USING INFORMATION VISUALISATION TO SUPPORT THE SELF-MANAGEMENT OF TYPE 2 DIABETES MELLITUS

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USING INFORMATION VISUALISATION TO SUPPORT SELF-MANAGEMENT OF TYPE 2 DIABETES MELLITUS

by

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Submitted in fulfilment of the requirements for the degree of Magister Scientiae in the Faculty of Science at the Nelson Mandela Metropolitan University

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I, Meggan Kate Naude with student number 213203510 and ID number 9405080117080, hereby declare that the dissertation for MSc Computer Science and Information Systems to be awarded is my own work and that it has not previously been submitted for assessment or completion of any postgraduate qualification to another University or for another qualification.

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Abstract

The globally increasing number of individuals suffering from Type 2 Diabetes Mellitus (T2DM), a completely preventable incurable disease of the pancreas, highlights the need for an effective tool for users to understand the relationship between their behaviours and the effect that those behaviours can have on their blood glucose levels (BGLs). There are few Information Visualisation (IV) tools available that can be used to reduce the cognition required to understand correlations between behaviour and BGLs.

Existing tools require time-consuming, lengthy inputs and provide simple visualisations that do not show correlations. This leads to ineffective self-management of T2DM. Information Visualisation (IV) techniques can be used to support effective self-management of T2DM and reduce the cognition required to interpret DM data. Suitable IV techniques were identified and used to visualize T2DM data to aid in the self-management of the disease.

Temporal charts, i.e. The Bar, Pie and Line Chart as well as heat maps, were selected as the most appropriate IV techniques to visualize T2DM data as they support time-series data well. A prototype, MedicMetric was created as an IV tool for visualizing T2DM data. MedicMetric incorporated three designed charts, namely the Change Rate Line View, the Radial Progress View, and the Annotated Line View. The Change Rate Line View and Annotated Line View both used line IV techniques, while the Radial Progress View made use of the bar IV technique. The Change Rate Line View performed the worst overall.

A usability evaluation was conducted to compare these techniques and to determine which technique is most suitable for visualizing T2DM data. The results leaned significantly in favour of the Annotated Line View. This view is most similar to the line charts typically used in other IV tools. For this reason, the MedicMetric app was briefly compared to the MySygr and Diabetes:M application. In effectiveness and efficiency, MedicMetric and MySugr obtained almost identical results. However, participants indicated that MedicMetric supported their tasks using the Visual Information Seeking Mantra (VISM) the best overall, with 100% of participants stating that they would prefer to use the MedicMetric application.

Several usability problems were identified with the IV techniques and they were addressed shortly after the study was complete. Overall participants were most satisfied with the Annotated Line View.

Keywords: Diabetes Mellitus, Information Visualisation, Self-Management, Information Visualisation Techniques

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Abbreviations

API	Application Programming Interface
BGL	Blood Glucose Level
BP	Blood Pressure
CGM	Continuous Glucose Monitor
DoD	Details-on-Demand
DM	Diabetes Mellitus
GFHP	Gordons Functional Health Patterns
GUI	Graphical User Interface
IV	Information Visualisation
JSON	JavaScript Object Notation
MBGM	Medtronic Blood Glucose Monitor
PGHD	Patient Generated Health Data
RPM	Remote Patient Monitoring
T1DM	Type 1 Diabetes Mellitus
T2DM	Type 2 Diabetes Mellitus
VISM	Visual Information Seeking Mantra

1 Introduction

1.1 Background

Diabetes mellitus (DM) is a long-lasting, and rarely completely cured chronic disease that affects roughly 422 million people worldwide (Roglic, 2016) Many diabetes cases are preventable through lifestyle change (Hu, 2011), but most of those who struggle with the condition lack the correct tools for understanding and tracking their insulin intake.

The most prominent cause of death for people with Type-2 DM (T2DM) is cardiovascular disease (Tancredi et al, 2015). This is an indicator that besides poor insulin intake tracking, patients have habits that impede their recovery. By not understanding the relationship between their insulin intake, blood sugar levels (BGLs), exercise, food intake, heart disease, and blood pressure (BP) (Delahanty, 2017), individuals living with DM are less likely to make health decisions, which are in their best interest.

DM occurs when the pancreas fails to produce insulin, a hormone that allows sugar (glucose) to be transferred from the bloodstream to cells that depend on it for energy (Smith and Frost, 2003). DM patients typically measure their blood sugar levels to understand their present physiological state. As a measure of one's state of health, this data cannot explain the fundamental factors leading to abnormal health. DM can be a predecessor to many other degenerative diseases, including heart disease, strokes, and birth defects and is the leading cause of kidney failure, amputations and adult blindness (Eknoyan et al, 2003).

DM cannot be cured, but it can be controlled with insulin supplements, oral medication and lifestyle changes such as increasing exercise, decreasing fat and carbohydrate consumption and monitoring Blood Glucose Levels (BGLs) (Schiffrin and Belmonte, 1982). Glucose meters (GMs) allow patients to monitor their BGLs and facilitate a dramatic increase in the lifespan of DM patients by giving them immediate feedback on how they are managing their BGLs (Smith, 2002).

A 'health pattern' can be described as a model used to give a regular or intelligent form to data. It can be used to predict outcomes for patient actions based on historical data. Patients' understanding of their health and medical conditions can be improved by interactive visual presentations that allow drilling down to gain background information, show comparisons and highlight anomalies

(Schneiderman, Hesse and Plaisant, 2013). Health pattern visualisations can also help reduce errors in clinical care, provide essential and up-to-date information about a patient's medical and other activities, and provide insight into a potential solution to their health-related problems (Bui & Hsu, 2010).

Information Visualisation (IV) is a method for representing data in a nontraditional, interactive, graphical form (Gelman and Unwin, 2013). IV allows for clear indication of information structure, navigation and alteration through graphical interactions. IV is utilized in many fields, including human-computer interaction (Few, 2015), computer science, graphics, psychology and business methods, and can be customized for various applications (Schneiderman, Hesse and Plaisant, 2013). Interactive IV and visual analytics methods could bring profound changes to personal health programs, healthcare delivery and self-management for patients through effective presentation of visual information (Chou, 2012).

In research conducted at Pennsylvania State University (Smith and Frost, 2003), a group of diabetics were asked to use a visual aid (in their case photographs) to help them visualize their daily routines. In the hospital classroom, patients photographed their activities and shared their experiences with their peers and medical professionals. A secondary visualisation was created to aid in showing them overviews of their glucose levels to help them identify a connection. The patients claimed that the system allowed them to easily find long-term blood sugar trends, while the daily views allowed them to make connections between their blood glucose levels (BGLs) and daily activities.

It is believed that a lack of social critique and reminder, makes it easy for diabetic patients to rely on past beliefs and slip into past routines, ultimately enabling them to continue a behavior pattern typical of someone living without the disease (Tol et al 2015). It was shown that patients must be made to interpret the connection between their BGLs and visualisations if a change is to be made in their beliefs and practices (Smith & Frost, 2003).

Remote patient monitoring (RPM) is a subcategory of homecare that allows patients to use mobile medical devices and technology to gather patient-generated health data (PGHD) and send it to healthcare professionals (Foster et al, 2022). Common physiological data that can be collected with RPM programs include vital signs, weight, blood pressure and heart rate. Once collected, patient data is sent to a physician's office through the use of software applications that can be installed on a computer, smartphone, or tablet.

RPM is frequently used to help patients that require chronic, post-discharge, or senior care. By connecting high-risk patients with remote monitoring, it can notify healthcare organizations of potential health issues or keep track of patient data between visits. These systems also increase patient engagement - RPM devices allow patients to play a crucial role in managing and understanding their health conditions.

1.2 Relevance of Research

As the number of DM cases increase, so too does the need for an effective tool to support the self-management of the disease. Current self-management tools require lengthy and time-consuming input of variables such as BGLs, food intake and exercise, and yield little, if any, graphical displays for trend identification between different variables (Adu, Malabu and Malau-Aduli, 2019).

Few tools have been discovered regarding the application of IV to the self-management of DM (Whittemore et al., 2019). Individuals affected by DM have also been shown to struggle with the skills and self-efficacy for diabetes self-management (Ciemins, Coon and Sorli, 2010). This research will investigate how IV can be applied to create an effective tool to aid in the process of self-management of DM and will produce a usable RPM as a result of this process. The aim of the research is to improve the presentation of variables strongly associated with the self-management of DM to support DM patients and assist in the process of health-pattern identification. This could in turn lead to a cause-and-effect awareness for DM patients and allow them to self-manage their DM more effectively.

1.3 Research Outline

The research outline for this project is described by identifying the problem and thesis statements. The research objectives and corresponding research questions are outlined in this section. The research methodology used to achieve the identified research objectives is described in detail. The scope and constraints, as well as the envisaged contribution of the research, are discussed and conclude this section.

1.3.1 Problem Statement

The following problem statement further defines the problem the research will aim to solve:

There is a lack of effective information visualisation tools that can be used to support the self-management of DM.

1.3.2 Aim of Research

The aim of this research is defined as follows:

To develop a tool using information visualisation techniques to support effective self-management of DM.

1.3.3 Research Objectives and Questions

The purpose of this research is to investigate the viability of an IV RPM tool, which makes use of appropriate IV techniques, to monitor, advise and represent DM information to both the patient and clinician, so that self-management can be made easier, require less manual effort and become more comfortable. This tool must be easy to use, convenient and must be usable in an at-home environment to prevent deviation from the normal routine. The main investigation for this project will evaluate the effectiveness of IV in aiding the above process. Thus, the main research question that this research will aim to answer is:

How can IV techniques be used to develop a tool to support effective self-management of DM?

The following are sub-questions that must be answered for further development of the research to take place.

- **RQ1**: *What are the existing problems with self-management for DM patients?*
- **RQ2**: *How can existing health patterns be used to improve self-management of DM?*
- **RQ3**: *What possible IV techniques can be used to improve self-management of DM?*
- **RQ4**: *How can IV techniques be applied to support self-management of DM?*
- **RQ5**: *How effective are these IV techniques in supporting self-management of DM?*

The research objectives of this project include:

- **RO1**: *Identify existing problems with self-management of DM.*
- **RO2:** *Identify health patterns for patients with DM.*

- **RO3:** *Identify possible IV techniques that can be used to support self-management of DM*
- **RO4:** *Design an IV tool to aid in the self-management of DM.*
- **RO5:** *Evaluate the effectiveness of the developed tool*

1.3.4 Research Methodology

This research will focus on the development and effectiveness of an RPM tool developed for the self-management of DM by using existing IV techniques. This relates to the main aim of developing an IV tool, which will be applied to address the problems identified in the self-management of DM patients. Thus, the Design Science Research Methodology (DSRM) will be used for this research. This methodology suggests that new and innovative artifacts are to be developed and that a contribution must be made to the field of study (Zimmerman, Forlizzi and Evenson, 2007). This methodology will be discussed in detail throughout the dissertation and consists of the following phases:

1.3.4.1 Awareness

During this phase, a problem is made known and allows for the opportunity to contribute to research and development in the specified field of study (Peffers, Tuunanen and Niehaves, 2018). The problem identified for this research is that there is a lack of IV tools available to aid in the self-management of DM. This phase will help determine the requirements, scope and constraints of this research, required to develop and evaluate the artifact.

1.3.4.2 Suggestion

Once the problem has been identified, the suggestion phase allows for an exploration into past research and knowledge, which will aid in the understanding of the problem domain. This phase enables new knowledge, that is produced by this research, to be added to the growing knowledge base. To gain knowledge relevant to this research's problem domain, literature reviews will be conducted to identify any health patterns and IV techniques needed for this research. For the scope of this research, health patterns refer to a model for prediction of medical data relating to T2DM. By using these health patterns, outcomes for patient actions can be predicted based on historical data. The health patterns that will be used include patient health perception, exercise and its effect on the patients BGLs and the effect of sleep on BGLs. This phase acts as the bridge between the proposal and the design of an implementation idea (Kuechler and Vaishnavi, 2008).

Development

Design and implementation are done in this phase (Kuechler and Vaishnavi, 2008). After the conclusion of the suggestion phase, an adequate knowledge base of the problem domain would have been established. Development of an IV tool can commence, drawing from the requirements established in the awareness phase, and by making use of the knowledge gained from the suggestion phase.

1.3.4.3 Evaluation

The deviations from expectations, both positive and negative, are noted in this stage. Evaluations will be conducted on the IV tool by making use of identified metrics that are adequate in determining the effectiveness of said artifact. At this point, a new design is suggested, accompanied by new ideas for future research.

1.3.4.4 Conclusion

This phase marks the end of the research cycle. The results of the research and evaluation effort previously performed are written up and documented. Facts that have been learned are shown to assist in future works. Figure 1-1 illustrates the cognitive processes that take place during the process of DSRM.

