

Figure 31: Drop down menu for Motive

Step 7:

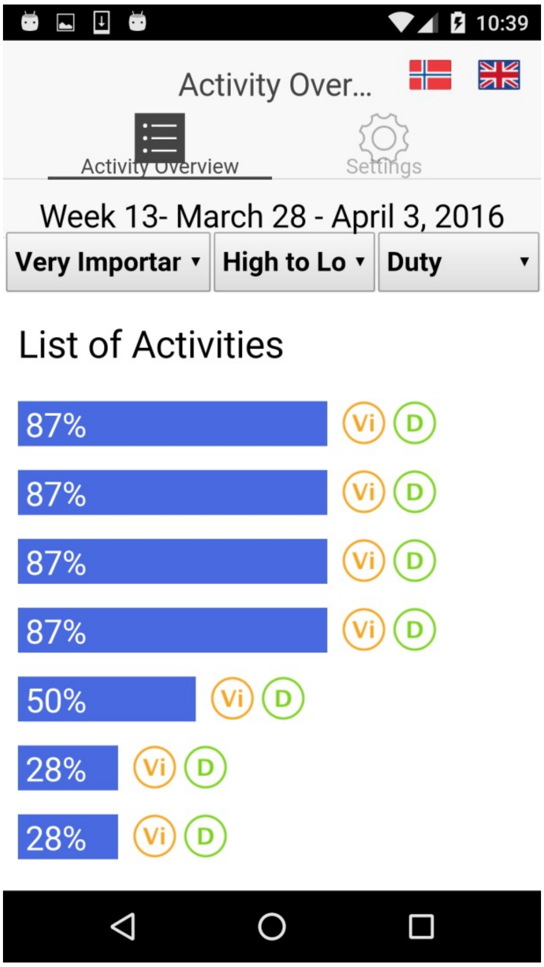

Figure 32 shows the seventh step. In this step, the user has selected all the three variations for all three categories.

In the first drop down menu, the user selected "Very Important"

In the second drop down menu, the user selected "High to Low"

In the third drop down menu, the user selected "Duty"

After the selection of all of these categories, the user can see a list of activities which match to all the above mentioned variations.

Figure 32: Final View

Step 8:

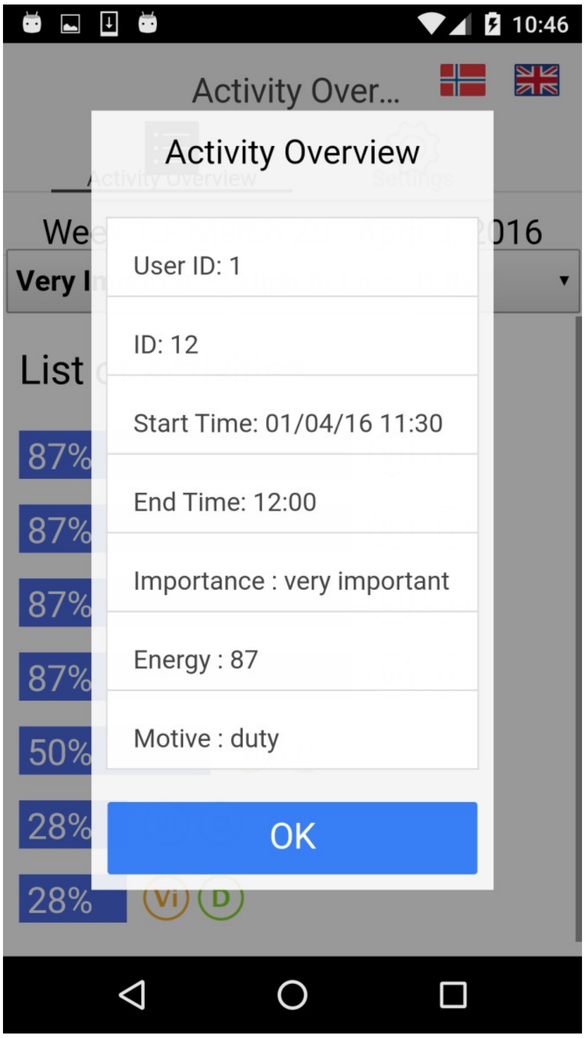

Figure 33: Activity Details

Figure 33 shows the details view. When the user taps on the bars which represent activities, the details of that activity is shown.

6.1 Features in Settings view of new prototype:

1. Main Menu for Settings:

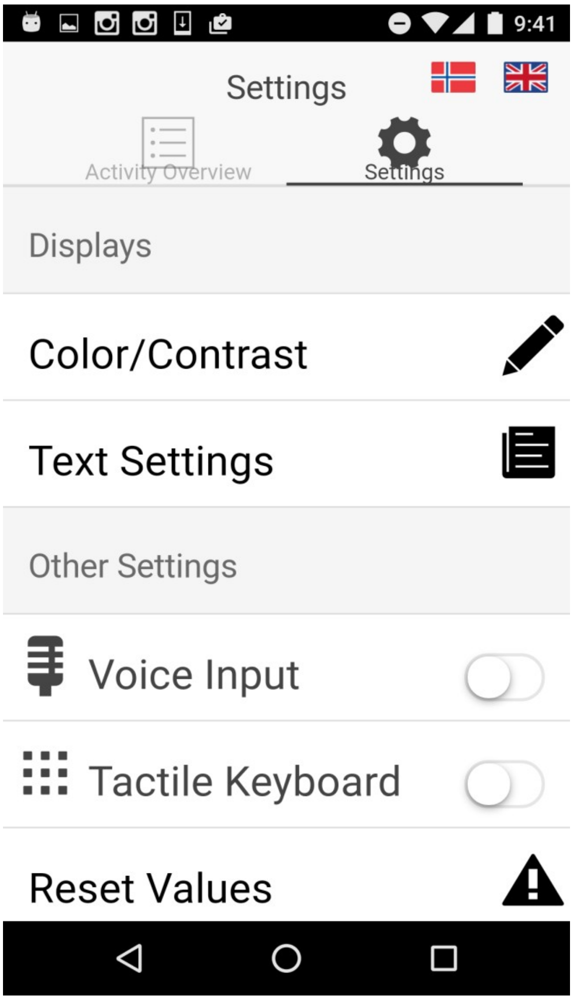

Figure 34 shows the list of options which can be used to customize the visualization according to the need of the user.

It is divided into two sections:

1. Displays

2. Other settings

"Display" consists of two categories:

1. Color/Contrast
2. Text Settings

"Other settings" consists of two categories:

1. Voice Over
2. Tactile Keyboard

Figure 34: Setting Home menu

2. Color/Contrast menu

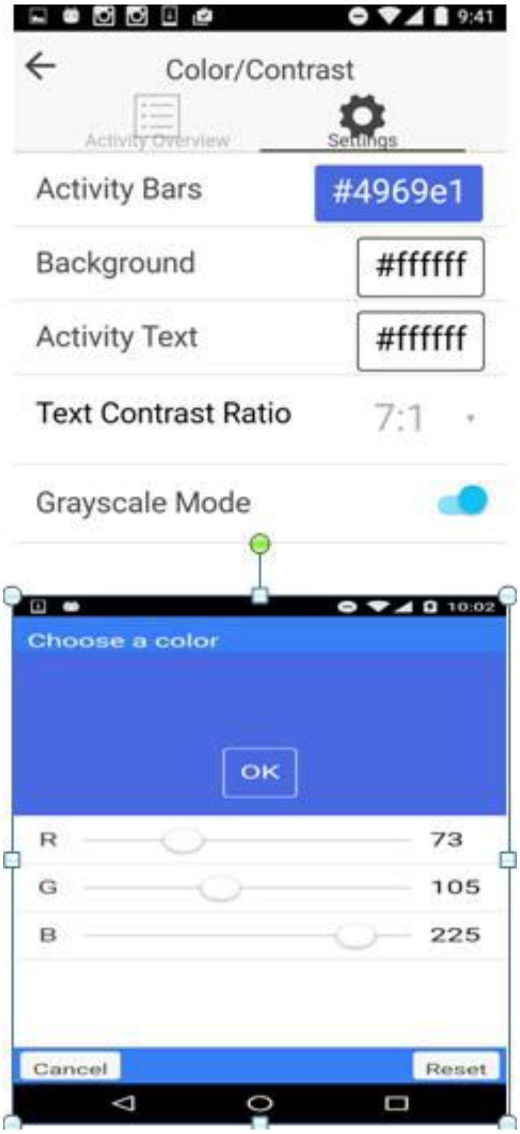

Figure 35: Color / Contrast Settings

Figure 35 shows the color /contrast settings. When the user clicks on the “Color/Contrast” option in the “Settings” home menu, the user will be shown this screen.

The user can customize the colors of the “Activity Bars”, “Background” and “Text”. Greyscale option can be turned on and off using the toggle button.

The user can also set the textual contrast ratio according to the need which has two variations, 7:1 and 4.5:1. The user can choose a color by sliding the RGB scale. Once a required color is obtained then the user can select “OK” button to commit the changes. The reset button can be used to reset the values.

3. Text Settings:

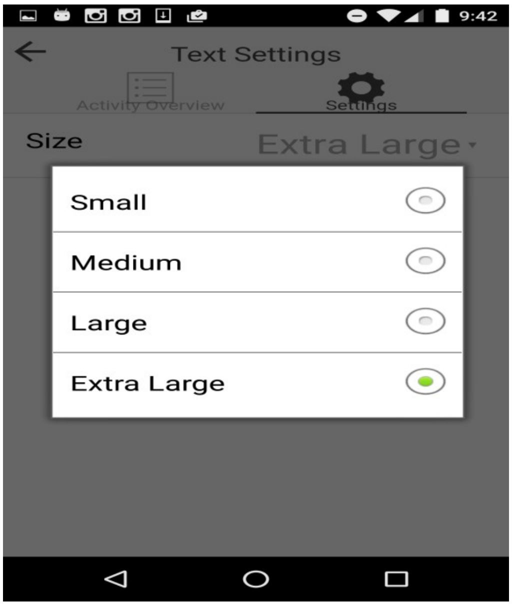

Figure 36: Text Menu

Figure 36 shows the “Text” setting menu.

Once the user taps on the “Text” category on the “Settings” home menu, the user will be shown this screen.

The user can change the size of the text according to the need. Four categories are provided for users:

1. Small
2. Medium
3. Large
4. Extra Large

4.