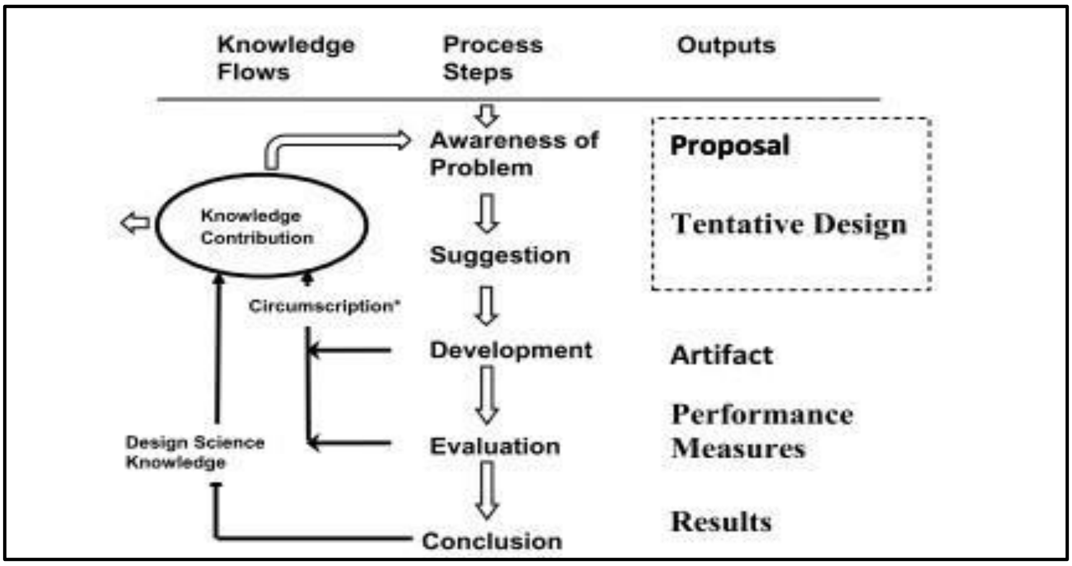


Figure 1-1 Design Science Research Process Model (Kuechler and Vaishnavi, 2008)

1.3.5 Scope and Constants

The proposed solution is to make use of appropriate IV methods, to track patients' blood sugar levels as well as provide an easy mechanism for tracking times of medication intake, food intake and exercise. The RPM system is intended to aid in self-management and be utilized by a clinician to estimate the progress of a patient. Times of intake and amounts of insulin require volatile calculation and usually rely heavily on the judgement of the clinician. For this research, the time of medicine intake will be calculated based on the times of food intake, past provided data related to heart rate, blood pressure, blood sugar levels, exercise, gender and age.

The RPM system may be impeded by the lack of an appropriate data set for use. Because of this constraint, and the inability to access patient history files for large groups of patients affected by DM, it may be necessary to find alternate methods of sourcing the data that is necessary to track. It should be stated that the purpose of this project is not to visualize patients' past medical information, but to provide an effective tool to aid in self-management. If no acceptable data is found to visualize, it may be necessary to capture this data. This could take up a lot of time and be a hindrance to the project.

1.3.6 Ethical Considerations

The following ethical considerations will be implemented throughout the research:

- Voluntary participation of all respondents that take part in this research is of high importance. As such all participants must be willing participants who have had no exterior pressure placed on them to be a part of this research.
- Fair subject selection will be considered, as no participant shall be denied the opportunity or participating in the study without a good scientific reason or a particular susceptibility to risk.
- Every step will be taken to minimize the risk and inconvenience of the research on the participants to maximize the potential benefits, and to determine that the potential benefits are proportionate to, or outweigh the risks.

- The use of offensive, discriminatory or any other unacceptable prejudicial language must be avoided in formation of questionnaires/ interviews or any focus group questions that may be required.
- There will remain a highest level of objectivity in discussions and analyses throughout the research.
- The contribution to the scientific understanding of health or improving the methods of self-managing DM must justify exposing participants to the risk and burden of this research.
- Individuals should be treated with respect from the time they are approached for possible participation — even if they refuse enrollment in this study — throughout their participation and after their participation ends. This includes:

    1. respecting their privacy and keeping their private information confidential
    2. respecting their right to change their mind, to decide that the research does not match their interests, and to withdraw without a penalty
    3. informing them of new information that might emerge in the course of research, which might change their assessment of the risks and benefits of participating
    4. monitoring their welfare and, if they experience adverse reactions, unexpected effects, or changes in clinical status, ensuring appropriate treatment and, when necessary, removal from the study
    5. informing them about what was learned from the research.

The ethical clearance reference number for the research is: H18-SCI-CSS-007

1.3.7 Envisaged Contribution to the Domain

The existing methods of T2DM self-management are chiefly reliant on the responsibility taken by the patient. Patients forget to take medication, lack understanding of the importance of diet, exercise and medication and can lose sight of the progress they have made so far. It is also difficult for clinicians to track the progress of each of their patients. The aim of this research is to produce a non-intrusive, cheap method for visually representing blood sugar levels and other relevant information (e.g. heart rate, blood pressure) to someone with DM to help with self-management of their diabetes.

This will be done by identifying ideal times to take medication so that the best results are yielded. If possible, health patterns will be highlighted. This will be done to increase accuracy and provide a non-invasive alternative to the existing methods of self-management for T2DM.

1.3.8 Chapter Outline

The following is a brief discussion of the chapter structure of the research dissertation:

1.3.8.1 Chapter 2

Chapter 2 will cover a large portion of the research. Literature reviews will be applied to investigate details of the problem space. The research conducted in a literature study will be utilized as a summary of the topics specific to this project. Problems with existing systems can be discovered through a literature study. Diabetes and the main types of diabetes will be briefly discussed as well as their causal factors and basic treatment. Management of T2DM will also be discussed. Shortcomings with existing management and treatment methods can be identified for the disease and will act as a bridge to a better, more precise management system.

A brief study will be conducted into visualisation methods and the best type of visualisation for time series data as this can aid in the discovery of the best way to represent this data intuitively to patients. A general background into the field of data visualisation will be discussed as well as existing systems that represent large amounts of correlated data. This can then be reviewed to discover the shortfalls of data visualisation systems.

Once these are complete, research can be done into existing systems for T2DM self-management that utilize data visualisation. Next, a sequence of shortfalls will be identified for improvement in the developed prototype system.

The following research objectives will be met in this chapter:

- **RO1**: *Identify existing problems with self-management of DM.*
- **RO2**: *Identify health patterns for patients with DM.*

1.3.8.2 Chapter 3

Chapter 3 will contain information about the literature review of IV techniques that was performed as part of the Design Science Research Methodology. This in-depth literature review will critically analyze the selected IV techniques and the benefits thereof. The shortcomings of each technique available for this research will also be evaluated.

The following research objective will be met in this chapter:

RO3: *Identify possible IV techniques that can be used to support self-management of DM*

1.3.8.3 Chapter 4

Chapter 4 will cover the design and implementation techniques that will be used in the project and the development will be tracked and explained. A prototype will be developed to conduct further research and express it in a more useful way. This will act as a proof of concept and will be used to determine whether the developed system is an effective tool for the self-management of DM. A tool will be developed based on the problems identified in the literature review. The developed prototype will incorporate both the health informatics and visualisations necessary to conduct the first round of experimental studies. From these studies shortcomings of the developed system will be identified for fixing. This process will be completed iteratively, to enable optimization of the system over several time intervals.

The following research objective will be met in this chapter:

- **RO4:** *Design an IV tool to aid in self-management of T2DM.*

1.3.8.4 Chapter 5

Chapter 5 will comprise an overview of the evaluation of the proposed system. This is the chapter in which all testing and test results will be discussed. The prototype's accuracy, efficiency and user satisfaction will be evaluated.

Experiments will be conducted utilizing the prototype to assess its viability and the outcome of the given intervention. Usability evaluations will be conducted to properly evaluate the viability of this system. In this way, it will be determined whether the prototype is effective. Metrics will be identified alongside questionnaires as an effective measure of the success or failure of the system.

The following research objectives will be met in this chapter:

· **RO5:** *Evaluate the effectiveness of the developed tool.*

1.3.8.5 Chapter 6

Chapter 6 will comprise a summary of the practical and theoretical contributions made by the research. The system will be critically analyzed so that useful information for future projects can be documented. This chapter will include an overview of the processes used in development, reflections, conclusion and recommendations for future research.

The dissertation is structured as follows (partnered research objectives):

Table 1-1 Dissertation Structure

Chapter	**Focus**	**Research Objectives**
Chapter 01	Introduction	-
Chapter 02	DM Literature Review	RO1, RO2
Chapter 03	IV Literature Review	RO3
Chapter 04	Design and Implementation	RO4
Chapter 05	Evaluation	RO5
Chapter 06	Conclusion	

1.4 Conclusion

Self-management of DM is an important research area in medical computing. As DM spreads there is an increased need for an effective IV tool to aid in the self-management process. This research will determine how IV techniques can be applied to the self-management of DM. The aim of the research is to determine whether IV can be used to improve the presentation of DM variables, but a helpful consequence of the research will be the development of a framework that can be used as an RPM. The DSRM will be utilized throughout the research as the selected research methodology.

The following chapters will address the identified research questions. Chapter 2 will address the first research question by identifying the problems with existing DM self-management tools.

2 Diabetes Mellitus and Self-Management

2.1 Introduction

Effective methods for self-management of chronic diseases are an important research area in medical computing. To identify appropriate IV techniques for the self-management of DM, DM needs to be investigated. DM, self-management and health patterns are discussed in detail in this chapter. This chapter will act as a systematic review of the self-management of DM. As such, an examination must be done on a broader spectrum: using self-management and health patterns to make sense of personal health. To contextualize the background information, an overview is provided for DM data, self-management, health patterns, RPMs and existing medical systems.

The chapter also addresses the first two research questions identified in Chapter 1, namely:

- *What are the existing problems with self-management in DM patients?*
- *How can existing health patterns be used to improve self-management of DM?*

2.2 Diabetes Mellitus

Diabetes Mellitus (DM) is a term used to describe a group of metabolic disorders which are characterized by high BGLs for long periods of time (Kerner and Brückel, 2014). DM is due to either the pancreas not producing enough insulin, or the cells of the body not responding to the produced insulin correctly (Smith and Frost, 2003). Many diabetes cases and associated long term side effects can be avoided, but this requires intervention and social as well as at a medical level (Tol et al, 2015).

There are three main types of DM:

1) Type 1 DM (T1DM): This form of diabetes results from the pancreas's failure to produce enough insulin and was previously referred to as 'insulin dependent DM' (IDDM) or 'juvenile diabetes'. The cause of this form of diabetes is unknown (Popović-Djordjević, 2021).

2) Type 2 DM (T2DM): This form of diabetes begins with insulin resistance. This is a condition in which cells fail to respond to insulin properly. As the disease progresses, a lack of insulin may also develop. This form of diabetes was previously referred to as ‘non-insulin-dependent DM’ (NIDDM) or ‘adult-onset diabetes’. The most common cause of this form of diabetes is increased body weight and lack of exercise (Tripathy, Chandalia, Das and Rao 2012).

3) Gestational diabetes is the third form of diabetes that occurs in pregnant women with no prior indication of diabetes (Pettitt et al, 1980).

2.2.1 T1DM

T1DM typically presents symptoms in childhood or early adult life but can present at any age. It is differentiated from T2DM by a few immune and genetic markers. It is characterized by the loss of most of the beta cells in the pancreas, which act as the insulin secreting cells (Davies, Storms and Shurler, 2005). This type of DM requires insulin treatment. The risk of complications increases with long term exposure to high BGLs, and generally treatment that returns the circulating glucose levels to near normal can reduce the risk of developing long term complications (Holleman, 2014).

T1DM can progress to severe insulin deficiency, which can result in a loss of regulation in many metabolic processes, such as hyperglycemia, which is associated with the breakdown of fat and muscle proteins (Taylor, Accili and Imai, 1994). As a secondary example, catabolism (the breakdown of complex molecules into smaller simpler ones) can cause rapid weight loss and causes the overproduction of ketones by the liver. In excessive levels, this can lead to diabetic ketoacidosis (the metabolic state associated with high ketone bodies in the blood).

The diagnosis of T1DM is not always clear and difficulties may arise in adolescents and young adults with features of T1DM in association with characteristics of T2DM, such as obesity or insulin resistance. This has been referred to as ' double diabetes' (Leslie et al, 2021).

2.2.2 T2DM

T2DM affects over 300 million people worldwide and has thus reached pandemic proportions (Castillo, 2012). It is a result of inadequate insulin production relative to the demands of the body, which can be increased by obesity or other factors. It reflects the interaction of several disease processes. It therefore lacks a precise definition and its features vary widely within and between populations. It is best considered a syndrome rather than a disease (Piccoli et al, 2015). This metabolic abnormality can be reversed or delayed by weight loss and a proper diet, but beta cell failure is typically progressive with declining insulin production and increasing reliance on medication (Boardus et al, 1984).

When it comes to treatment, lifestyle change is the mainstay (Wang, Wang and Chan, 2013). This should be backed with a range of oral therapies, although due to inconsistency in this regime, sufferers typically progress to insulin in most cases. Glucose control has been shown to reduce the impact of small vessel complications in diabetics, with arterial disease being the leading cause of death in T2DM patients.

2.3 The Pancreas and Insulin

To fully understand the way that DM manifests itself, one must first understand how it is caused, anatomy and basic biology.

2.3.1 The Pancreas

The pancreas is a fish-shaped organ that stretches across the back of the abdomen, behind the stomach. Several major blood vessels surrounding the pancreas: the superior mesenteric artery, the superior mesenteric vein, the portal vein and the celiac axis, supplying blood to the pancreas and other abdominal organs (Columbia Surgery, 2022). A depiction of the pancreas' positioning can be seen in Figure 2-1 and 2-2.

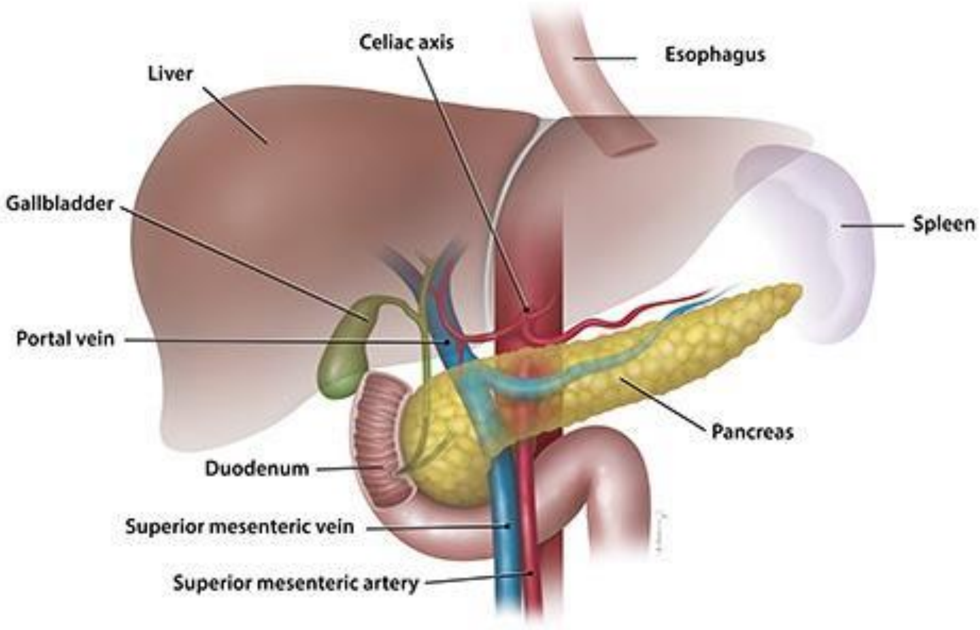


Figure 2-1 The Position of the Pancreas Relative to the Liver (Columbia Surgery, 2022)

Ninety five percent of the pancreas consists of exocrine tissues, which produces pancreatic enzymes (used for digestion). The remainder of the pancreas consists of endocrine cells called islets of Langerhans. These clusters of cells produce hormones that regulate BGLs and pancreatic secretions (Columbia Surgery, 2022).

The pancreas contributes to both exocrine and endocrine systems within the body and has a unique function for each system.

2.3.1.1 Exocrine Function

The enzymes produced by exocrine glands within the pancreas are important for digestion. The enzymes contain trypsin and chymotrypsin, which aid in the digestion of proteins, amylase for the digestion of carbohydrates and lipase to break down fats. When food enters the stomach, pancreatic enzymes are released into a system of ducts that culminate in the main pancreatic duct, which joins the common bile duct to form the ampulla of Vater. The common bile duct originates in the liver and produces another vital fluid called bile. The pancreatic and bile fluids combine to aid the body in the breakdown and digestion of fats, carbohydrates and proteins.

2.3.1.2 Endocrine Function

The endocrine component of the pancreas consists of isleT-cells (the islets of Langerhans), which create and release hormones into the bloodstream. The main pancreatic hormones are insulin, which lowers BGLs and glucagon, which increases BGLs. Maintaining proper BGLs is crucial to the functioning of key organs including the brain, liver and kidneys.

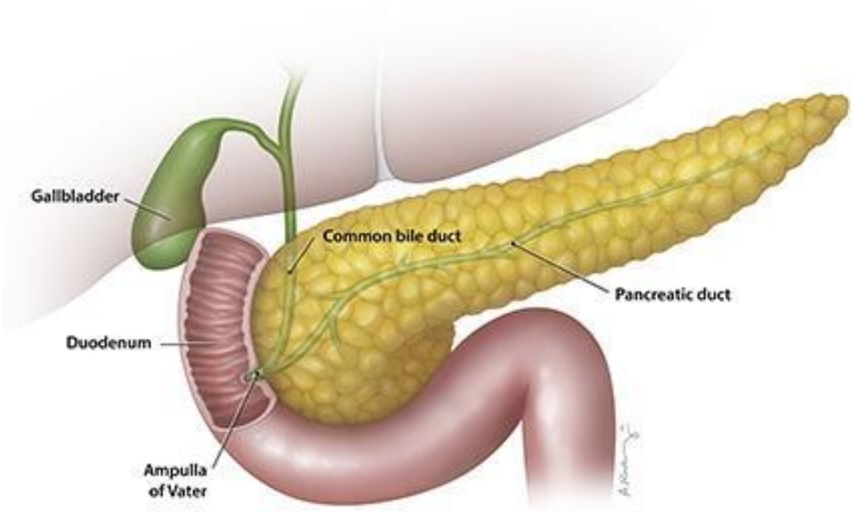


Figure 2-2 The Human Pancreas (Columbia Surgery, 2022)

2.3.2 The Role of the Pancreas

DM is an auto-immune disease. This means that the immune system launches an attack on healthy body cells. To understand how this is possible, it is imperative to understand how the immune system fights diseases.

T-cells are the cells in the bloodstream, which identify and destroy foreign bodies. T-cells interact with many cells and tissues and actively search for cells infected by bacteria or viruses (Gebhardt et al, 2018). All cells, whether they are infected or not, recycle the proteins that they produce within their walls. They deposit these proteins onto their cell surfaces. Healthy cells display remnants of healthy body proteins and infected cells are covered with bits of viral or bacterial proteins. T-cells are programmed to recognize foreign proteins and attack the cells that are covered in them.

T-cells are capable of learning, which proteins signify an infection and which are the body's natural proteins in a small organ called the thymus, which is found behind the breastbone and above the heart. Cells residing in the thymus, thymus epithelial cells are responsible for the programming of

T-cells. The thymus epithelial cells produce proteins that the T-cells might encounter throughout the body, such as the proteins that help the body function normally, including insulin. T-cells that are activated to attack by proteins like insulin get eliminated in the thymus, and only T-cells that are non-reactive to the body's own proteins can migrate out of the thymus and begin patrolling the tissues.

This process becomes faulty in individuals with T1DM. T-cells begin to attack healthy beta-cells, implying a failure in the thymus to protect the body from defective T-cells (Bender et al, 2020).

T2DM stems from the same essential cause, a problem with insulin, but the mechanism for activation is different. Insulin causes the liver to convert more glucose into glycogen (a process known as glycogenesis), and forces 2/3 of body cells (primary muscle and fat tissue cells) to take in glucose through a GLUT4 transporter, thus decreasing BGLs (Vijayakumar et al, 2017).

In T2DM insulin resistance occurs, the exact cause of which is still unknown. In insulin resistance, muscle, fat and liver cells fail to respond correctly to insulin and can no longer absorb glucose from the bloodstream. This results in higher levels of insulin to aid the glucose in entering cells (Bray et al, 2009).

The beta cells in the pancreas attempts to produce more insulin to lower BGLs and eventually they are unable to produce enough insulin to lower BGLs to within a healthy range. Without enough insulin, excess glucose builds up in the bloodstream, leading to diabetes (Forstner et al, 2017).

While the exact cause of insulin resistance is unknown, a few factors are known to increase the risk of this phenomenon:

2.3.2.1 Excess Weight

Obesity is a primary cause of insulin resistance (Kahn and Flier, 2000). Fatty tissue was once believed to act solely as energy source; however, studies have shown that fat produces hormones that can cause serious health problems like insulin resistance, high blood pressure and cardiovascular diseases. It has been discovered that large reserves of fat within the body can cause inflammation, a trigger for the immune system to send acting T-cells to the area. This inflammation can contribute to the development of insulin resistance. Studies have revealed that losing weight can reduce insulin resistance and prevent or delay T2DM.

2.3.2.2 Physical Inactivity

Physical inactivity is associated with insulin resistance (Krekoukia et al, 2007). In the body, more glucose is used by muscle than by other tissues. Normally, active muscles burn their stored glucose for energy and stockpile their reserves with glucose taken from the bloodstream, keeping BGLs in balance.

After exercising, muscles become more sensitive to insulin, reversing insulin resistance and lowering BGLs. Exercise also helps muscles absorb more glucose without insulin. The more muscle the body has, the more glucose it can burn to control BGLs.

2.3.2.3 Sleeping Problems

Untreated sleeping problems like sleep apnea can increase the risk of obesity, insulin resistance and T2DM (De Sousa, Cercato, Mancini and Helpern, 2008). Night shift workers may also be at increased risk for these problems. Sleep apnea is a common disorder in which a person’s breathing is interrupted during sleep. Poor sleep cycles lead to tiredness during the day when it is crucial for the body to produce insulin for food intake.

2.3.2.4 Other Factors

Other causes of insulin resistance may include ethnicity, steroid use, medication, age, sleep problems, and smoking (Al-Shawwa, Al-Huniti, DeMittia and Gershan, 2007).

2.3.3 Insulin

Insulin is a hormone. As mentioned previously, it is produced by the beta cells in the islets of Langehans in the pancreas. Its fundamental purpose is to counter glycogen (which raises BGLs) by lowering BGLs. Insulin does this by activating cells to remove glucose from the blood and utilize it as a source of energy. In people without diabetes, the production of these two hormones can keep BGLs within the healthy range.

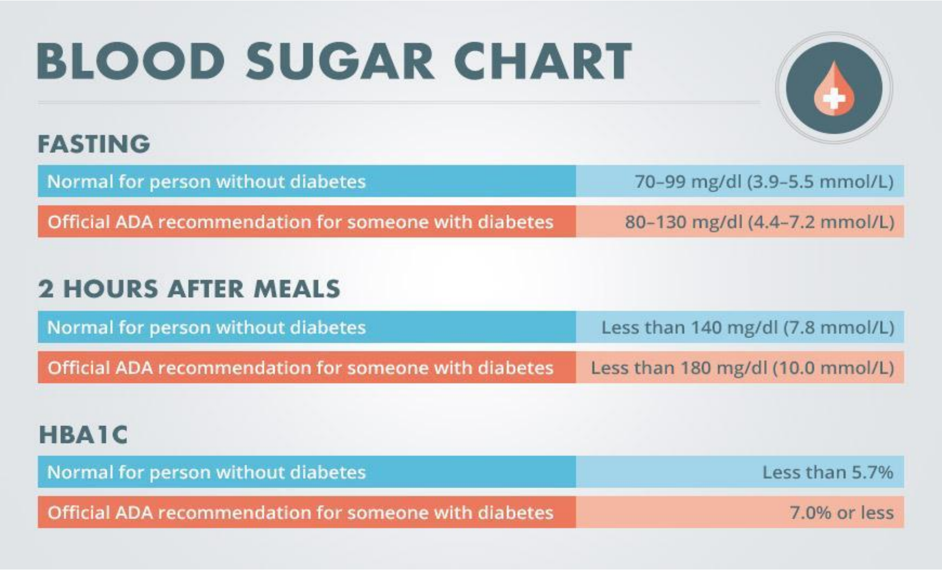


Figure 2-3 BGLs and Food Intake (Campbell, 2016)

Insulin acts as a key to open cells to receive glucose, and as a secondary purpose, it is also responsible for the transportation of amino acids. In healthy individual's insulin production goes up when food has been ingested. Insulin also acts as a storage hormone, since high BGLs signal the insulin to trigger glucose storage in the liver (Bartlet, Gaspers, Pierobon and Thomas, 2014).

Since insulin is a hormone, and most hormones are types of proteins, insulin cannot be ingested in tablet form. The stomach lining and esophageal walls are responsible for breaking down various proteins. An ingested protein-like insulin would be broken down before enough of it could be absorbed into the blood. It is for this reason that insulin must be injected directly into the bloodstream (Thorpe, 1976).

2.4 Defining Self-Management

A gap currently exists between the promise and the reality of diabetes care. Despite the great strides that have been made in the treatment of diabetes, many patients do not achieve optimal outcomes, which results in a decreased length and quality of life due to catastrophic failure in their ability to self-manage the disease. Self-management is defined as management of or by oneself. It is essentially the taking of responsibility for one's own behavior and well-being (Millington, Miller, Rubenstein and Kelly, 2014).