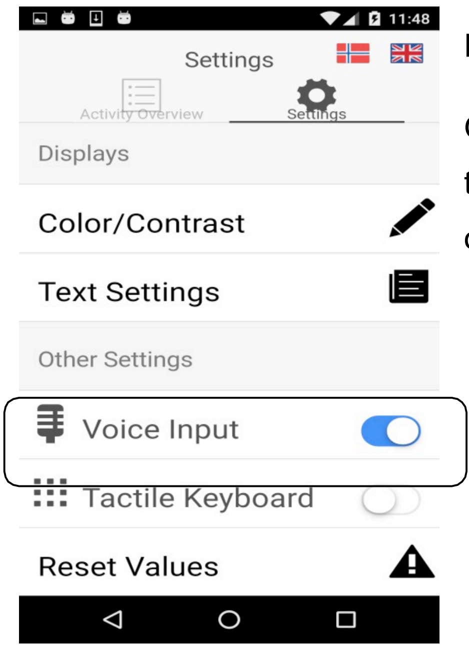

Figure 37: Voiceover Menu

Figure 37 shows the “Voice Over” menu.

Once the user taps on the “Voice Input” option in the “Settings” home menu, the user can toggle on or off this option.

5.

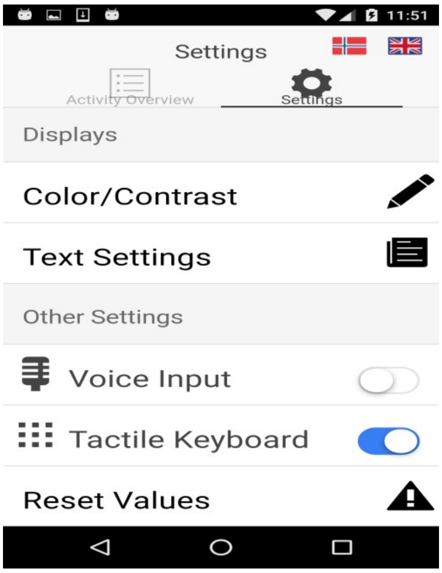

Figure 38 shows the "Tactile Keyboard" menu.
Once the user taps on the "Tactile Keyboard" option on the "Settings" menu, the user will see this screen.

The user can activate or deactivate the tactile keyboard using the toggle button.

Figure 38: Tactile Keyboard Menu

Conclusion of chapter 6:

In this chapter, I have described about the designs of the prototype development. The user interaction and interface details for the new prototype were explained to familiarize the readers with the mobile application. The different features within the mobile application including data visualization features and the accessibility features located in the “Settings” view were described as well.

The new prototype is developed according to the standards set by Universal Design. This adherence to Universal Design standards has helped to develop an accessible prototype which also solves the universal design issues which are raised in section 4.3 of Chapter 4:

1. Color is not used as the only means of conveying information instead use of colors is supplemented with the use of shapes and size of visual objects such as the length of the bars represent the level of energy as shown in figure 30. This information is also supplemented by numerical value which is displayed on the bars.
2. Another issue is the accessibility of screen readers. The new prototype can be used with screen readers quite easily. The user interface elements are compliant with screen readers and informative text is used for labels and element names.
3. Users are provided the ability to change the size of the text as shown in figure 36. The users also have the ability to change the colors of the user interface elements as per their needs as shown in figure 35.
4. Users are given ample amount of time to complete tasks.
5. The changes in the display of data is initiated only by the user therefore, the user is in direct control of the prototype and changes can be reverted if the user thinks is necessary.
6. Finally the visualization is made in compliance to standards set forth by WCAG 2.0 for mobile accessibility.

The usability issues as mentioned in section 4.4 of Chapter 4 are addressed in the new prototype. Some of the solutions achieved for these issues are as following:

1. Learning Curve: In this visualization the user can select the data which they want to see and the data according to their selections is visible.
2. Efficiency: Another important usability aspect is the amount of time required to complete the tasks within the application is also considered when developing the new prototype. The number of interactions required to complete a task is kept to minimum which means than they need less time to complete tasks and since, the tasks require less user interactions, affects such as fatigue after using the mobile application is reduced.
3. Memorization: The prototype is also designed in a simple and understandable way so it is easier for users to understand, use and memorize.
4. Errors and effects: Finally, the prototype is designed in a flexible manner so that any errors made by the users can be reverted back to previous stage without any obstacles

   In the next chapter, I discuss about the experiment which was conducted for both the data visualizations (i.e. Old and new) to compare and understand possible benefits and find evidence regarding the accessibility and usability of the new prototype. The details regarding the experiments and its various aspects are explained further in the following chapter.

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Chapter 7:

Data Visualization Experiment

In this chapter, I explain about the various aspects of the experiment which was conducted for both data visualizations. In this part, I discuss about the hypotheses, participants, experimental design, variables and apparatus used to conduct the experiments. I will further explain the tasks and procedures carried out in the experiments as well.

7.1 Hypothesis:

H_1: The new data visualization represented data to the users as per their selections of categories which made it faster to understand the data than the old visualization.

H_{01}: The availability of selectable categories in new data visualization makes no difference over the old data visualization

H_2: Customization settings in the new visualization help to change the appearance of data visualization to suit the needs of users and make it more accessible.

H_{02}: Adding customization settings makes no difference to increase accessibility of the visualization.

H_3: Use of rectangular bars to represent activities in the new data visualization makes it easier to tap or click with fingers for interaction by providing bigger interaction space than using squares on the old data visualization

H_{03}: Use of rectangular bars to represent activities in the new data visualization makes no difference than using squares in the old data visualization.

H_4: Users have a better user interaction experience with the new data visualization interface in terms of touch target for user interface elements such as bars representing activities.

H_{04}: Users have no difference on user interaction experience between old and new visualization interfaces in terms of touch target for user interface elements such as squares representing activities.

7.2 Participants:

18 participants were recruited for this experiment. The participants were of various international backgrounds and all of them are students while two of these participants were student of health sciences. The participants of varying abilities were selected for the experiment. For this experiment, participants were expected to be experienced with mobile phones especially smart-phones as well as laptops. The level of experience can range from use of smart phones for at least a period of one year, normal use of smart-phone applications such as organizer application, browsing the web with internet browsers. A recruitment questionnaire is used to understand the abilities of participants in terms of familiarity with mobile devices such as Apple and Android devices. Two of the eighteen participants were studying healthcare related subjects at Masters level in university.

To recruit participants with required set of skills and experience, I used a recruitment questionnaire. I asked questions specific to the experience of using smart-phones and mobile applications. The recruits were asked to state the amount of time they have been using smart-phones in terms of years. Based on this, the participants who spent more than year using smart-phones were selected as it indicated familiarity with smart-phone and various mobile applications. I also asked participants about their familiarities with different kinds of smart-phones and operating platforms. The highest number of participants used Android devices followed by Apple's iPhone. Consequently I also developed the two applications specific to Android and iPhone for the purpose of experiments.

7.3 Experimental Design:

For this experiment, I have chosen "within user" design. This design was chosen so that all the participants can be exposed to both data visualizations. Participants were randomly chosen to use old or new data visualizations. Some participants were first allowed to use new data visualization while others were first allowed to use old data visualization. Therefore, participants were randomly allowed to use one among the two data visualizations at first. This randomization was done to avoid the possibility of memorization on how to use data visualization.

7.4 Variables:

The independent variables were the two prototypes and the tasks which were performed on the two different data visualization prototypes.

The dependent variables were the performance, attitude and experiences and dependent measures were completion of tasks (success/failure), time for overall task, rate of errors, participants' subjective opinions while interacting with the data visualizations and their features.

A semi-structured interview was conducted after the experiments for each individual. This interview was conducted to get an in-depth understanding about participants' views toward both data visualizations and their different features. The interviews were also conducted to understand accessibility issues for either data visualizations and to understand participants' feelings and experiences towards accessibility of either data visualizations. The interview consisted of questions relating to comprehension of data visualization to understand what they mean, accessibility of data visualizations and user interaction capabilities and experiences while using either data visualizations.

7.5 Apparatus and Materials:

The following materials were required in the experiment:

- Two smart-phones, Android smart-phone running android version 6.0(marshmallow) and Apple iPhone running iOS 9.3.
- Data visualization already present in RevmaRApp and the new proposed visualization
- A stopwatch to record the time for completion of tasks
- A recruitment questionnaire and a consent form for participants before conducting experiments
- A sheet of instructions for participants to inform them about details regarding experiments in which they are involved
- A consent form
- A post experiment semi-structured interview guide

- One pair of Cambridge Simulation Gloves (Size L) designed by University of Cambridge, Engineering Design Center.

Cambridge Simulation Gloves were used to simulate the obstruction of movement of hands and fingers. These gloves were designed by the Engineering Design Centre of University of Cambridge. The main focus of the usage of gloves in this experiment is to understand how reduction in mobility of hand and fingers affects usage of the two prototypes for data visualizations. The usage of these gloves can simulate the affects arthritis might have on the hands and fingers of the participants, which also creates familiarity towards the real users and the problems faced by them when using mobile devices and applications.

Structural Design of gloves:

1. The gloves consist of plastic strips which limit the strength as well as the range of motion of the fingers and thumb(Cambridge, 2015).
2. The straps on the wrist can be adjusted according to need.
3. The length of the straps can also be adjusted for the plastic strips according to the size of the fingers of the participants.

Although the gloves help to simulate dexterity problems, they cannot help to simulate problems such as pain, tremors, problems of the wrist, loss of tactile sensitivity and deformities to the shape of the hand(Cambridge, 2015).