Health care systems are designed to deliver acute, symptom-driven care, resulting in poorly configured management plans to treat chronic diseases such as DM. Clinicians also struggle with the realities of dealing with a chronic disease for which daily care is in the hands of the patient.

Traditionally, the success of patients to manage their diabetes has been judged by their ability to adhere to a prescribed regimen. The chronic nature of diabetes, the complexity of its management, and the multiple daily self-care decisions that diabetes requires mean that being devoted to a predetermined care program is generally not adequate over the course of a person's life with diabetes (Wyckoff, Hanchon and Gregg, 2015).

It is important to differentiate between self-care and self-management as these terms are similar but have intrinsic differences. Self-care refers to individual responsibilities for healthy lifestyle behaviours required for human development and functioning, as well as those activities required in order to cope with health conditions (Ncama, 2011).

Self-management refers to a set of skills and strategies by which inidviduals can effectively direct their own activities toward the achievement of objectives, and includes goal setting, decision making, self-intervention and self-development. Self-management is directed toward specific outcomes and the preparation of individuals to manage their health condition on a day-to-day basis. It highlights the practice of specific behaviour and the development of the skills and abilities needed to reduce the physical and emotional impact of illness, with or without the collaboration of a healthcare team (McGowan, 2005).

This is particularly true when the self-management plan has been designed to fit patients' diabetes but has not been tailored to fit their lifestyle. To manage diabetes successfully, patients must be able to set goals and make daily decisions that are both effective and fit their values and lifestyles (Millington, Miller, Rubenstein and Kelly, 2014).

The role of clinicians in promoting self-care is vital and must be emphasized. Realizing the nature of the problem, a systematic, integrated approach is required for promoting self-care practices among diabetic patients to avoid long-term complications.

2.4.1 Methods of DM Self-Management

The goal of DM self-management is to keep BGLs as close to normal as safely possible (Davies, Storms and Shurler, 2005). Since the risk of heart disease and peripheral artery disease increases with diabetes, measures should be taken to control blood pressure (BP) and cholesterol levels (CLs) (Huysman and Mathieu, 2009).

The steps that must be taken by DM patients can greatly inhibit or accelerate their own recovery (Report of a WHO/IDF Consultation, 2006). DM patients are required to monitor BGLs, meet dietary requirements, participate in physical activity, keep stress under control, monitor oral medication and if it is deemed necessary, take insulin via injections or a pump (Razana, 2017). These factors are all part of the treatment of DM, and all of them are factors which require self-management (Shrivastava, Shrivastava and Ramasamy, 2013).

There are seven essential self-care behaviors in people with diabetes, which predict good outcomes, namely:

1) Healthy Eating
2) Physically Activity
3) Monitoring BGLs
4) Medical Compliance
5) Problem-solving Skills
6) Healthy Coping Skills
7) Risk-reduction Behaviors

All of these seven behaviors have been found to be positively correlated with good glycemic control, reduction of complications and improvement in quality of life. Individuals with diabetes have been shown to make a dramatic impact on the progression and development of their disease by participating in their own care (Shrivastava, Shrivastava and Ramasamy, 2013).

2.4.1.1 Healthy Eating and Physical Activity

Lifestyle is the biggest triggering factor for T2DM and is therefore the cornerstone for treatment of this disease. The disease is more likely in individuals who consume excessive amounts of food and partake in little or no form of exercise, as an extension of this fact, individuals can reverse or manage their symptoms easily through proper diet and exercise (Sami, Ansari, Butt and Hamid, 2017).

Modifying an eating plan and increasing participation in physical activity are typically the first steps that are taken toward reducing blood sugar levels. Patients work with their doctors and a certified dietician to develop a dietary plan.

High carbohydrate and high fat diets improve insulin sensitivity. Several dietary interventional studies recommended nutrition therapy and lifestyle changes as the initial treatment for DM. Diet control can be considered as the cornerstone in DM self-management (Sami, Ansari, Butt and Hamid, 2017). A good diet minimizes the risk for developing complications and may also protect from cardio-vascular diseases (CVD), particularly in newly diagnosed patients. Carbohydrate intake has a direct effect on glucose levels in people with diabetes and is the principal cause of worry in glycemic management. In addition, an individual's food choices and energy balance influence body weight, blood pressure, and fat levels directly.

2.4.1.2 Monitoring BGLs

Many people who live with diabetes don't feel any symptoms, unless they are experiencing hyperglycemia (when the BGLs are too high) or hypoglycemia (when the BGLs are too low). Hyperglycemia can cause damage to organs, which can lead to complications, including:

- cardiac or vascular such as heart attacks or strokes;
- kidney problems;
- eye problems, which can lead to blindness; and
- circulatory problems, which can lead to amputation.

To avoid the above-mentioned issues, BGLs must be monitored and controlled to reduce the risk of hyperglycemia.

Monitoring BGLs daily, also known as self-testing, is an essential part of managing diabetes, just like changing lifestyle habits and taking medication. It allows patients to see the impact of the measures taken to better control diabetes.

When blood-glucose meters indicate that BGLs are too high, required measures can be taken to bring BGLs back to normal right away. This can involve modifying or increasing medicine.

2.4.1.3 Medical Compliance

Insulin Therapy

People affected by type 1 diabetes are required to take multiple insulin injections daily to maintain safe insulin levels. Various forms of insulin can be required for treatment of individuals who have type 2 diabetes. An insulin pump was devised as an alternative to injections. The pump is a small device, around the size of a pager, that can be worn on a belt in much the same way as a pager (Rentschler et al, 2021).

There is no standard dosage as it largely depends on body weight, when eating occurs and exercise. Insulin therapy mimics natural secretion of insulin from the pancreas by constantly supplying background levels of insulin as well as peak levels when food is consumed.

Pancreas and isolated islet transplantation (where isleT-cells are placed in the pancreas) can reverse insulin dependence for longer periods of time, but this is limited to select cases where the risk of surgery is lower (Viberti et al, 1982). Apart from high surgical risks, limited availability of donor human pancreases and cost are other factors influencing the viability of this option on a larger scale.

Oral Medication

Blood sugar levels may remain high in people with type 2 diabetes, even with a healthy food and exercise regime (Razana, 2017). When this happens, medications are taken in pill form. The medication works in several ways. The pills can improve the effectiveness of the body's natural insulin, reduce blood sugar production, increase insulin production and inhibit blood sugar absorption. These medications are sometimes required to be taken in conjunction with insulin.

2.4.1.4 Problem Solving Skills

The American Association of Diabetes Educators (AADE) has identified problem solving as one of seven core diabetes self-management behaviors. AADE defines problem solving as a learned behavior that includes generating a set of potential strategies for problem resolution, selecting the most appropriate strategy, applying the strategy, and evaluating the effectiveness of the strategy (Schumann, Sutherland, Majid and Hill-Briggs, 2011).

In the AADE framework, problem solving is conceptualized as intervening on barriers to self-care and thus enables patients to carry out all other self-management behaviors (i.e. healthy eating, physical activity, self-monitoring, medication taking, risk reduction, and healthy coping) (Shrivastava, Shrivastava and Ramasamy, 2013).

Hill-Briggs proposed a model for understanding problem solving in the context of diabetes self-management. The model highlights four key components of problem solving that are particularly noticeable in disease self-management.

- *Problem-solving skill* refers to the approach an individual takes to solving problems (i.e., rational, impulsive/careless, or avoidant), with a rational approach being most effective.
- *Problem-solving orientation* refers to individuals' attitudes and beliefs about their disease and the problems they encounter. Problem-solving orientation can be positive (e.g., problems viewed as a challenge) or negative (e.g., problems viewed as a threat).
- *Transfer of experience/learning* refers to the use of previous experience in attempting to solve novel problems. This transfer of experience can also be effective (e.g., using a solution that was effective in a similar situation in the past), or ineffective (e.g., trying an ineffective solution repeatedly in the same situation).
- *Disease-specific knowledge*. To solve problems related to disease self-management effectively, individuals must have a working knowledge base about the disease and its management. Each key component of problem solving operates within the problem environment, composed of the social/physical context and characteristics of the problem itself (Schumann, Sutherland, Majid and Hill-Briggs, 2011)

2.4.1.5 Healthy Coping Skills

Contemplating the need to manage DM for a lifetime can cause anxiety. It is for this reason that good coping skills are necessary to harbor feelings of relief and hope (Steed, Cooke and Newman, 2003).

The basic idea of a coping strategy is that it should ease stress, provide comfort, or enhance mood in a difficult situation. It is important for patients to be wary of coping mechanisms that provide immediate gratification, but have secondary consequences. The key is to look for coping strategies that provide comfort but also have a constructive, lasting impact on the mind and body (Schumann, Sutherland, Majid and Hill-Briggs, 2011).

Since lifestyle choices directly affect diabetes control, it is important to develop a holistic plan for managing the condition that includes not just diet and exercise, but also ways of coping with stress, particularly since stress can affect blood glucose control.

2.4.1.6 Selection of T2DM

Since the aim of all therapies for diabetes is to prolong the life and wellbeing of their users, overall safety and cost have become major factors when choosing therapy.

T2DM has been selected as the focus for this research for the following reasons:

- Using proper self-management, it is possible to reduce the side effects of T2DM in patients' lives and sometimes remove symptoms all together (Smith and Frost, 2003).
- The factors that are involved in treatment for T2DM (such as oral medication, exercise, healthy dieting) all lie in the spectrum of elements which a patient must self-manage and thus a tool might be more useful for T2DM (Razana, 2017).
- Patients of T2DM have been shown to require motivation and have a lack of understanding regarding how lifestyle impacts their disease (Smith and Frost, 2003).
- Partial recovery is possible for patients with T2DM. This means that improvement of the proposed tool might be seen in improved BGLs.

2.5 Health Patterns

A pattern is defined as a regular and intelligible form or sequence discernible in the way in which something happens or is done. It makes sense then, that a health pattern could be considered a pattern which gives order or form in otherwise random medical data.

2.5.1 Gordons Functional Health Patterns

Gordon's Functional Health Patterns (GFHP) provide a useful framework for assessing the factors which influence drug response, and impact compliance and successful outcomes of drug therapy. Gordon developed eleven patterns. These patterns were initially used by nurses to provide a more comprehensive care to patients (Karaca, 2016).

Table 2-1 below represents each conceptual pattern and contains an explanation of each:

Table 2-1 Organising Data According to GFHP (Karaca, 2016)

Organizing Data According to Gordon's Functional Health Patterns		
Health Pattern	**Pattern Describes**	**Examples**
Health Perception/ Health Management	The person's perceived level of health and well-being.	● How does the person describe her/ his current health? ● What does the person know about links between lifestyle choices and health? ● What does this person know about medical problems in the family?
Nutritional Metabolic	Food and fluid consumption relative to metabolic need.	● Is the person well nourished? ● How do the person's food choices compare with recommended food intake?
Elimination	Excretory patterns (bowel, bladder, skin).	● Are the person's excretory functions within the normal range? ● Does the person have any disease of the digestive system, urinary system or skin?
Activity/ Exercise	Activities of daily living requiring energy expenditure, including self-care activities, exercise, and leisure activities.	● How does the person describe her/ his weekly pattern of activity and leisure, exercise and recreation? ● Does the person have any disease that affects his/her cardio-respiratory system or muscular-skeletal system?

Cognitive/ Perceptual	Ability to comprehend and use information and sensory functions. Neurologic func tions, Sensory experiences such as pain and altered sensory input.	● Does the person have any sensory deficits? Are they correct? ● Can this person express her/ himself clearly and logically?
Sleep/ Rest	Sleep, rest, and relaxation practices. To identify dysfunctional sleep patterns, fatigue, and responses to sleep deprivation.	● Describe this person's sleep-wake cycle. ● Does this person appear physically rested and relaxed?
Self-Perception/ Self-Concept	Attitudes toward self, including identity, body image, and sense of self-worth.	● Is there anything unusual about this person's appearance? ● Does this person seem comfortable with her/ his appearance?
Role/ Relationship	Roles in the world and relationships with others. Evaluated Satisfaction with roles, role strain, or dysfunctional relationships.	● How does this person describe her/ his various roles in life? ● Has, or does this person now have positive role models for these roles?
Sexuality/ Reproduction	Satisfaction or dissatisfaction with sexuality patterns and reproductive functions.	● Is this person satisfied with her/ his situation related to sexuality? ● How have the person's plans and experience matched regarding having children?
Coping/ Stress Tolerance	Perception of stress and coping strategies Support systems, evaluated symptoms of stress,	● How does this person usually cope with problems?

	effectiveness of a person's coping strategies.	● Do these actions help or make things worse?
Value/ Belief	Values and beliefs.	● What principles did this person learn as a child that are still important to her/ him? ● Does this person identify with any cultural, ethnic, religious, regional, or other groups?

2.5.2 DM Health Patterns

All the above patterns are derived from medical patterns used for diagnostics. The questions can quickly enable diagnosis if followed properly. The above patterns are not specific to DM but can offer quick diagnosis of problems resulting from DM. In a similar manner, patterns can be observed for DM and results can be affected by tailoring behaviors according to these patterns. By using GFHP as a guideline for observable health patterns in DM, a new set of DM focused health patterns can be established. As an example, GFHP highlights a category of questions surrounding food and nutrition. Nutrition is central to T2DM and it is common knowledge that an individual with a larger BMI is more susceptible to the comorbidities of T2DM (Ross et al, 2011). Thus, a health pattern specific to T2DM can be determined i.e.: an individual with a high BMI is more likely to suffer from the comorbidities of T2DM. Thus, an individual whose food and fluid consumption are poor relative to metabolic need, will have a higher likelihood to be affected by T2DM.

2.5.2.1 Neutritional Metabolic

Individuals without DM have a BGL of between 4.0 and 7.8 millimoles per liter of blood throughout the day, regardless of food intake, exercise or stress. Keeping BGLs in this range is difficult when individuals have DM and hypoglycemia is just 1 mmol/L away (van Dam, Rimm, Willett, Stampfer, and Hu, 2002).

Everyone with DM is provided with their own unique target by their GP or specialist, but general guidance in the form of health patterns do exist.

T1DM have target BGLs of 4-6 mmol/L before meals and 4-8 mmol/L two hours after consumption. T2DM have a target BGLs of 6-8 mmol/L before meals and 6-10mmol/L two hours after consumption. These BGLs are not achieved without medication, so it is often necessary for medication to be consumed up to 1 hour after food is ingested (van Dam, Rimm, Willett, Stampfer, and Hu, 2002).

It is known that BGLs begin to rise within 15 to 30 minutes of eating food. This is conditional and only occurs if the meal contains carbohydrates. The speed and level of BGLs increase depends on the type of carbohydrate and nutrients found in the food which is eaten.

Studies have shown that western dietary patterns are associated with a substantially increased risk for T2DM.

2.5.2.2 Health Perception and Health Management

As highlighted in GFHP, health perception and health management are another indicator of an individual’s likelihood to respond to treatment. Individuals who have prior health problems such as hypotension indicate that their current health management is poor.

High blood pressure or hypertension, is a condition, which is closely related to T2DM. It is currently unknown as to why there is such a significant relationship between the two diseases, but it is believed that the following contribute to both conditions (Eguchi et al, 2008).

- Obesity
- Diets high in fat and sodium
- Chronic inflammation
- Inactivity

These categories directly align with GFHP. Obesity and diet are an indicator of nutrition and metabolic stability, inactivity aligns with activity/exercise and chronic inflammation is an indicator of poor health management.

Hypotension is also known as the silent killer because it often has no obvious symptoms and many people are unaware that they may have it.

Blood Pressure & Glucose Tracker

BLOOD PRESSURE

TARGET PRESSURE		CALL PHYSICIAN
120	SYSTOLIC	142
80	DIASTOLIC	90

Date	Time	Event	Systolic	Diastolic	Heart Rate
[Date]	6:00 AM	Wake	120	79	72
[Date]	7:00 AM	Before meal	120	80	74
[Date]	9:00 AM	After meal	123	80	75
[Date]	10:00 AM	BP only	143	91	75
[Date]	12:00 PM	Before meal	180	84	70
[Date]	3:00 PM	After meal	170	80	68

Figure 2-4 Blood Pressure Measurements Over the Course of a day

Figure 2-4 illustrates the relationship between blood pressure and blood sugar. It can be seen in Figure 2-4 that the blood pressure increases to above normal at times when BGLs are low, such as before meals, and stabilizes to a healthier pressure when BGLs increase to normal levels (Jovinelly, 2012).

2.5.2.3 Cholesterol and BGLs

Studies have determined that individuals who consume more added sugars have more high-density lipoprotein (HDL). HDL works to take up extra cholesterol, or low-density lipoprotein (LDL), and transport it to the liver. As a result, it is healthy to have high HDL levels (Gotto and Brinton, 2004).

These individuals are also found to have higher levels of triglycerides. A high triglyceride level combined with low HDL cholesterol or high LDL cholesterol is linked with fatty buildups in artery walls. This increases the risk of heart attack and stroke.

2.5.2.4 Sleep/ Rest

Studies have shown that individuals who consistently have a bad night's sleep are more likely to develop conditions linked to diabetes and heart disease (Grandner, Jackson, Pak and Gehrman, 2012). Loud snoring sleepers, when compared to quiet sleepers, double their risk of developing certain types of syndromes, including diabetes, obesity, and high blood pressure (Su et al, 2015).

Sleeping Problems

Sleep can affect blood sugar levels, and blood glucose control can also affect sleep. As the amount of sleep decreases, blood sugar increases, escalating the issue**.** Higher blood sugar means less long-lasting fat metabolism in the night and less sleep. Researchers at Boston University School of Medicine found that people who slept less than 6 hours a night have more blood sugar complications compared to those who received 8 hours of sleep.

Hyperglycemia

Sleeplessness and restlessness are a form of chronic stress on the body. When there is added stress on the body, it can result in having higher blood sugar levels. When researchers restricted people T1DM to just 4 hours of sleep, their sensitivity to insulin was reduced by 20% compared to that after a full night of sleep (Barone et al, 2015).

When BGLS are high, the kidneys attempt to eliminate glucose by removing it from the body via urination. This most likely causes nighttime wakefulness, resulting in inconsistent sleep patterns. It can also wake individuals up with a feeling of thirst (Barone et al, 2015).

The Dawn Phenomenon

The dawn phenomenon occurs when the body releases growth and other hormones around 3 a.m. or 4 a.m. to prepare the body for arousal. This forces individuals to wake up to high BGLs in the morning, even if BGLs were good the night before.

These hormones make the body less sensitive to insulin, the hormone that lowers blood sugar. In people with diabetes, these changes can lead to a morning blood sugar spikes.

Hypoglycemia

If BGLs are too low, DM patients may also wake up during the night. Glucose is necessary for cell functions, and if the BGLs are too low, the following symptoms can arise (Su et al, 2015):

- Hunger
- Weakness

- Dizziness
- Nervousness
- Anxiousness
- Irritability
- Chills
- Sweating
- Tingling or numbness of mouth
- Blurred Vision
- Headache
- Confusion
- Nightmares
- Sleepwalking
- Restlessness

The above symptoms can keep DM sufferers awake during the night. They display similarity to the patterns identified in Table 2-1 and therefore display evidence that health patterns and health pattern detection can be applied to the detection of patterns in diabetes data, if the effect of these factors on BGLs are known.

2.5.3 Synopsis of DM Health Patterns

The following will serve as a developed guide to health patterns for DM. Since a health pattern has previously been described as medical patterns for diagnostics' and 'a model used to give regular or intelligent form to data', it stands to reason that the effects of known behaviors on BGLs can be used as a basis for forming health patterns specific to BGLs and DM.

Factors affect BGLs aligned with GFHP:

Nutritional Metabolic: Too much food, like a meal or snack with more carbohydrates than usual, cause BGLs to rise. Dehydration, or lack of considering the amount of water that should be consumed can also cause BGLs to rise. In a similar manner, not consuming enough food can cause BGLs to drop.

Activity/ Exercise: Exercise causes BGLs to drop during exercise as energy is being expended, however, exercise is essential to maintaining a stable weight. As a result, inactivity can cause individuals to gain weight and maintain a higher overall BGL.

Coping/ Stress Tolerance: Stress can produce hormones which raise BGLs. Short or long-term pain, like pain from a sunburn can cause the body to release hormones which will raise BGLs. Unhealthy stress management strategies, like alcohol consumption or drug abuse can also cause BGLs to drop.

Sleep/ Rest: Different stages of sleep have different effects on BGL, but it can rise and fall in alignment with stages of sleep.

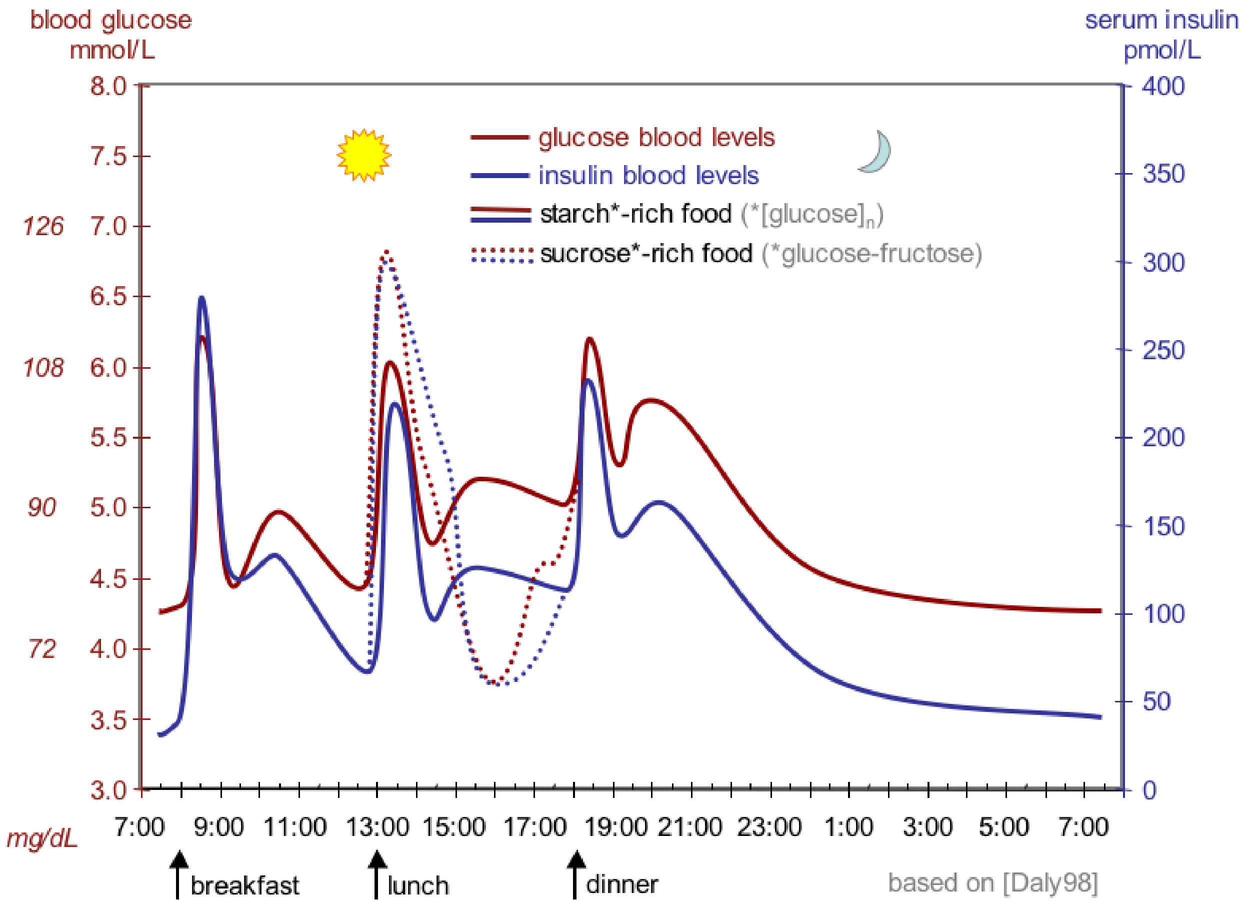


Figure 2-5 BGLs Over the Course of One Day (Cahill, 2006)

The above image illustrates BGLs throughout the course of a single day, in a patient with DM. From this chart, it is observable that food intake, sleep and medication administration all influence BGLs. This is known because of the derived BGL and DM health patterns above. The reasons for the rise and fall of BGLs are evident and clear.

2.6 Existing Systems

The current methods of self-management for diabetes do not involve management systems that make use of IV. While IV has previously been used for visualisation of medical data, systems that are currently in use are limited (Whittemore et al., 2019). For these reasons, systems that are used to visualize large amounts of data will be analyzed. These systems are mobile applications, capable of interfacing with a Continuous Glucose Monitors (CGM) and displaying DM specific data to a user in an easy to interpret manner, i.e., using visualisations.

They were selected for analysis due to the fact that they are currently the most used mobile DM applications for tracking DM data. They are capable of taking more than just DM data as input and are compatible with many CGMs. They provide immediate feedback to their users about their current health and could form a good basis for design of a new IV system.

2.6.1 DEXCOM G5 Mobile Continuous Glucose Monitoring System

This system is the closest existing system to the proposed IV tool. It makes use of Continuous Glucose Monitoring (CGM) to keep track of DM patients glucose levels throughout the day.