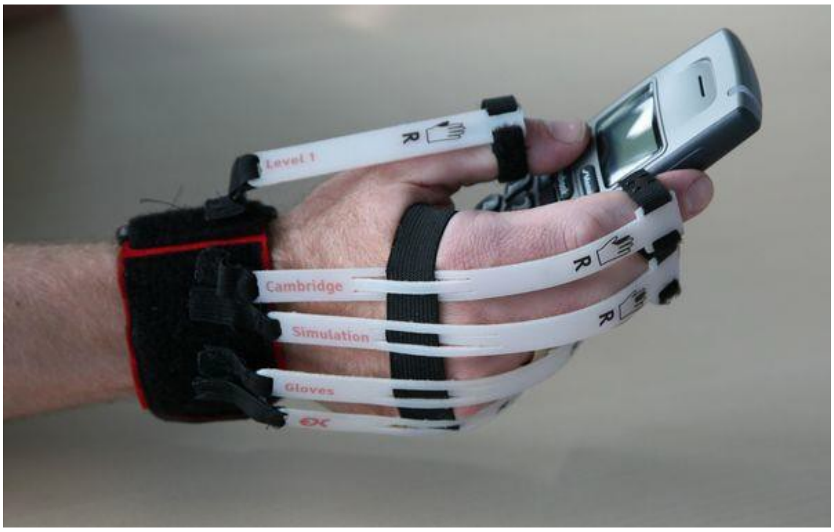

Figure 39: Cambridge simulation gloves

University of Cambridge. (2015). *Inclusive Design Toolkit* Retrieved April 22, 2016, from http://www.inclusivedesigntoolkit.com/betterdesign2/gloves/gloves.html#p20

There were six tasks in total and these tasks were performed on both of the data visualizations separately. There are some small variations in tasks, due to the fact that the data visualizations are different from each other in terms of features and concept. However, the tasks performed on them have similarities in terms of the goal of each task, level of difficulty, intention and efficiency.

7.5.1 Tasks for Newly proposed data visualization:

Task 1: Find out which activities are considered “Very Important” by selecting it from the “Importance” category.

Task 2: Find out which activities are considered “Duty” by selecting it from the “Motive” category.

Task 3: Find out which activities gained energy from looking at the data visualization.

Task 4: Tap on the bars which represent activities and find out details about at least three activities.

Task 5: Use a screen reader to use the app

7.5.2 Tasks for Old and present data visualization:

Task 1: Find out which activities are considered important from looking at the data visualization.

Task 2: Find out which activities are considered duty from looking at the data visualization.

Task 3: Find out which activities gained energy from looking at the data visualization.

Task 4: Tap on the small green squares which represent activities and find details for at least three activities.

Task 5: Use a screen reader to use the app

7.5.3 Tasks specific to New data visualization

Task 6: Change the font-size and color of text.

7.5.4 Tasks specific to Old data visualization

Task 6: Tap on each quadrant to discover any further information.

7.6 Procedure:

A total of 18 participants were recruited. The recruitment was first conducted through a survey that was created in a website called www.surveymonkey.com. The recruitment survey was used to understand the capabilities of the participants because for this experiment we only needed participants who were familiar using smart phones and mobile applications. The survey was also used to gain further insight regarding the usage of different types of mobile devices by the participants. The recruitment survey lasted for three days and participants were recruited at the final day. After the recruitment, the experiment was conducted for a period of one week. The experiments were conducted in a group study room in the university. The participants and the experimenter were located in the same room at the same time for the experiments. The environment was quiet and we tried to avoid as much distractions as possible by selecting rooms which were distant and secluded. Overall each session with participants lasted for almost 30 minutes for the experiment and the time varied from 10 to 15 minutes for the semi-structured interviews.

Each participant was allocated a time slot in advance. Social media such as Facebook and messenger were used to keep in contact with the participants to confirm their schedules. Conventional communication medium such as telephone calls and text messages were used for those participants who wished to share their contact details. When the participant arrived he/she was greeted and asked to take a seat. They were introduced to the experiment and then the consent form was presented to them. The participants carefully read the consent form and signed it. The consent form informed the participants about the research and the use of the information provided by them for this research. It also explained that the research will not harm any of their personal information and presented no risks for them. It explained that the information for each participant would remain confidential and if they did not want to continue further then they could reject to complete the individual tasks or the entire experiment.

Participants were randomly assigned to use one of the two data visualizations at first which means some participants were given the old data visualization to use at first while some were given the new data visualization to use at first. The experimenter familiarized the participants to the data visualizations by providing some explanations about the two data visualizations. At the start of each task the experimenter asked the participant to perform a particular task. Then the participants were allowed to complete the tasks for each data visualization in sequence. Each participant was asked to speak aloud while performing the tasks..

After the completion of the sets of tasks for both data visualizations, a semi-structured interview was conducted to gain further insight about their experiences, performance and features of data visualizations. The interview targeted the user experience, feature specific explanations, preference regarding the data visualizations and the comprehensibility of the data represented by the visualization models.

This concluded the experiment process.

Chapter 8:

In this chapter, I discuss about the results which were obtained from the first heuristic evaluation of the old prototype. Then I further explain about the results from the experiments. The results from the experiments and the suggestions and comments provided by the participants were also used to improve the new prototype. This new and improved prototype was also evaluated using heuristic evaluation and the results of that evaluation are described at the end of this chapter.

Results and Evaluation:

8.1 Results of heuristic evaluation of old data visualization:

In current context, WCAG 2.0 on mobile accessibility and WAI – ARIA are relevant standards to be followed however, all the guidelines mentioned in these standards are not relevant therefore some relevant guidelines are listed below which were applicable on the current data visualization and these points must be considered while designing a new prototype for data visualization:

The following table shows the Mobile Heuristics Walkthrough, as described by Vetere et al.

Table 6: Mobile HeuristicWalkthrough

WCAG 2.0 Principles	Guidelines from Mobile Accessibility	Explanation of problems within previous data visualization	Techniques that must be used to overcome problems and incorporate into new visualization
Perceivable	2.1 Small Screen size	Small screen size makes it difficult for people to view entire information at a glance especially when magnification or zoom-in feature is used.	• Minimize the amount of information that is put on each page. • A dedicated mobile version which can be customized • A responsive design which

WCAG 2.0 Principles	Guidelines from Mobile Accessibility	Explanation of problems within previous data visualization	Techniques that must be used to overcome problems and incorporate into new visualization
			can be used to render contents depending on viewport width. • Provide a reasonable default size for contents and touch control elements to minimize the use of zoom in/out features by users with visual impairments.
	2.2 Zoom/Magnification	Zoom/Magnification is not available.	• Ensure that the browser pinch zoom is not blocked by the page's viewport meta element so that it can be used to zoom the page to 200%. • Support for system fonts that follow platform level user preferences for text size

WCAG 2.0 Principles	Guidelines from Mobile Accessibility	Explanation of problems within previous data visualization	Techniques that must be used to overcome problems and incorporate into new visualization
	2.3 Contrast	Color contrast for the data visualization was tested. The squares in light green color were tested against the white background for color-contrast ratio test and the test was reported as failed in http:/webaim.org/resources/contrastchecker. Older users have decreased color and contrast perception capabilities and mobile devices are used under different situations such as outdoor, indoor, in motion and people especially with low vision have issues to access contents with poor contrast.	• G18: Ensure a contrast ratio of at least 4:5:1 exists between text and background • G14: Ensure the information conveyed from color differences is available in text • G183: Use contrast ratio of 3:1 with surrounding text and distinguishable visual cues for links and controls • For mobile platforms, use of text that is 1.5 times the default size on mobile devices does not guarantee that the text will be readable by persons with visual impairments. Under such cases, they may need to use built-in assistive technologies such as magnification, zoom in/out or audio output.
Operable	3.1 **Keyboard Control for touch-screen devices:**	Mobile devices consist of different interfaces ranging from physical keypads to on-screen and touch-sensitive	G59: Placing the interactive elements in an order that follows sequences and relationships

WCAG 2.0 Principles	Guidelines from Mobile Accessibility	Explanation of problems within previous data visualization	Techniques that must be used to overcome problems and incorporate into new visualization
		keyboard interface. These different keyboard interfaces must be useful for people with different disabilities including visual, dexterity and mobility.	within the content SCR26: Inserting dynamic content into the Document Object Model immediately following its trigger element C27: Making the DOM order match the visual order G149: Using user interface components that are highlighted by the user agent when they receive focus
	3.2 Touch Target Size and Spacing	Many interactive elements can be shown on a small screen, however, these elements must be big enough and have enough distance from each other so that they can easily and distinctly target each one of them. There are four quadrants in the data visualization which are the touch targets.	• Ensuring that touch targets are at least 9 mm high by 9 mm wide. • Ensuring that touch targets close to the minimum size are surrounded by a small amount of inactive space
	3.3 Touchscreen Gestures	Many mobile devices are designed to be primarily operated via gestures made on a touch-screen. Therefore, gestures must be simple and easy to	• Gestures in apps should be easy enough to replace touch interactions with screen reader

WCAG 2.0 Principles	Guidelines from Mobile Accessibility	Explanation of problems within previous data visualization	Techniques that must be used to overcome problems and incorporate into new visualization
		use and learn. In RevmaRApp, the gesture controls do not work with screen readers. It is not compliant with the voice-over accessibility feature available in iPhone 6S.	interactions using a two-step process of focusing and activating elements. • Do not use multi-touch gestures, rather use simple gestures easy enough for people who rely on head pointers or a stylus. • Activating elements via mouseup or touchend event. This means the element can only be accessed via touch trigger events such as: the user has lifted the finger off the screen, the last position of the finger is inside the actionable element, and the last position of the finger equals the position at touchstart. • Use touchscreen gesture instructions and
	3.5 Placing buttons where they are easy to access	Mobile application should position interactive elements where they are easily accessible if the device is held in	• Design applications for one hand use. • Design for left-handed and

WCAG 2.0 Principles	Guidelines from Mobile Accessibility	Explanation of problems within previous data visualization	Techniques that must be used to overcome problems and incorporate into new visualization
		different positions.	right-handed use. • Implement work around means to allow users to shift the display in multiple ways to facilitate one-handed operations.
Understandable	4.1 Changing Screen Orientation (Portrait/Landscape)	Mobile application must be able to change orientations to be used with assistive technologies. While testing with screen readers, orientation changes had no positive affect. There was no screen reader compatibility..	• Make it easy to change the orientation to return to a point at which their device orientation is supported • Make changes in orientation automatically detectable by assistive technologies using programmatically exposed means.
	4.2 Consistent Layout	In responsive designs, component arrangements depend on device size and screen orientations including consistency in placement of repeated components and navigational elements. However, under WCAG 2.0, consistency of components is not a requirement.	• G61: Presenting repeated components in the same relative order each time they appear. • G197: Using labels, names, and text alternatives consistently for content that has the same functionality • Ensuring that the text alternative conveys the