The system is comprised of three main parts (Dexcom, 2015):

1. Small Sensor that measures glucose levels just underneath the skin.
2. An element that is fastened on top of the sensor and sends data wirelessly to a compatible smart device or receiver.
3. A Compatible Smart Device with the Dexcom G5 Mobile app.

BGLs can then be viewed in vivid colours to identify when they are high, low or within range.

With the Dexcom G5 Mobile CGM System, users are alerted directly on their compatible smart device when their BGLs are too high or too low. Alerts and alarm sounds can also be customized to appear as a text message, allowing for additional discretion and privacy.

The system allows users to keep track of events that affect their glucose levels on their compatible smart device. The Dexcom G5 Mobile CGM System provides a platform to enter customizable events, giving users the ability to track how their daily activities influence your glucose trends.

Through Diasend's website users can analyze their glucose patterns and trends from the convenience of their home. Customized reports can even be shared with physicians. This provides a healthcare team additional insight to better manage DM.

Shortfalls of this system include:

- Lack of automated input systems for diet or exercise plans.
- Lack of existing health pattern identification.
- Lack of analysis within the mobile system (requires Diasend's website for analysis)

2.6.2 MySugr

MySugr (mySug, 2012) is a free cellular application available on both the iStore and Google PlayStore. MySugr (mySugr, 2012) has the direct purpose of aiding individuals with the self-management of their condition. It does so by taking recorded information from the user and representing it as a report summarizing their BGLs over time. Food intake, medicine intake and BGLs are all represented in a calendar with time stamps and line graphs.

The entry of this data becomes time consuming for users and was thus made optional. Whichever data the user chooses to track will be represented. Any data, which the user does not track, is discarded and not forecast (Johnson et al, 2019).

Two features of the application which deserve attention are reminders and tags, as seen in Figure 2-6. Tags are the notable events, which occur and influence BGLs and reminders can be set manually by the user so that an alarm can sound when medication is required. The reminder is typically set for 15 minutes to 3 hours to remind users about a post meal medication intake.

Shortfalls of this system include:

- Lack of CGM
- Lack of alerts for abnormally high/low blood glucose levels
- Lack of an automated input system for BGLs, exercise or diet plan

- Lack of existing health pattern identifications
- Unable to link Fitbit data

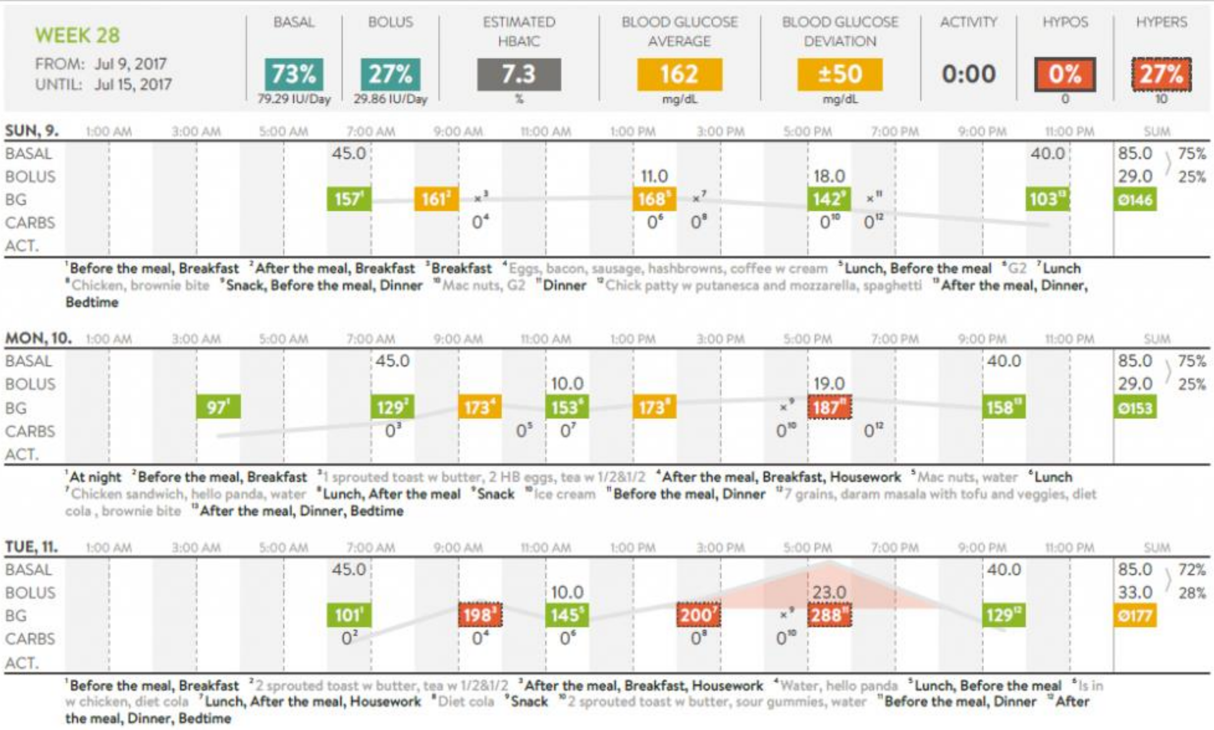


Figure 2-6 Example of report screen (Johnson et al, 2019)

As a secondary point, the visualisation represented by Figure 2-6 is difficult to interpret. This representation can be improved by using IV. The image is an attempt at visually representing food intake, blood glucose and carbohydrate intake for each day of the week.

2.6.3 Diabetes:M

Diabetes:M (Sirma Medical Systems, 2021) is an award-winning diabetes logbook app that was first published in Google Play in April 2013. It was developed by diabetics to meet the needs of people who want to manage all aspects of their condition. Users can track, analyze, review and export data.

The main features of the application include (Yordanov, 2016):

- Clean Logbook: A logbook for glucose, insulin, nutrition, medication, injection sites, notes and categories.
- Food Database: Food database with portion and quantity selection. Bolus Calculator: Carbohydrates counting and insulin dose calculator.

- Extended bolus calculator mode: For diabetics on both multiple daily injections and insulin pump therapy.
- Detailed Graph: Detailed timeline graph of blood sugar tests including also boluses, basal insulin, activity chart and other useful data.
- Analytical Charts: A summary of all the users collected data in a visual way using charts and diagrams.
- Various Reports: Log entries and charts can be shared with diabetes specialists for review.
- Data Import/Export: Users can export the collected data and import external data from other diabetes management systems.
- Reminder System: A reminder system to prevent users from forgetting to log BGLs.

Shortfalls of this system include:

- Lack of CGM
- Lack of alerts for abnormally high/low blood glucose levels
- Lack of an automated input system for BGLs, exercise or diet plan
- Lack of existing health pattern identifications
- Unable to link Fitbit data

2.6.4 Comparison of Existing Systems

Table 2-2 brief tabular comparison of the three selected systems:

Table 2-2 Comparison of MySugr, Diabetes:M and Dexcom

	MySugr	**Diabetes:M**	**Dexcom**
Makes use of CGM	No, glucose levels require input.	No, glucose levels require input.	Yes, the device is essentially a CGM wearable.
Provides alerts for high/low BGLs	No such alerts are provided.	No such alerts are provided.	Users are alerted directly on their compatible smart device when they are BGLs are too high or too low
Automated input system for food intake	No, food intake requires input.	No, food intake requires input.	The system allows users to keep track of events that affect their glucose levels on

			their compatible smart device. Additional information requires input.
Automated input system for exercise completed	No, exercise input does not exist.	No, exercise input does not exist.	The system allows users to keep track of events that affect their glucose levels on their compatible smart device. Additional information requires input.
Includes some form of IV	Yes, graphics are included.	Yes, some graphics are included.	Through Diasend's website users can analyze their glucose patterns and trends.
Includes health pattern identification and highlighting	No, interpretation of reports is left to the user.	No, interpretation of results is left to the user.	Through Diasend's website users can analyze their glucose patterns and trends, but no additional analytics are performed.
Includes report for user behavior	Yes, the app provides report screens for BGL levels, among other independent variables.	Yes, the app provides report screens for BGL levels, among other independent variables.	No, the system is reliant on a separate website for such analytics
Is possible to send feedback to a clinician	No	No	Yes, through a link from Diasends website.

2.6.4.1 Shortfalls of Existing Systems

The above two systems were selected for analysis because they are two of the most popular self-management tools used in the process of self-management of DM. They were highly ranked, receiving 4.6 stars each in the Google PlayStore. The apps were also both easily accessible, as they were both free and available for mobile devices. They offer a form of visualisation of data for users and are a good base model for requirements of a tool to support the self-management of DM.

A brief review of existing systems highlighted several shortcomings (Section 2.6.3, 2.6.2 and 2.6.1):

- Require manual input: The above-mentioned applications require time consuming input of medical and dietary information. This can become a deterrent for many users.
- Missing visualisations: The graphics that are displayed lack imagery, which highlight any form of existing health patterns.
- Lack vital reminders and information: Because these applications do not make use of CGM, they are unable to alert the user if BGLs are dangerously high or low. No diet plans or foods are recommended and the information within the application cannot be communicated well to clinicians.

The following are general shortcomings previously identified in IV tools, that are not necessarily issues with the three reviewed systems (Chen, 2005):

1. *Representation Loss:* The visualisations are often used in conjunction with source material that is highly statistical and technical and as a result become complex to use. Some of the charts in the evaluated applications were detailed and small. The details overshadowed the underlying trends in the data. When evaluating Diabetes M, large amounts of data were represented on the charts, which could cause users to lose focus on the important overarching information about how exactly they are doing in terms of health on a specific day. MySugr's screen design meant that users would be required to scroll in order to see the BGLs for a full week or day, and thus it was difficult to view an overall trend or measure of performance.
2. *Incongruence Between Data Visualisation and Design Principles:* The visual metaphors that inform the presentation of information can impact user recollection and understanding. To some extent, users can determine whether they agree with the represented data. To some extent, this effect can be blamed on the differences between data visualisation techniques and visual design best practices. Data in the applications such as MySugr is always represented in green, this could mislead the user as green is often a color associated with healing and positivity.
3. *Lack of Explanation:* IV tools show information, but they do not explain underlying meaning. Data visualisation tools help represent data results in pictorial/graphical formats. And while data visualisation tools are meant to help analysts see trends and understand data, there are significant

limitations that can become problematic as data sets grow. This could be the case with the existing systems. In the case of MySugr the chart showing BGLs over time stretches across the top of the screen but doesn't allow the user to zoom out to get an evident overview of trends in the data.

4. *Lack of Guidance*: The most basic systems assume that users know what they are looking for. Trend lines are not highlighted so identifying patterns is left to the human eye. This is still apparent in the evaluated systems. There were no indication lines for where the users BGLs should fall or what they were aiming toward.

2.7 Functional Requirements

The functional requirements can now be determined based on the needs of the individuals that are required to utilize the artefact, which requires development for evaluation of the results of this research. The type of application that requires development will be determined in Chapter 4 Design and Implementation. The following functional requirements were determined after evaluating existing systems and discovering their shortfalls. A brief interview with a medical representative for a CGM company was also conducted in order to discover if any other useful and beneficial features could be included in the system.

In order for the application to be considered done, the following functions must be supported:

- Alerts must be sent to users during health critical times. i.e.: unhealthily elevated heart rates or BGLs so that they can take immediate action to rectify the problem.
- BGLs must be displayed to users in an intuitive way that facilitates cognition so that data interpretation is not drowned out by too much detail.
- The system should be designed to require very little user input, as this is a deterrent and can cause users to feel discouraged by the amount of input required in order to obtain a decent output.
- Data represented to the user should be simple and indicate quickly if the user is performing well on a given day.
- Patients must be able to create a report in the form of an image or document so that it can be analyzed by a medical professional if necessary.

- Patients must be able to set reminders for water consumption or medicine intake in order to aid them with their self-management.
- The visual metaphors used to inform the patient should be intuitive and easy to understand. I.e. red for bad behaviours and green for good behaviours.

The functional requirements will be extended to include requirements specific to the visualisations that are to be used in Chapter 3.

2.8 Conclusion

DM is a chronic BGL disease affection millions of people worldwide. The types of DM include T1DM and T2DM and each type of the disease require different self-management methods which can yield different medical results. The benefits of improving the self-management of T2DM include increases in lifespan and quality of life as well as potential recovery.

As the number of diabetes cases increase rapidly, it becomes necessary for an effective tool to aid in the self-management process to be developed. Self-management is a process in which patient care factors are solely the patient's responsibility, i.e.: medication intake, food consumption and exercise plans.

Extant systems, which aid in the process of self-management of DM, include MySugr (mySugr, 2012), Diabetes:M (Sirma Medical Systems, 2021) and Dexcom G5 CGM. Each of these takes in various user inputs as diabetes data and display the information back to the user.

The abovementioned extant systems were investigated and shortfalls for each were discovered. The result of this yielded multiple problems due to lengthy user inputs and lack of graphical intuitive displays. Current use of these tools does not direct focus on the presentation of diabetes data and does not contribute to connections between relevant diabetes data.