WCAG 2.0 Principles	Guidelines from Mobile Accessibility	Explanation of problems within previous data visualization	Techniques that must be used to overcome problems and incorporate into new visualization
			function of the component and what will happen when the user activates it • Using the same non-text content for a given function whenever possible
	4.3 Positioning important page elements before the page scroll	The small screen size on mobile devices limits the amount of content which can be displayed without scrolling. The list of activities in RevmaRApp has tendencies to get very lengthy and scrolling is required to view all of them.	Place important elements before the page scroll so that users who use screen magnifiers can locate important information easily. Consistent and predictable location of elements especially for users with cognitive impairments or low vision.
	4.4 Grouping operable elements that perform the same action	Multiple elements which perform the same action or direct to the same direction should be contained within same actionable element.	• ARIA8: Using aria-label for link purpose • G91: Providing link text that describes the purpose of a link
	4.5 Provide clear indication that elements are actionable	Elements that trigger changes should be sufficiently distinct to be clearly distinguishable from non-actionable	G61: Presenting repeated components in the same

WCAG 2.0 Principles	Guidelines from Mobile Accessibility	Explanation of problems within previous data visualization	Techniques that must be used to overcome problems and incorporate into new visualization
		elements. Interactive elements must also be detectable using assistive technologies such as screen readers. Elements such as forward button shown as “ >” is not distinguishable as active in RevmaRApp.	relative order each time they appear • ARIA6: Using aria-label to provide labels for objects • ARIA14: Using aria-label to provide an invisible label where a visible label cannot be used • ARIA16: Using aria-labelledby to provide a name for user interface controls
Robust	5.1 Set the virtual keyboard to the type of data entry required	Enable standard keyboard to be customized according to the settings of the device.	• Provide different virtual keyboards depending on type of data entry. • Provide settings to install custom keyboards
	5.2 Provide easy methods for data entry	Enable users to enter information on mobile devices using multiple	• Use of different modes of input such as on-screen keyboard, Bluetooth

WCAG 2.0 Principles	Guidelines from Mobile Accessibility	Explanation of problems within previous data visualization	Techniques that must be used to overcome problems and incorporate into new visualization
		ways	keyboard, touch and speech. Reduce the amount of text entry needed by providing select menus, radio buttons, check boxes or by automatically entering known information (e.g. date, time, location)

8.2 Results of heuristic evaluation for the new prototype:

The final improvements were made on the new prototype as per the comments and suggestion provided by the users during the experiments. The information from the experiments were used make necessary changes to the prototype. The final prototype was then evaluated using heuristic evaluation.

Table 7: Mobile Heuristic Walkthrough

WCAG 2.0 Principles	Guidelines from Mobile Accessibility	Explanation of problems within previous data visualization	Techniques that must be used to overcome problems and incorporate into new visualization
Perceivable	2.1 Small Screen size	The zoom in feature is not provided in the prototype but rather data is divided as per the selection of categories from the drop down menu. Only the data which match the selected categories are shown.	• Minimize the amount of information that is put on each page. • A dedicated mobile version which can be customized • A responsive design which can be used to render contents depending on viewport width. • Provide a reasonable default size for contents and touch control elements to minimize the use of zoom in/out features by users with visual impairments.

WCAG 2.0 Principles	Guidelines from Mobile Accessibility	Explanation of problems within previous data visualization	Techniques that must be used to overcome problems and incorporate into new visualization
	2.2 Zoom/Magnification	Zoom/Magnification is not available.	• Ensure that the browser pinch zoom is not blocked by the page's viewport meta element so that it can be used to zoom the page to 200%. • Support for system fonts that follow platform level user preferences for text size
	2.3 Contrast	Color contrast for the data visualization was tested. The base color of the user interface components were tested and found to pass the http:/webaim.org/resources/contrastchecker. Older users have decreased color and contrast perception capabilities and mobile devices are used under different situations such as outdoor, indoor, in motion and people especially with low vision have issues to access contents with poor contrast.	• G18: Ensure a contrast ratio of at least 4:5:1 exists between text and background • G14: Ensure the information conveyed from color differences is available in text • G183: Use contrast ratio of 3:1 with surrounding text and distinguishable visual cues for links and controls • For mobile platforms, use of

WCAG 2.0 Principles	Guidelines from Mobile Accessibility	Explanation of problems within previous data visualization	Techniques that must be used to overcome problems and incorporate into new visualization
			text that is 1.5 times the default size on mobile devices does not guarantee that the text will be readable by persons with visual impairments. Under such cases, they may need to use built-in assistive technologies such as magnification, zoom in/out or audio output.
Operable	3.1 Keyboard Control for touch-screen devices:	Mobile devices consist of different interfaces ranging from physical keypads to on-screen and touch-sensitive keyboard interface. These different keyboard interfaces must be useful for people with different disabilities including visual, dexterity and mobility. The interactive icons such as the activity bars, buttons such as the language buttons and settings and activity overview buttons are placed so that one handed operations can be performed easily but they seem to work not very well and response is slower or absent when screen reader is	G59: Placing the interactive elements in an order that follows sequences and relationships within the content SCR26: Inserting dynamic content into the Document Object Model immediately following its trigger element C27: Making the DOM order match the visual order G149: Using user interface components that are highlighted by the user agent when they receive focus

WCAG 2.0 Principles	Guidelines from Mobile Accessibility	Explanation of problems within previous data visualization	Techniques that must be used to overcome problems and incorporate into new visualization
		activated.	
	3.2 Touch Target Size and Spacing	The interactive icons such as the activity bars, buttons such as the language buttons and settings and activity overview buttons are placed so that one handed operations can be performed easily but they seem to work not very well and response is slower or absent when screen reader is activated.	• Ensuring that touch targets are at least 9 mm high by 9 mm wide. • Ensuring that touch targets close to the minimum size are surrounded by a small amount of inactive space
	3.3 Touchscreen Gestures	Many interactive elements can be shown on a small screen, however, these elements must be big enough and have enough distance from each other so that they can easily and distinctly target each one of them. The touch target size of interactive space around the buttons for settings and activity overview are small. Some icons seem very small for touch interactions including the slider for changing of color. The RGB sliders are also difficult to use.	• Gestures in apps should be easy enough to replace touch interactions with screen reader interactions using a two-step process of focusing and activating elements. • Do not use multi-touch gestures, rather use simple gestures easy enough for people who rely on head pointers or a stylus. • Activating

WCAG 2.0 Principles	Guidelines from Mobile Accessibility	Explanation of problems within previous data visualization	Techniques that must be used to overcome problems and incorporate into new visualization
			elements via mouseup or touchend event. This means the element can only be accessed via touch trigger events such as: the user has lifted the finger off the screen, the last position of the finger is inside the actionable element, and the last position of the finger equals the position at touchstart. Use touchscreen gesture instructions and
	3.5 Placing buttons where they are easy to access	Many mobile devices are designed to be primarily operated via gestures made on a touch-screen. Therefore, gestures must be simple and easy to use and learn. In the new application, the double tap gesture to activate user interface elements while using screen reader can be confusing for users and the double tap motion can be difficult to accomplish for people with arthritis.	• Design applications for one hand use. • Design for left-handed and right-handed use. • Implement work around means to allow users to shift the display in multiple ways to facilitate one-handed operations.
Understandable	4.1 Changing Screen Orientation	Mobile application must be able to change orientations to be used	• Make it easy to change the

WCAG 2.0 Principles	Guidelines from Mobile Accessibility	Explanation of problems within previous data visualization	Techniques that must be used to overcome problems and incorporate into new visualization
	(Portrait/Landscape)	with assistive technologies. Changing of orientation must not affect the responsiveness of the application.	orientation to return to a point at which their device orientation is supported • Make changes in orientation automatically detectable by assistive technologies using programmatically exposed means.
	4.2 Consistent Layout	In responsive designs, component arrangements depend on device size and screen orientations including consistency in placement of repeated components and navigational elements. However, under WCAG 2.0, consistency of components is not a requirement. The navigational features such as back button do not give the correct feedback when used with screen reader. Language change settings do not work as well when used with screen reader.	• G61: Presenting repeated components in the same relative order each time they appear. • G197: Using labels, names, and text alternatives consistently for content that has the same functionality • Ensuring that the text alternative conveys the function of the component and what will happen when the user activates it • Using the same non-text content for a given function whenever possible
	4.3 Positioning important page	The small screen size on	• Place important

WCAG 2.0 Principles	Guidelines from Mobile Accessibility	Explanation of problems within previous data visualization	Techniques that must be used to overcome problems and incorporate into new visualization
	elements before the page scroll	mobile devices limits the amount of content which can be displayed without scrolling. The list of activities shown in the overview consists of long list of activities which can be confusing since the user needs to scroll the entire list to get to specific activities.	elements before the page scroll so that users who use screen magnifiers can locate important information easily. Consistent and predictable location of elements especially for users with cognitive impairments or low vision.
	4.4 Grouping operable elements that perform the same action	Multiple elements which perform the same action or direct to the same direction should be contained within same actionable element.	• ARIA8: Using aria-label for link purpose • G91: Providing link text that describes the purpose of a link
	4.5 Provide clear indication that elements are actionable	Elements that trigger changes should be sufficiently distinct to be clearly distinguishable from non-actionable elements. Interactive elements must also be detectable using assistive technologies such as screen readers. Elements such as forward button shown as " >" is not distinguishable as active in RevmaRApp. The activities visualized as bars are not	G61: Presenting repeated components in the same relative order each time they appear • ARIA6: Using aria-label to provide labels for objects • ARIA14: Using aria-label to

WCAG 2.0 Principles	Guidelines from Mobile Accessibility	Explanation of problems within previous data visualization	Techniques that must be used to overcome problems and incorporate into new visualization
		recognized as interactive elements. They need to be marked as interactive elements so that users know that they can be clicked or tapped.	provide an invisible label where a visible label cannot be used • ARIA16: Using aria-labelledby to provide a name for user interface controls
Robust	5.1 Set the virtual keyboard to the type of data entry required	Enable standard keyboard to be customized according to the settings of the device. Tactile keyboard.	Provide different virtual keyboards depending on type of data entry. Provide settings to install custom keyboards
	5.2 Provide easy methods for data entry	Enable users to enter information on mobile devices using multiple ways Voice recognition	• Use of different modes of input such as on-screen keyboard, Bluetooth keyboard, touch and speech. Reduce the amount of text entry needed by providing select menus, radio buttons, check boxes or by automatically entering known information (e.g.

WCAG 2.0 Principles	Guidelines from Mobile Accessibility	Explanation of problems within previous data visualization	Techniques that must be used to overcome problems and incorporate into new visualization
			date, time, location)

8.3 Results from the experiment:

The data that was collected from the experiment was explored through summary statistics. The focus of this exploration was to discover the validity of data and selection of appropriate statistical test. The data showed that for tasks 1, 2 and 3 in the new prototype, the values for skewness and kurtosis were high. However for the remaining tasks, the skewness and kurtosis values remained low. This suggested that a paired – t test could be used. This was also selected because of its robustness.

There were significant differences of time taken to complete the tasks for old and new prototypes according to the paired t-test.

From the t test results, it is suggested that for the task 1 which asked participants to identify an activity or activities which were considered as important. The means suggested that participants took on average, 7.11 seconds to complete the task with the new data visualization while for old data visualization the average time was 29.31 seconds. The null hypothesis was rejected with, $t = -3.60$, $p < 0.001$. Therefore, the new data visualization prototype scored significantly higher than the old data visualization prototype in terms of time taken to complete the tasks.

For task 2, this asked participants to identify activities which were considered as duty. The means suggested that participants took on average, 7.35 seconds to complete the task with the new data visualization while for old data visualization the average time was 20.48 seconds. The null hypothesis was rejected with, $t = -3.39$, $p < 0.0006$. Therefore, the new data visualization prototype scored significantly higher than the old data visualization prototype in terms of time taken to complete the tasks.

For task 3, this asked participants to identify activities which were considered as less energy consuming or giving energy. The means suggested that participants took on average, 8.97 seconds to complete the task with the new data visualization while for old data visualization the average time was 35.25 seconds. The null hypothesis was rejected with, t = -4.91, p < 6.48031E-05. Therefore, the new data visualization prototype scored significantly higher than the old data visualization prototype in terms of time taken to complete the tasks..

For task 4, this asked participants to find out details of at least three activities. The means suggested that participants took on average, 27.59 seconds to complete the task with the new data visualization while for old data visualization the average time was 35.97 seconds. The null hypothesis was not rejected with, t = -1.24, p < 0.11. Therefore, the new data visualization prototype did not score significantly higher than the old data visualization prototype in terms of time taken to complete the tasks..

For task 5, this asked participants to interact using a screen reader. The means suggested that participants took on average, 131.34 seconds to complete the task with the new data visualization while for old data visualization the average time was 129.44 seconds. The null hypothesis was not rejected with, t = 0.08 , p < 0.46. Therefore, the new data visualization prototype did not score significantly higher than the old data visualization prototype in terms of time taken to complete the tasks. In the interviews the participants clarified that the new prototype was significantly better when used with screen readers than the old prototype. However, there were still serious issues with the new prototype as well and needed some improvements.

Task 6 was specific to each data visualization prototype. These tasks were not considered as a part of the paired t – test because the data is statistical irrelevant since the two tasks are not similar to each other and measure different things. Task 6 for new data visualization asked participants to change the color and size of the text, whereas the Task 6 for old data visualization asked participants to discover further information about each quadrant in the XY-axis plane. The participants were asked to think aloud when they were performing these tasks. The reactions thus obtained from the participants were used as suggestions for improvements before the final version of the new prototype was developed.

8.4 Results from the semi-structured interview:

A semi-structured interview was conducted at the end of every experiment for all 18 participants of the experiment. Each participant was asked a total of nine questions as shown in the interview plan in the appendix. This interview was conducted to get opinions and discover impressions of the participants on the two prototypes. For the first question which asked the participants about their experiences using smart-phones, all the participants answer they were familiar with it and everyone had used it for more than 1 year, which was the mandatory minimum that was set in the recruitment survey. All the users used various features of smart-phones and they were familiar with different mobile applications such as organizer, games, etc. The main purpose of using smart-phones for all the users for most cases was social media. For the second question, which asked users about their preference between the two prototypes, all 18 of the participants suggested they would prefer new prototype because it was easier and more convenient to use. They said it was more understandable and visualized data in a more legible manner. For the third and fourth questions which asked about the meaning of icons in each prototype, the opinions were almost similar for both prototypes. For the old prototype all 18 participants replied that none of them were able to understand the meanings of icons until they were explained about it. For the new prototype, the icons were not even realized as important since the data was sorted according to selection so they could remember what they could easily understand the visualizations. Some participants never even realized that there were icons in the new visualization and they were familiar with icons such as: Settings Icon, icon used for voice input, text-size and language options.

The fifth question asked the participants about the customization settings available in the new prototype. Almost all the participants were satisfied with the base design of the prototype and they did not feel it necessary to change it.

However, they tried changing the colors of the user – interface elements for exploration purposes and discovered it to be very useful. The sixth and seventh questions, asked the participants about whether they were able to obtain details about desired activities for each prototype. For both of these questions, the answers were almost the same and they found it almost equally easy for both prototypes to navigate for finding the details of activities since all 18 participants were able to complete the tasks. However, for the new data visualization the interaction time was found to be faster and easier as well as it also required less touch gestures for interaction. The eighth and the ninth questions asked about their experiences while using the two prototypes with screen readers. For the old prototype, the participants were not satisfied since the data visualization lacked screen reader compatibility and nothing on the screen was read and nothing could be interacted with. However, for the new prototype there was a mixed reaction. Some users found it easy to use and understand with screen reader while some wanted it to have further improvements. None of the participants were completely satisfied with the screen reader compatibility of the new prototype as well but all of them appreciated that it was much more screen reader friendly than the old prototype.

Chapter 9:

Discussion:

The purpose of this thesis is to design and develop a data visualization which is accessible and designed according to universal design standards. Therefore, this thesis is focused on two aspects: 1. Evaluation of existing data visualization available in a mobile application called RevmaRApp, 2. Development of a new prototype based on finding from evaluation. After the development of new prototype, an experiment was conducted with both the prototypes (i.e. Old and New data visualizations) to understand a variety of factors for both data visualizations. The process of development of prototype and the experiment, including the findings are discussed further in this chapter.

The design and development of interactive systems is highly demanding in terms of the requirements of the users and the different contexts of use(de Sá & Carriço, 2008). The context of use for mobile devices becomes even more complicated due to their nature of ubiquitous and pervasive computing as well as the availability of different type of mobile devices in the market(de Sá & Carriço, 2008). In this context, small sizes of screens adds additional challenge(de Sá & Carriço, 2008). Therefore, the first thing that was understood was that due to small screens of mobile devices it becomes extremely difficult to visualize all the information on a single screen.

RevmaRApp is an application which is targeted towards patients who are diagnosed with RA (Rheumatoid Arthritis) in Norway specifically. The percentage of elderly citizens in the developed nations is increasing, similarly, in Norway, it is estimated that 15-28% of the population will be over 67 years(13% in 2006)(Hellman, 2007). Such information must be taken into account when developing technologies for future and long term use. Therefore, accessibility issues play significant roles in success of technologies.

The seven principles of Universal Design which are discussed in section 2.3 of Chapter 2 are discussed further here in connection to the new prototype and the findings from the experiment and interviews.

Principle 1: Equitable Use:

To achieve this objective of equitable use, the prototype consists of customization features which can be used to change the appearances of user interface elements. Guideline 1a, suggests that same means or at least equivalent means of use must be provided for all users (NorthCarolinaStateUniversity, n.d.-a). Although the customization option helps to change different features such as color and size of text, only the appearances change but the underlying functionalities remain the same for any customizations. Guideline 1b, suggests that stigmatization and segregation of users must be avoided (NorthCarolinaStateUniversity, n.d.-a). Hence, the prototype is designed to be compliant with screen reader users and again different customization options address this issue as well. Guideline 1d, suggests that the design must be appealing to users (NorthCarolinaStateUniversity, n.d.-a). During experiments, most of the participants were satisfied with the base design of the prototype.

Principle 2: Flexibility in Use:

Guideline 2a, suggests that choice must be provided for methods of use. In the new prototype the users can interact with user elements using screen readers and customization settings help to customize the application according to the needs of the users. However, some other features such as speech input and tactile keyboard were not incorporated into this prototype. Guideline 2b, suggests that either right or left handed use must be supported. The experiments were conducted with participants wearing simulation gloves which simulated the affects of arthritis on hands. All the participants used the devices with both hands to navigate various features. Guideline 2c, suggests that user interactions must be precise and accurate. This was achieved for every touch target available on the screen such as icons, menu items and data elements. However, when screen reader was activated the new prototype had some issues which have been presented in the results section in Chapter 8.

Principle 3: Simple and Intuitive Use

This principle suggests that the design must be easy to understand, regardless of the user's experience, knowledge, language skills or concentration level.

Guideline 3a, suggests that unnecessary complexities must be avoided, therefore, the new prototype is especially designed with simplicity in mind. The interactions required to complete tasks to obtain required data visualization is kept very simple. The time taken to complete tasks were recorded using the experiment where almost all the tasks were completed faster for the new prototype in comparison to the tasks for the old prototype. These results are also explained further in chapter 8. Guideline, 3c suggests that different language and literacy skills must be accommodated as well. Therefore, simple language is used in the new prototype and technical jargons are avoided. Another important aspect is the availability of two language options where the users can select between Norwegian and English languages. The design of the new prototype is kept simple enough so that people with cognitive impairments may also benefit from using the new prototype. Therefore, it also fulfills guideline 3d which suggests, that arrangement of information must be consistent to importance.

Principle 4: Perceptible information

Guideline 4b of the fourth principle, suggests that adequate contrast must be provided between information and surroundings. This is achieved in the base design which uses white as the default background color and data is visualized in blue colors. This contrast level was checked in the contrast checker and discovered to be compliant with WCAG 2.0 standards. During the period of experiments as well, all the participants were satisfied with the default (base) design of the new prototype.

Principle 5: Tolerance for Error

In the fifth principle, it is suggested that error tolerance is very important. Guideline 5a, suggests that arrangement of elements must be done in such a way that errors are avoided, therefore, related elements are clustered in the same category. For example, the prototype consists of three categories, and each category consists of different variations which are listed under each category. Another important factor is that users are provided with the ability to revert back any changes without any problems.

During the experiment it was discovered that the users were confused when using ”None” variation available in the three categories (Importance, Energy and Motive). One of the participants suggested to use “All” instead of “None” in the menus. Although, all the participants were able to change the colors, it was difficult to use the sliders which are available in the color/contrast settings, especially when wearing the simulation gloves. This was also made more difficult when the participants used it with screen – readers. One of the causes of such problem was noticed as the inexperience of using screen-readers which was confessed by two of the participants.