Placing the responsibility of care for a disease in the patient's hands also leads to many problems. Patients may not follow sufficient diet plans, remember to take medications or understand the link between sleep, diet, exercise and medication consumption to their fluctuating BGLs and potentially worsening DM. The first research question, '*What are the existing problems with self-management in DM patients?*', has thus been answered.

The use of health patterns in medicine is not a new concept and has been utilized previously in the form of GFHP's for diagnostic purposes. Health patterns in DM were identified and can be useful in developing a cognitive awareness of the connections existing between BGLs and variables like sleep patterns, blood pressure, medication intake, food intake and exercise plans. This discovery thus answers the second research question: *How can existing health patterns be used to improve self-management of DM?*

The next chapter will identify IV techniques in more detail that can address the above-mentioned problems and shortfalls to assist in the self-management of DM.

3 Information Visualisation

3.1 Introduction

IV is the study of visual representations of abstract data to reinforce human cognition. It is a useful way of representing large amounts of data easily. One of the core problems associated with tools to aid the self-management of DM involves short-comings of the health pattern displays available and poor presentation of diabetes data.

This chapter will focus on identifying appropriate IV techniques for use in a tool to support effective self-management of DM. This chapter addresses the third research question identified in Chapter 1, namely:

What possible IV techniques can be used to improve self-management of DM?

In order to reach the ultimate goal of answering this question, this chapter will focus on defining IV and identifying its purpose and benefits. IV techniques suitable for use in a tool to support the effective self-management of DM will then be identified and requirements of the IV tool will be defined. Existing IV tools will be discussed and compared.

3.2 Introduction to Information Visualisation

Thinking or the process of drawing conclusions is not a process that occurs entirely without peripheral intake. Little or very small percentages of intellectual work is accomplished without the eyes and ears. Most cognition or thought processes are completed with the interaction of cognitive tools, such as pencils, paper and calculators. There is an increased use of computer-based intellectual support and information systems.

"Thinking" occurs through an interaction between individuals, using cognitive tools and operating within a social network. Visualisations play a small but crucial role in cognitive systems. Visual displays provide the highest bandwidth from the computer to a human. Individuals acquire more information through vision than through all other senses combined (Hutmacher. F, 2019).

Improving cognition means tightening the band between a person, any computer-based tool and other individuals (Ware. C, 2004). This provides a powerful tool, capable of combining the complex human visual system, a built-in flexible pattern finder and decision-making mechanism and the computational power and vast information resources of the computer. IV is currently narrowing the gap between the two and improving the interface between these two advanced resources, can improve the performance of the system overall.

Until recently, the term visualisation meant construction of a visual image in the mind (resource), however, the definition has been altered to mean a graphical representation of data or concepts. A visualisation has moved from being a mental construct, to being an external tool to support decision making.

3.3 Defining IV and the IVRM

IV is a powerful tool utilized daily to represent large bodies of information at once. When these tools are applied in daily life, properties and internal relations between data can be shown. A patient with a disease, such as DM, can be represented visually with ease. Disease, gender and many variant properties of the patient can be encoded visually using colour and shape, and due to the brains' natural perceptive abilities, essential information can be extracted and retained at a glance.

3.3.1 Information Visualisation

The most common definition for information visualisation in computational systems was proposed by Card et al (Card, Mackinlay and Shneiderman, 1999). It started with a more general definition of visualisation in computational systems and defined visualisation as:

The use of computer-supported, interactive, visual representations of data to amplify cognition (Card, Mackinlay and Shneiderman, 1999)

The "cognition" is further defined as "*acquisition or use of knowledge"* (Card, Mackinlay and Shneiderman, 1999).

This definition implied that the main goal of visualisations is to provide insights and not only imagery. Visualisations may represent a vast number of different types of data. In the case of representing physical data, the tendency is to use the term scientific visualisation.

Based on the type of data to be visualized they define IV as:

The use of computer-supported, interactive, visual representations of abstract data to amplify cognition (Card, Mackinlay and Shneiderman, 1999).

The difference in the latter definition is the term “abstract data”, which is implied because no obvious spatial mappings can be assigned to the data. Without a spatial abstraction, one challenge is the problem of rendering the data into an effective image.

3.3.2 IV Reference Model

To face the mapping problem of raw data to visual forms a reference model for visualisation was proposed (Card, Mackinlay and Shneiderman, 1999), using outcomes of previous works on non-computational visualisation of abstract data. The proposed reference model for visualisation counts today as the most influential reference model for information visualisation. It provides a data transformation process from raw data to views involving the human in the interaction processing.

A structural pattern for dealing with the complexity of visualisation system architectures is known as the Information Visualisation Reference Model (Huang et al. 2005), and Figure 3-1 below illustrates the pipeline of four major steps taken when utilizing the model.

IV application development requires balancing issues of data management, visual mappings, computer graphics, and interaction (Heer and Agrawala, 2006). Determining the correct separation of these issues has serious consequences for the complexity, extensibility, and reusability of software architectures. The IVRM provides a general template for structuring applications that separates raw data, data tables, visual structures, and interactive controls.

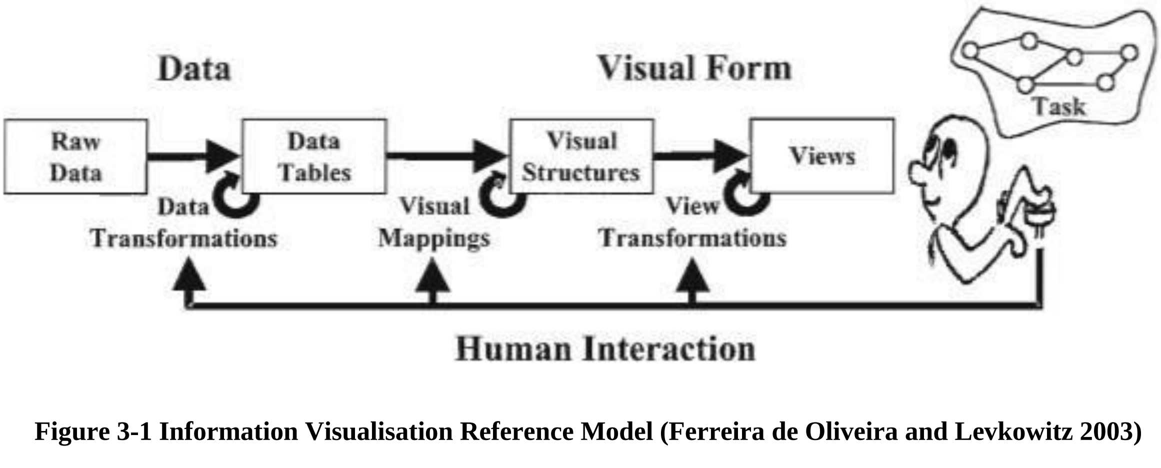


Figure 3-1 Information Visualisation Reference Model (Ferreira de Oliveira and Levkowitz 2003)

The arrows flow from raw data on the left, though a set of data transformations into data tables. The mapping from data tables to visual structures is arguably the most important step, because structures combine values and visual elements. Visual structures can be further transformed by view transformations, such as visual distortion or 3D viewing angle, until it finally forms a view that can be perceived by the human eye.

The first step of transformation is data transformation. This step transforms the diverse raw data formats to relations or sets of relations (data tables) that are structured and easier to visualize (Card, Mackinlay and Shneiderman, 1999). These are often defined mathematically as a set of tuples.

A Data Table combines relations with their describing metadata. The data table is represented by rows, which contains ‘variables’ as a set of values in the tables and ‘cases’ as a set of values for each variable. Data tables introduce categorization of data variables and their possible sequences. Data tables propose that there are three basic types of variables:

- Nominal: unordered sets
- Ordinal: ordered sets
- Quantitative: numeric ranges

The next step in the transformation process of the reference model is the mapping of the data tables to Visual Structures. The IVRM proposes that two main factors are important to provide an effective mapping to visual structures. The mapping should preserve the data with their type of variables and emphasize the important information to be perceived well by the human. The visualisation should enable the human to interpret faster, distinct graphical entities, or make fewer errors (Card, Mackinlay and Shneiderman, 1999).

In today’s evaluation methods the two main factors for measuring the efficiency of visualisations are task completion time and task completion correctness. The visual structures of the reference model are enhancements of graphical symbols. The symbols (visual variables) used can be subdivided into retinal variables and layout, but the reference model does not propose such a differentiation. It consists of spatial separation, marks, and graphical properties. Although some visual encodings are more appropriate for uncontrolled processing in tasks like search or pattern detection and others for controlled processing, the reference model itself does not spread this separation. It focuses more on a general transformation of data tables and their sequential characteristics to visual structures.

Visual structures may appear as marks, connections and enclosures, and temporal encodings, whereas the transformation encloses the entire group of visual structures.

The final step of the reference model completes the loop between human and task. It transforms still graphical presentation by incorporating humans' interaction to create different views of visual structures and provide an interactive visual environment.

There are three main view manipulations:

- Location probes use location to reveal additional information from data tables
- Viewpoint controls magnify or change the viewpoint, e.g., by zooming or panning, and
- Distortion provides a modification of the visual structure by creating a context plus focus view.

The IVRM describes in a comprehensible way the transformation processes from raw data to visual structures, the view manipulations, and human operations on different levels back to the transformation steps. These steps focus on how abstract data can be visualized interactively with computational systems and provide an explanation of IV.

The reason for separation in this manner is as follows:

- Separation of data and visual models: Enables multiple visualisations of a data source
- Separation of visual models and displays: Enables multiple views of a visualisation
- Separation of controllers through modularity: Enables a flexible and reusable method for handling user input

The IVRM has been widely used. Both Chi et al's data state model (1998) and Card et al's IV reference model (1999) are noted to use the IVRM. In their exploration of design choices for creating visualisations, Tang et al. (2003) also discusses the importance of separating data and visual models.

3.3.3 Visual Analytics

Visual Analytics (VA) has evolved from IV and other areas to emphasize the knowledge generation aspect. VA are often used in conjunction with IV, although both terms have definitions. The early and most influential definition of Visual Analytics was proposed by Thomas and Cook (Thomas & Cook, 2005):

Visual analytics is the science of analytical reasoning facilitated by interactive visual interfaces.

One of the main focuses of VA is to "detect the expected and discover the unexpected, from massive and ambiguous data" (Thomas & Cook, 2005). They outlined that the main areas of the interdisciplinary field of VA are:

- Analytical reasoning techniques: for obtaining insights and supporting analytical tasks such as decision making.
- Visual representations and interaction techniques: for enabling users to explore and understand large amounts of data and interact with them with their visual perception abilities.
- Data representations and transformations: to convert all types of data, even conflicting and dynamic, to support visualisation and analysis.
- Production, presentation and dissemination: to provide a reporting ability for a broader audience and communicate the analysis results (Thomas & Cook, 2005).

From the above definition it is deducible that to some extent, research into sufficient VA techniques will be required for an effective self-management tool to be developed.

3.4 Purpose of IV

The core purpose of IV is to explore and refine unclear or undefined properties of data (in this case, data related to DM) and the relationships between these properties (Yi et al, 2008). IV is used to provide insight or further understanding of data (Yi et al, 2008). When IV is used, vast amounts of data are displayed in relatively small screen space, thus producing a challenge in IV: to develop techniques and metaphors that present information which is easy to understand. The amplified cognition that comes with easy extraction and understanding of information (abstraction) is part of a process known as sense making.

This process is best explained in terms of the data-frame theory. According to this theory, when engaged in sense making, elements are explained by first being placed into a representation that can be linked to other elements that have resulted from past experiences. These representations are subjective lenses through which people view, filter and structure data. Sense making is recognized as a complex activity. It is a compound process that considers various interconnected components ranging from medical readings to the surrounding environment and associated lifestyle (Faisal, Bladford and Potts, 2013).

3.5 Benefits of IV

There is a need for understanding of complex, ever-changing, volatile information, which has led to the continuing development of IV techniques. It is essential for all stakeholders or users including DM patients, clinicians and emergency response teams to be able to find useful information from the vast amount of data provided (Keim, D. A. *et al.* 2008).

The following are benefits of IV:

- Visualisation provides an ability to comprehend huge amounts of data. The important information from more than a million measurements is immediately available.
- Visualisation allows the perception of emergent properties that were not anticipated. The perception of a pattern can often be the basis of a new insight
- Visualisations often enable problems with the data itself to become immediately apparent. A visualisation commonly reveals things not only about the data itself, but about how the data was collected. With an appropriate visualisation, errors and artifacts in the data often emerge. For this reason, visualisations can become invaluable in quality control.
- Visualisation facilitates understanding of both large-scale and small-scale features of data. It can be especially valuable in allowing the perception of patterns linking local features.
- Understanding without training: A sensory code is one for which the meaning is perceived without additional training. Usually, all that is necessary is for the audience to understand that some communication is intended.
- Sensory immediacy: The processing of certain kinds of sensory information is hard-wired and fast. We can represent information in certain ways that are neutrally processed in parallel.