Principle 6: Low Physical Effort

The sixth principle consists of guidelines which address issues related to efficient use with minimum fatigue. Guideline 6c, suggests that repetitive actions must be minimum therefore, in the new prototype, the touch interactions required to obtain specific results are kept simple. In the experiments it was discovered that the new prototype was easier to use for this particular fact as repetitive actions were minimum and mostly single interaction with one user – interface element was enough to obtain required results. Consequently this also fulfills guideline 6d, which suggests that physical effort must be minimized. Due to the need of fewer interactions the users felt less fatigue while using the new prototype even while they were wearing simulation gloves. Simulation gloves played an important role in the experiments as they simulated some of the problems faced by people with rheumatoid arthritis such as difficulty in movement of joints, fingers and wrists. It restricted the directional movement of joints and fingers as well as the plastic strips on the fingers made it difficult to move them by applying tensile pressure on them which also consequently simulated the affects of fatigue.

Principle 7: Size and Space for Approach and Use

The seventh principle consists of guidelines which address issues related to ease of use regardless of user’s body size, posture or mobility. Guideline 7b suggests that all components must be made easy to use and Guideline 7c suggests that accommodation must be provided according to hand and grip size. The new prototype is tested to have easy interaction capabilities with either hands. The user-interface elements are placed in such a manner that right or left handed users can easily access them. While conducting the experiments with the simulation gloves, it was understood that participants found it difficult to grab the mobile device for a longer period of time due to fatigue however, touch interactions with the prototype were found to have less or no effect leading to fatigue. Also the elements displayed on the screen were easy to use and accuracy of touch gestures were satisfying for normal use. However, when the users activated the screen readers, some elements of the user – interface were not easily accessible such as the language button for English was not active and the users also found it very difficult to toggle between “Settings” button and “Activity Overview” button.

Universal design means that we must try to include a majority of the population while designing and developing a product .The main target user groups for the new prototype are people who have rheumatoid arthritis. Therefore, we focused on people with dexterity problems while developing the prototype. Other impairments such as vision impairments were also taken into account. The prototype has been designed to ensure ease of use for people with cognitive disabilities as well. The seven principles of Universal Design as mentioned in section 2.3 of Chapter 2 were followed to design an accessible new prototype.

Complicated tasks are simplified and logical grouping of user interface elements is created to continue in the tradition of ease of access. The user is provided with ample amount of time to make decisions and also revert them if necessary, which will not have any serious consequences on the data visualizations. For example, there is no particular time constraint on selecting the categories of data, the user is provided with flexibility of use and any changes can be reverted to return back to previous state. The user can also use the built in navigational features of devices such as back button and home button to navigate the prototype as well. Therefore, special considerations were made towards easy navigation and work flow(Hellman, 2007).

While visualization is one part of the thesis, another important aspect was accessibility. The two step methodology (unified methodology) was used to develop accessible prototype which is described in detail in Chapter 4. As per this methodology, both the visualizations were evaluated for accessibility issues. The old data visualization was discovered to have several issues related to accessibility such as use of colors as the only means to convey information and minimal screen reader support. These issues are detailed further in the Chapters 4 and 8. The evaluation was done using the WCAG 2.0 for mobile accessibility. The results from this evaluation were tallied against the data from the user testing that was done by the Norwegian Computing Center. A list of requirements was gathered from these results. Finally personas were used to create a user centered approach for prototype development where the personas were based upon the four participants who had taken part in the user testing.

After the completion of evaluation, a universal designed prototype which can be accessible for users and fulfill the maximum amount of requirements was developed. After the completion of the new prototype, an experiment was done with both (i.e. Old and New) prototypes. The experiment consisted of six tasks for each prototype. When the experiments were carried out for the old prototype, a number of participants found it difficult to find out specific details about the value for energy from looking at the graph. The graph represented energy in the form of colors which is described further in Chapter 1. Therefore, in the new prototype energy is represented by the size of the bars. This is done specifically to curb the dependency on the use of colors as the only means of conveying information.

Multimodal interaction techniques were also employed in the new prototype. The new prototype has been developed to comply with screen readers. The elements of the user interface and data elements are easily read by the screen reader and it is context aware which means changes to the data are also addressed. In terms of textual contents, two language options have been provided and users can easily select either English or Norwegian as their language of choice. Various customization options have been provided described further in Chapter 6. These customization options provide flexibility to change the color and size of textual and graphical contents according to the needs of the users.

The experiments were followed by semi-structured interviews; to get in-depth knowledge about prototypes and user experiences. The suggestions provided in the interviews were used to make improvements over the new prototype. Finally, a heuristic evaluation was done on the new prototype. This evaluation suggested the necessary adjustments for the future, which are described further in future scope.

The new prototype is developed as a new concept of data visualization especially targeted towards mobile applications such as RevmaRApp. Since mobile devices have small screens, it becomes difficult to visualize large amount of data into one screen. Therefore, in the new prototype the users are offered some features to sort the data according to their selections. However, the main focus of this thesis was to create an accessible prototype which adhered to the various technical guidelines such as WCAG 2.0 for mobile accessibility, WAI-ARIA and logistical guidelines such as ETSI – EG 202 116, BS8878. The prototype has been developed as an accessible product which adheres to the guidelines as mentioned above. The user is given the flexibility to customize the user interface elements which provides the user an ability to choose colors for various user interface elements and change the size of text as well as the language according to his/her needs. The old data visualization also did not possess the capability to interact with screen readers at all. In the new prototype I have developed the data visualization which can interact with screen readers using various accessibility libraries provided by Angular JavaScript such as ng-aria(AngularJS, n.d.).

The prototype however, still needs more improvements. In the case of multi-modal interaction, a speech input system can be integrated as well as a tactile keyboard can also provide added benefits for the users. However, there has not been much research on tactile technologies for touch-based devices (Hoggan, Brewster, & Johnston, 2008). Tactile feedback technologies such as vibration-based haptic uses vibration feedback when a button is tapped on a touchscreen device, however, such tactile feedbacks do not possess the same experience as interacting with button presses. Some issues such as errors in data entry, poor typing speeds and poor feedback are rampant among touchscreen devices such as smart-phones(Barde & Purkar, 2013). These issues make touchscreen devices inaccessible for people with severe vision impairments, dexterity impairments such as arthritis and severe cases such as Parkinson`s.

In most touch screen devices, tactile feedbacks such as vibrations or sound are used when users interact with user interface elements such as on-screen keyboard. Tactus (Barde & Purkar, 2013) is a new technology which has broken the conventional barriers of using vibrations and sounds as feedbacks in touch screen devices. Tactus consists of physical and completely transparent buttons which arise from the surface of touchscreen devices and they fall back whenever they are not required. These buttons are filled with fluid which fills up the button when they raise from the touchscreen devices. Such physical feedback can be useful for the target user groups of the new prototype as well.

The new prototype also consists of long lists of activities which have to be scrolled to view. This feature might also present difficulties especially for people with issues of dexterity and cognitive impairments(Hellman, 2007).

In the experiment, simulation gloves were used to simulate the affects of arthritis on hands. The user group consisted of students who wore these gloves while conducting the experimental tasks. A total of 18 participants were recruited using a recruitment questionnaire, which was sent to 23 individuals from which 18 agreed to take part in the experiment. The experiment was designed around the main research questions (see Chapter 1, Problem statements). Appropriate hypotheses were drawn (see Chapter 7). A list of six tasks for each prototype was created which were performed by the participants. For this experiment, I used the within groups approach, which means, the same 18 participants were asked to perform six tasks for each prototype. This approach is beneficial since it only requires small sample size and the sample of participants remains constant for both prototypes therefore, there is a little chance external factor will influence results. However, there can be issues with memorization of performance and tasks, fatigue etc. These issues were tackled using randomization technique where some users were given the new prototype first while others were given old prototype at first. The time taken to complete each task was recorded for each participant.

To test the hypotheses that the new prototype was more accessible in design and ease of use, a paired sample t-test was conducted. The new prototype (M_1 = 36.04, SD_1 = 48.06) and old prototype (M_2= 51.88, SD_2 = 40.30) were found to have a significant amount of difference. According to our hypothesis:

$H_0 : M_d = 0 \Rightarrow M_1 - M_2 = 0$ (i.e. $M_d = 0$)

$H_1: M_d < 0, M_1 < M_2 \Rightarrow M_1 - M_2 < 0$ (i.e. $M_d < 0$)

P-value < 0.05

The results of the experiment suggested that, the new concept of data visualization was statistically significant over the old data visualization in terms of the completion of tasks, which was directly related to performance. The tasks were designed in such a way that the error would lead to failure of task therefore; all the participants were able to perform the tasks. The four hypotheses (i.e. H_1, H_2, H_3, H_4) which are stated in chapter 8 are therefore accepted. However, the experiment has a few shortcomings in terms of experimental design, such as:

1. The number of participants is small.

2. The use of simulation gloves to simulate the affects of arthritis on hands.

Only 18 participants took part in the experiment. Although the results of the experiment showed significant positive lean towards the new prototype, in order to make a conclusive statement further experiment improving on the first one is still necessary. Simulation gloves were used to replicate the affects of arthritis on hands and fingers. The gloves could help to replicate the affects of arthritis in terms of diminished mobility and restrictions of directional movements of fingers and hands, however affects related to pain, motor and sensory stimulations cannot be replicated by the gloves. Therefore, recruitment of participants who are diagnosed with arthritis can lead to more accurate results, but the use of simulation gloves was also advantageous in terms of uniformity of impairment. The use of simulation gloves made it possible to have a better control over the uniformity of the impairments, than using people with real impairments because if people with real impairments were used then they would have had a variety of conditions and impairments.

Chapter 10:

Conclusion and Future Work:

The main goal of this thesis was to design and develop a data visualization prototype adhering to the standards of Universal Design. Various Universal Design and accessibility standards, principles and legislations relevant to our prototype are discussed further in different chapters in this thesis. Through literature survey and study of previous researches it was discovered that there is a lack of use of Universal Design standards in design and development of mHealth [sic] applications. There are several national and international laws which are created to enforce and encourage the use of Universal Design standards to provide equality for all. However, there seems to be a lack of strong motivation to adherence and enforcement of these laws.

This thesis consisted of two parts. The first part was the evaluation of the old prototype. This was done using data obtained from the user testing conducted by Norwegian Computing Center and the heuristic evaluation specifically done in this thesis. The second part of the thesis was to develop a new data visualization prototype.

The result obtained from the heuristic evaluation conducted in this thesis was tallied against the user testing information provided by the Norwegian computing center. Based on these two sources a list of requirements was created. It also confirmed the fact that there was a lack of use of Universal Design standards in the existing data visualization in RevmaRApp [sic]. Following the user-centered approach personas were created from the information provided by the user testing which was conducted by Norwegian Computing Center.

The two-step methodology (unified methodology) is used in this thesis. In the two-step methodology, the evaluation process is started early in the development process so as to discover as many accessibility issues as early as possible. The first step of the two-step methodology is to evaluate and test. The final product is delivered after development is completed which is again tested through heuristic evaluation done specifically in this thesis. This methodology was used in similar fashion in this thesis as well.

In any project involving development of software applications, it is necessary to select a good software engineering process to ensure that the delivery of the product is on time and under budget. In this thesis, I chose to use Scrum since it is suitable for designing new applications as well as updating the existing ones. Scrum also uses the iterative approach of software development which made it very suitable for this prototype development, because I have used the two step methodology (unified methodology).

People with various types of impairments occupy a significant amount of the global population. We must therefore, try to include them in design and development of technologies. “mHealth” [sic] applications which are especially targeted toward the healthcare industry must be even more accessible. Universal Design can be one stepping stone for this purpose. There are various technical guidelines such as WCAG 2.0 [sic], WAI-ARIA[sic] etc and there are also various logistical and legislative guidelines such as ETSI [sic], BS 8878, ADA, Rehabilitation Act. These technical and logistical guidelines are the basis for developing accessible systems. In this thesis, the new prototype is developed in compliance to the relevant guidelines to design and develop an accessible mobile application.

The goal of designing a new prototype was to make it accessible for people with rheumatoid arthritis who had problems related to dexterity and movement of hands and fingers. According to Universal Design, it is necessary to design and develop a system to make it accessible for a large volume of the population. Therefore, the new prototype consisted of various customization options which could be used to customize it according to the needs of the users. Special considerations were also made for screen-reader users and the prototype was designed to be compliant with screen-reader technologies. Experiments were conducted with the built-in screen reader technologies in Android and Apple mobile phones to extract further information regarding improving the screen reader experiences. The findings suggested that although the new prototype had better screen reader support, it still needs further improvements.

Many previous literatures from research as well as different Universal Design guidelines suggest that multi-modal means of communication must be established. Therefore, in future, the new prototype can consist of features containing multi-modal input like speech input and tactile keyboard. These features can be extremely beneficial for our user group. Another issue is related to the use of icons. Although this issue is not within the scope of this thesis, but in this thesis, there are some issues regarding usage of abbreviations in the place of icons. The icons used in the old data visualization model was discovered to be difficult to understand by the users, therefore these icons were replaced with new abbreviations of categories as shown in Table 5. Although this approach was found to be more relatable to categories when the English language was used for the prototype, it had no meaning when used with Norwegian language. This suggests that abbreviations are language dependent and it becomes difficult to use abbreviations when multiple languages are used for mobile applications. Therefore, a research is required to understand the use of suitable icons which can be universal in nature and translate across different languages. The evaluation study can be made more extensive to include more users. The experiments that were conducted for this thesis consisted of small amount of participants. Another issue was regarding the use of simulation technique using the Cambridge Simulation gloves. Therefore, in future, further experiment which could improve and ascertain the findings of this experiment consisting of a larger number of actual participants who have rheumatoid arthritis can be more accurate to provide conclusions. The experiments have shown that the new prototype seems promising to solve some issues related to Universal Design and with some improvements as mentioned before; it can be really useful for different user groups besides the target population. The experiment can also further incorporate users with cognitive impairments to test if the prototype is simple enough to be used by them.

Appendix:

List of Abbreviations:

Abbreviations	Full Forms
WHO	World Health Organization
mHealth	Mobile Health
ECG	Electro Cardio Graph
IBM	International Business Machine
WBAN	Wide Body Area Network
HIPAA	Health Insurance Portability and Accountability Act
IRD	Interactive Research and Development
NFC	Near Field Communication
RFID	Radio Frequency Identification
SSL	Secure Socket Layer
HTTP	Hyper Text Transfer Protocol
HTML	Hyper Text Markup Language
SDK	Software Development Kit
XML	Extensible Markup Language
WYSIWYG	What You See Is What You Get
ARM	Advanced RISC Machine
MVC	Model View Controller

Abbreviations	Full Forms
ETSI	European Telecommunications Standards Institute
CEN/ CENELEC	European Committee for Electro technical Standardization
ANEC	European Association for Co-ordination of Consumer Representation in Standards
ADA	Americans with Disability Act
RIA	Rich Internet Applications
NGOs	Non-Governmental Organizations
W3C	World Wide Web Consortium
WCAG	Web Content Accessibility Guidelines
ATAG	Authoring Tool Accessibility Guidelines
UAAG	User Agent Accessibility Guidelines
WAI-ARIA	Web Accessibility Initiative-Accessible Rich Internet application
BS 8878	British Standard 8878
DHTML	Dynamic Hyper Text Markup Language
ICT	Information Communication Technology
GUI	Graphical User Interface
LCD	Liquid Crystal Display
CG	Computer Generated

This is a survey for an experiment design for a thesis project. The target audience of this survey is primarily students studying Universal Design of ICT at HIOA, Oslo - Norway. Details of experiment: The users recruited from this survey will be requested to appear for an experiment at HIOA. The experiment consists of a comparative study between two data visualizations using two smart phones (Android and Apple). One of the two data visualizations is a prototype designed by the author of this survey.

1. Are you currently enrolled as a student?

- Yes
- No

2. Do you have a Smartphone?

- Yes
- No

3. What type of mobile telephone do you PRIMARILY use?

- Regular cell/mobile phone (not a Smartphone)
- Android
- iPhone
- Blackberry/RIM
- Windows Mobile
- I don't have a mobile phone

4. Are you familiar with smart phones?

- Yes
- No

5. What is your age?

- Below 20

- 20-35
- 35-40
- above 40

6. How long have you been using smart phones?

- less than a year
- 1-5 years
- 5-10 years
- more than 10 years

7. Do you download and use mobile applications on smart phones?

- Yes
- No

8. How often do you download new Smartphone mobile applications?

- Frequently
- Sometimes
- Never

9. Would you like to appear for an interesting experiment at HiOA?

- Yes
- No

Interview Plan:

Name of Interviewer: -------------------------

Name of the Participant: ---------------------------

Project Title: **A universally designed and usable method for data visualization.**

Questions:

Main Question	**Follow-up Questions**	**Clarifying Questions**
1. Are you familiar with smart-phones and mobile applications?	• How long have you been using it? • What do you use it for?	• Is there anything else you might want to add? • Can you provide some examples?
2. Which data visualization did you find easier to understand?	• Why? • Why not? What are the problems in it?	• Can you provide further information? • Can you provide any expert opinions?

3. Were you able to understand the meaning of icons in the old RevmaRApp application?	• Why? • Why not? What are the reasons for dissatisfaction ?	• Can you elaborate your problems? • Can you discuss some problems you faced to understand the meaning of icons?
4. Were you able to understand the meaning of icons in the new RevmaRApp application?	• Why? • Why not? What are the reasons for dissatisfaction ?	• Can you elaborate your problems? • Can you discuss some problems you faced to understand the meaning of icons?
5. Did the customization settings on the new RevmaRApp application seem beneficial for you?	• What do think should be added more? • Were you able to understand and make customizations?	• Can you provide any further suggestions?

6. Were you able to get further information about each activity in the new RevmaRApp application?	• Did anything confuse you? • Did you tap or interact with the bar which represented activity?	• Did you find it easy to interact with the bars? • Do you have any further suggestions to make it better?
7. Were you able to get further information about each activity in the old RevmaRApp application?	• Did anything confuse you? • Did you tap or interact with the bar which represented activity?	• Did you find it easy to interact with the bars? • Do you have any further suggestions to make it better?
8. Did the screen reader interaction with old RevmaRApp satisfy you?	• Where did you find difficulties when using the screen reader? • Is it easy to use?	• Can you tell me anything else? • Is there better solution/exampl es?
9. Did the screen reader interaction with new RevmaRApp satisfy you?	• Where did you find difficulties when using the screen reader? • Is it easy to use?	• Can you tell me anything else? • Is there better solution/exampl es?

Consent form: This is the consent form which was signed by all the participants.

Project Title:

A universally designed and usable method for data visualization.

I agree to participate in this project, whose conditions are as follows:

1. **The aim of the project is to understand the accessibility issues present in the data visualization in a mobile application called RevmaRApp and provide necessary recommendations and a prototype design for new data visualization.**
2. **Interviews will be conducted for up to 30 minutes.**
3. **The interview will only be used for the purpose of defined project research question.**
4. **The interview participant can refuse to answer questions or have a discussion regarding questions and stop the interview if he/she feels the interview is not relevant.**
5. **All of the interview data will remain confidential. Information will be kept anonymous and encrypted.**
6. **All types of data will be destroyed after the project is completed.**
7. **For any further information, please contact:**

    i. Suraj Shrestha, +47 40 59 37 75, s237415@stud.hioa.no

Respondent's Signature:

Date:

Interviewer's Signature:

Date:

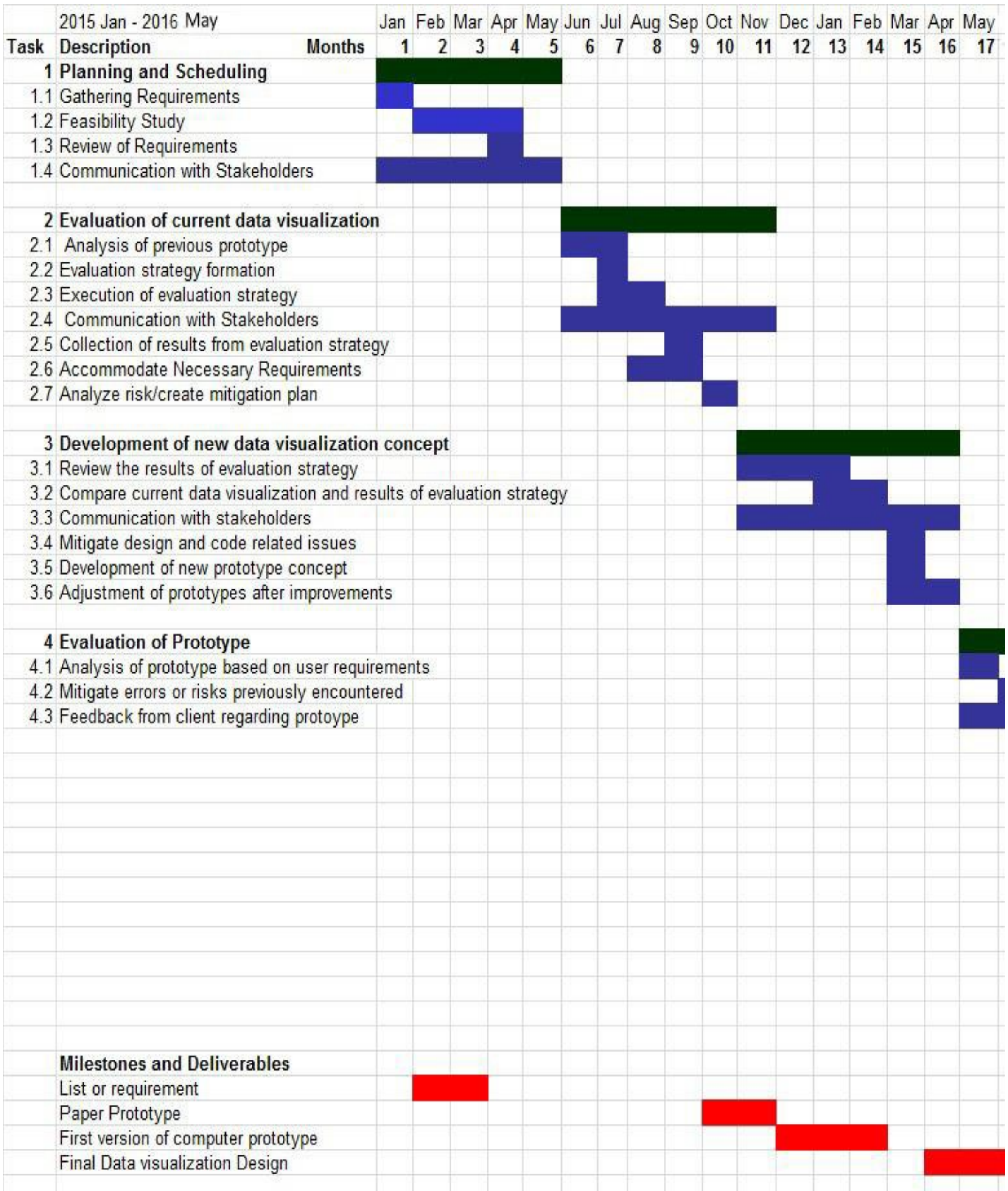

Figure 40: Gantt Chart

Summary Statistics:

	Task 1	*Task 2*	*Task 3*	*Task 4*	*Task 5*	*Task 6*	*Task 1*	*Task 2*	*Task 3*	*Task 4*	*Task 5*	*Task 6*
Mean	7.117777778	7.351666667	8.972222222	27.59888889	131.3466667	33.89111111	29.31777778	20.48833333	35.25166667	35.97388889	129.4444444	60.86
Standard Error	1.578636492	1.987096488	2.349212572	3.928520726	13.87285894	3.234431377	6.278091409	3.64220084	6.032887171	5.123217888	13.95633298	8.679236699
Median	5.45	4.515	5.48	20.355	135.5	30.835	22.005	18.56	30	35.625	129.5	52.45
Mode	6.84	#N/A	5	#N/A	#N/A	25	#N/A	#N/A	30	50	138	92
Standard Deviation	6.697587411	8.430536407	9.966864842	16.66730187	58.85755576	13.72253016	26.63568605	15.45254948	25.59537257	21.73597266	59.21170614	36.82288275
Sample Variance	44.85767712	71.07394412	99.33839477	277.7989516	3464.211871	188.307834	709.4597712	238.7812853	655.1230971	472.4525075	3506.026144	1355.924694
Kurtosis	6.071352341	13.09254139	12.44305217	-0.866351153	0.097338637	-0.350767449	1.014515674	1.731338395	0.188974726	1.614816979	-0.26646081	2.09158476
Skewness	2.522811918	3.444703655	3.337258363	0.721494982	-0.297389742	0.594528062	1.223996892	1.257383345	0.833572874	0.907377417	0.596239292	1.414820376
Range	26.1	36.61	43.55	49.79	227.47	46.6	93	59.37	89.38	86	203	144.57
Minimum	1.9	2.39	2.45	7.4	2.53	13.5	2	1.63	4.62	8	47	18.43
Maximum	28	39	46	57.19	230	60.1	95	61	94	94	250	163
Sum	128.12	132.33	161.5	496.78	2364.24	610.04	527.72	368.79	634.53	647.53	2330	1095.48
Count	18	18	18	18	18	18	18	18	18	18	18	18
Confidence Level(95.0%)	3.330631832	4.192407086	4.956405235	8.288454149	29.26917362	6.824053642	13.24561493	7.684372	12.72827922	10.80904481	29.44528846	18.31158862

Figure 41: Summary Statistics derived from Experiment

Paired t-test:

t-Test: Paired Two Sample for Means												
	Task 1	*Task 1 old*	*Task 2*	*Task 2 old*	*Task 3*	*Task 3 old*	*Task 4*	*Task 4 old*	*Task 5*	*Task 5 old*	*Task 6*	*Task 6 old*
Mean	7.117777778	29.31777778	7.351666667	20.48833333	8.972222222	35.25166667	27.59888889	35.97388889	131.3466667	129.4444444	33.89111111	60.86
Variance	44.85767712	709.4597712	71.07394412	238.7812853	99.33839477	655.1230971	277.7989516	472.4525075	3464.211871	3506.026144	188.307834	1355.924694
Observations	18	18	18	18	18	18	18	18	18	18	18	18
Pearson Correlation	0.200756475		0.392852058		0.47217122		-0.087543498		-0.175274801		0.068315081	
Hypothesized Mean Difference	1		1		1		1		1		1	
df	17		17		17		17		17		17	
t Stat	-3.767147198		-4.163660313		-5.107149071		-1.394376902		0.042291865		-3.089491909	
P(T<=t) one-tail	0.000768317		0.000325363		4.38124E-05		0.090580392		0.483379395		0.003326312	
t Critical one-tail	1.739606716		1.739606716		1.739606716		1.739606716		1.739606716		1.739606716	
P(T<=t) two-tail	0.001536634		0.000650727		8.76248E-05		0.181160783		0.96675879		0.006652624	
t Critical two-tail	2.109815559		2.109815559		2.109815559		2.109815559		2.109815559		2.109815559	

Figure 42: Paired t-test result derived from experiment

T Test: Two Paired Samples								
SUMMARY			Alpha	0.05		Hyp Mean	0	
Groups	*Count*	*Mean*	*Std Dev*	*Std Err*	*t*	*df*	*Cohen d*	*Effect r*
Task 1	18	7.117778	6.697587					
Task 1 old	18	29.31778	26.63569					
Difference	18	-22.2	26.12833	6.158506	-3.60477	17	0.849652	0.6582
T TEST								
	p-value	*t-crit*	*lower*	*upper*	*sig*			
One Tail	0.001093	1.739607			yes			
Two Tail	0.002186	2.109816	-35.1933	-9.20669	yes			

Figure 43: Paired t-test for Task 1(New and Old)

SUMMARY			Alpha	0.05		Hyp Mean	0	
Groups	*Count*	*Mean*	*Std Dev*	*Std Err*	*t*	*df*	*Cohen d*	*Effect r*
Task 2	18	7.351667	8.430536					
Task 2 old	18	20.48833	15.45255					
Difference	18	-13.1367	14.40482	3.39525	-3.86913	17	0.911963	0.684291
T TEST								
	p-value	*t-crit*	*lower*	*upper*	*sig*			
One Tail	0.000616	1.739607			yes			
Two Tail	0.001231	2.109816	-20.3	-5.97332	yes			

Figure 44: Paired t-test for Task 2(New and Old)

T Test: Two Paired Samples								
SUMMARY			Alpha	0.05		Hyp Mean	0	
Groups	*Count*	*Mean*	*Std Dev*	*Std Err*	*t*	*df*	*Cohen d*	*Effect r*
Task 3	18	8.972222	9.966865					
Task 3 old	18	35.25167	25.59537					
Difference	18	-26.2794	22.66174	5.341423	-4.91993	17	1.159639	0.766444
T TEST								
	p-value	*t-crit*	*lower*	*upper*	*sig*			
One Tail	6.48031E-05	1.739607			yes			
Two Tail	0.000129606	2.109816	-37.5489	-15.01	yes			

Figure 45: Paired t-test for Task 3 (New and Old)

T Test: Two Paired Samples								
SUMMARY			Alpha	0.05		Hyp Mean	0	
Groups	*Count*	*Mean*	*Std Dev*	*Std Err*	*t*	*df*	*Cohen d*	*Effect r*
Task 4	18	27.59889	16.6673					
Task 4 old	18	35.97389	21.73597					
Difference	18	-8.375	28.52511	6.723433	-1.24564	17	0.293601	0.289203
T TEST								
	p-value	*t-crit*	*lower*	*upper*	*sig*			
One Tail	0.114895	1.739607			no			
Two Tail	0.229791	2.109816	-22.5602	5.810204	no			

Figure 46: Paired t-test for Task 4 (New and Old)

T Test: Two Paired Samples								
SUMMARY			Alpha	0.05		Hyp Mean	0	
Groups	*Count*	*Mean*	*Std Dev*	*Std Err*	*t*	*df*	*Cohen d*	*Effect r*
Task 5	18	131.3467	58.85756					
Task 5 old	18	129.4444	59.21171					
Difference	18	1.902222	90.50924	21.33323	0.089167	17	0.021017	0.021621
T TEST								
	p-value	*t-crit*	*lower*	*upper*	*sig*			
One Tail	0.464996	1.739607			no			
Two Tail	0.929991	2.109816	-43.107	46.91141	no			

Figure 47: Paired t-test for Task 5 (New and Old)

T Test: Two Paired Samples								
SUMMARY			Alpha	0.05		Hyp Mean	0	
Groups	*Count*	*Mean*	*Std Dev*	*Std Err*	*t*	*df*	*Cohen d*	*Effect r*
Task 6	18	33.89111	13.72253					
Task 6 old	18	60.86	36.82288					
Difference	18	-26.9689	38.40824	9.052909	-2.97903	17	0.702164	0.58565
T TEST								
	p-value	*t-crit*	*lower*	*upper*	*sig*			
One Tail	0.004211	1.739607			yes			
Two Tail	0.008423	2.109816	-46.0689	-7.86892	yes			

Figure 48: Paired t-test for Task 6 (New and Old)

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