- Cross-cultural validity: A sensory code will, in general, be understood across cultural boundaries. These may be national boundaries or the boundaries between different user groups. Instances in which a sensory code is misunderstood occur when some group has dictated that a sensory code be used arbitrarily in contradiction to the natural interpretation. In this case, the natural response to a pattern will, in fact, be wrong.

To take full advantage of the benefits of IV, it is imperative to understand the focal issues that come with its use. The following issues are in conjunction with issues already mentioned in section 2.6.4.1 (Shortfalls of Existing Systems):

Usability: The gap between the known usefulness of IV in the presentation and understanding of data and the user's perception of IV's usefulness. The existing evaluation methods for IV systems do not convey its usefulness effectively to larger audiences, simply because the methods are known to be restrictive, and prevent users from interacting with the systems as they would naturally in the real world.

Uncertainty: The capability of an IV system is not known or familiar to users, which breeds uncertainty, one consequence of which is hindered decision making. The reasons for these uncertainties are rooted in the following reasons: limited affordance, simple operations involved with IV, predetermined representations, static representations and a general decline of determinism in decision-making.

Scalability: As datasets grow, representations can become more cluttered, slower and disorganized.

Unsuitable adoption: Available data influences appropriate IV techniques. If the incorrect techniques are used to represent data, the data can become difficult to understand or interpret.

3.6 Information Visualisation Techniques

Different IV techniques are suitable for different data types. Depending on the data that is required for representation, specific techniques must be identified. The IV techniques that support the type of diabetes data that is necessary for a self-management tool, must be analyzed further to determine which techniques would be appropriate for visualisation. In this section, IV techniques, which are classified according to their data type are discussed.

3.6.1 Data Types

- *1D or Linear*: One dimensional or linear data is not typically visualized. It is comprised of an attribute, often mapped against a single set of features or objects. Lists of items in alphabetical order are an example of this. Alternate visual examples include 1-dimensional scatter plot or pie charts as shown in Figure 3-2.

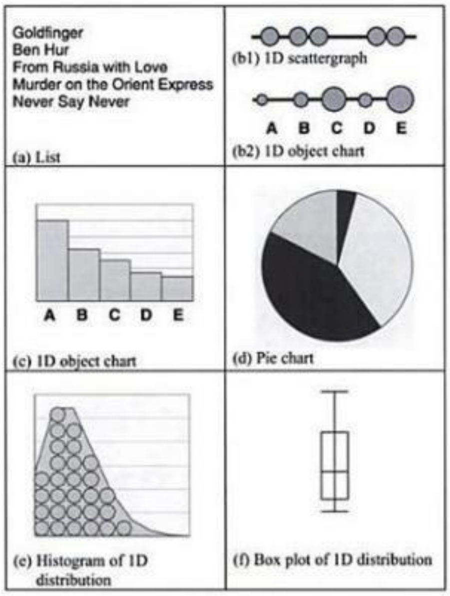


Figure 3-2 1D or Linear Visualisation Examples (Jacko and Sears, 2007)

- *2D or Planar / Geospatial*: Two-dimensional or Planar data is often easily represented in 2dimensional space. It involves plotting an attribute or variable against other attributes or variables. Because it is done in two dimensions, usually each attribute or variable is placed along a separate axis, the x or y axis. Examples of two-dimensional or planar visual representations include scatter plots and are especially prevalent in geospatial visual representations such as cartograms, dot distribution map and contour maps, which can be seen in Figure 3-3 (Zoss et al, 2017).

Figure 3-3 Dot Distribution and Contour Map (Zoss et al, 2017)

- *3D or Volumetric*: Three-dimensional or volumetric data is a representation of data in three dimensions where each dimension is used to encode a corresponding variable or attribute. Three-dimensional data representations are mapped similarly to two-dimensional data representations but gain a third axis, the z axis. Examples of three-dimensional or volumetric visual representations include 3D computer models, surface and volume rendering and computer simulations. This is demonstrated in Figure 3-4.

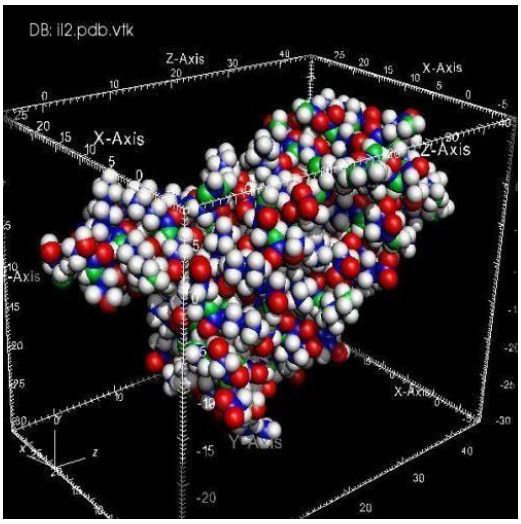


Figure 3-4 Molecular Rendering in 3D Space (Zoss et al, 2017)

- *Temporal*: Temporal visualisation and analysis is the process of looking at and analysing features or data that are dependent variables where time is the independent variable. Examples of this type of visualisation include timelines, time series and Gantt charts. This is demonstrated in Figure 3-5.

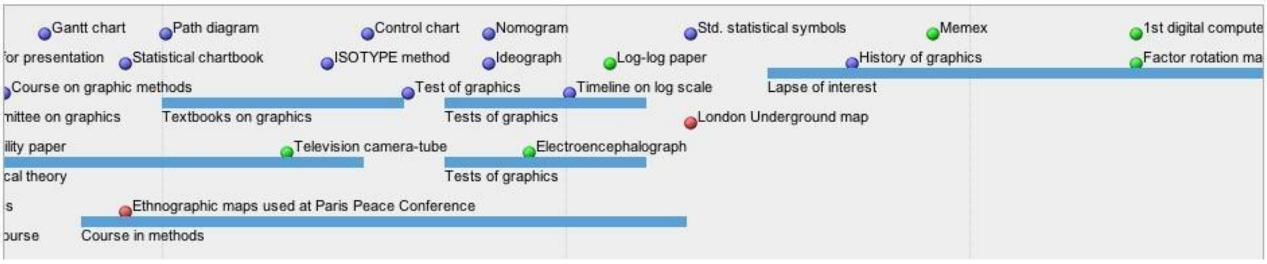


Figure 3-5 Timeline (Zoss et al, 2017)

- *nD or Multidimensional*: nD or multi-dimensional data is an extended version of three-dimensional data. It is a complex visualisation that contains data representations to the nth number. Examples of these include unordered bubble charts, tree maps, radar/spider charts and parallel sets, which are demonstrate in Figure 3-6.

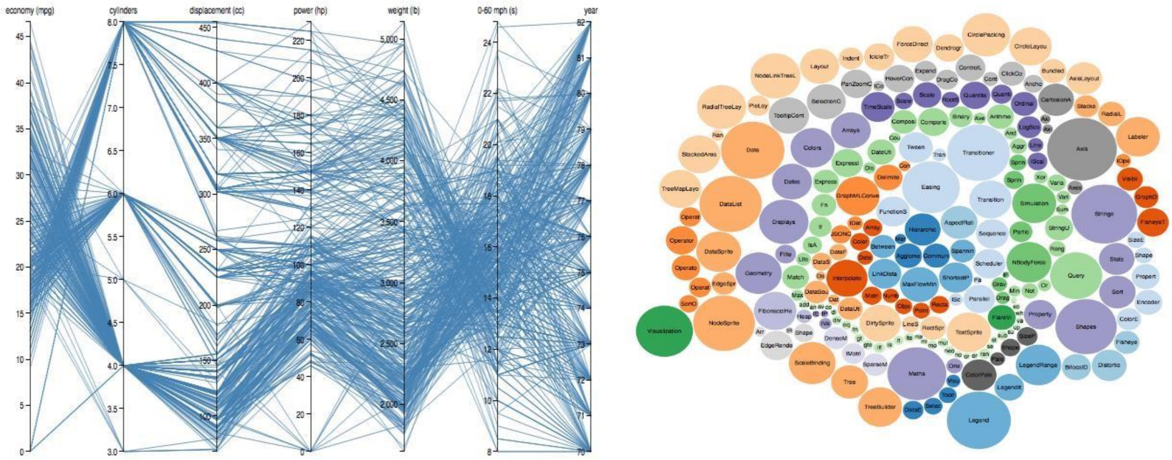


Figure 3-6 Parallel Sets and Unordered Bubble Charts (Zoss et al, 2017)

Tree or Hierarchical: Trees are used to visualize data by creating linkages between variables and attributes that form data structures with a hierarchy. Examples of this include radial trees and dendrograms.

Network: Network visualisations represent a network of interactive data. It is a visual representation of a collection of nodes and edges, typically represented by circles or lines that vary in width to represent volume or strength of connection. As an example, in the image presented below, dots were used to represent patients moving between different states of a health network. The more dots that are present, the more patients, or in terms of the network, the stronger the connection (Yau, 2016).

3.6.2 Visualizing Relevant DM Data

Because of the vast number of IV techniques, it is imperative to understand the type of data that requires representation. For this to be possible, the DM data that must be represented necessitates classification. As previously mentioned, measures that must be self-managed by DM sufferers include: oral medication, exercise, diet and sleep. These factors directly influence the BGLs of patients, which forms a fourth factor which requires representation. The influence of the prior three factors on BGLs must be highlighted to patients using IV to facilitate understanding and minimize cognitive strain.

Since these three factors have been shown to affect BGLs over time, it can be assumed that the BGLs must be collected for representation over time, where diet, exercise, time and medication intake are the independent variables which influence the BGLs, BP and cholesterol otherwise referred to as the dependent variables. Data that is collected over time is known as time series data (Takeuchi, Kodama and Tsurumi, 2009). Since this research makes use of data collected over time and the changes in that data over time, it is important to have a basic understanding of what time series data is and how BGLs can be analyzed as time series data.

3.7 Diabetes Data

3.7.1 2003 Time Series Data

Time series data is useful in understanding past events as well as predicting future occurrences of events in the data. When plotting data against time it is possible to recognize patterns in the data. Since the data collected for individuals with DM is not a single set of data plotted against regular intervals of time, there is more complexity in the collected data (Ostom, 1990).

It is possible when representing lifestyle changes and BGLs as time series data to extract associated rules among lifestyle events, BGLs and the level of severity of DM. Generally, BGLs are difficult to manage for many people with DM, since it is affected in a complex and non-linear manner by carbohydrate intake, medication and exercise. It is imperative when collecting data for this research, to exclude the influence of non-target lifestyle events on BGLs. Only data which occurs in a relevant time window can be considered target lifestyle events. A manner of controlling the reduction of data considered which can be classified as a ‘non-target lifestyle event’, would be to only include BGLs collected within one hour after food intake, exercise or medication intake.

3.7.2 Analysis of Time Series DM Data

The analysis of DM time series data will be based on the idea that the accumulation of the effects of lifestyle events such as ingestion and exercise can affect personal health conditions with some delay (Takeuchi, Kodama and Tsurumi, 2009). During the analysis, the accumulation of the effects of lifestyle events should be represented by a summation of energy supply or expenditure data (kilojoules) due to ingestion or exercise. The accumulation of these effects may cause variation of health data such as BMI, BGLs, BP and body-fat percentage with some delay.

3.7.3 Health Patterns in DM Data

Connecting points in scatter plots of time series data is one method of trying to identify patterns in seemingly random sets of data (Bishaard and Kulahci, 2011). Overall trends are identified in much the same way. If patterns in time series data are identified as repeating over similar periods of time, these are known as seasonal patterns. From these patterns, conclusions can be drawn that can induce action to change the data for the better. In the case of diabetic patient's data, patterns should repeat daily, hourly or weekly to be considered as seasonal data. This is useful as time series data can be projected into the future for forecasting purposes so that action can be taken, which correlates with this predicted future event so that full advantage can be taken of it. Identifiable patterns of this sort, when the related data represents health data, are known as health patterns.

3.7.4 Acquisition of DM Data

A dataset of useful BGLs, food intake and exercise tracking has been identified. The dataset includes a large amount of missing data, however, for the purposes of this research, the initial data that will be used will contribute to representation and testing and may require some form of forecasting to reduce any blank entries. Once the system has been developed, more data will need to be captured during the testing. This data will contribute to determining the effectiveness of the developed tool, as improvement can be measured by monitoring of BGLs.

The following are proposed methods for capturing BGLs effectively (Johnson, 2016):

- Continuous glucose monitoring devices (CGMDs): Continuous glucose monitoring (CGM) provides information unattainable by intermittent capillary blood glucose, including instantaneous real-time display of glucose level and rate of change of glucose, alerts and alarms for actual or impending hypo- and hyperglycemia, "24/7" coverage, and the ability to characterize glycemic variability. Such devices include experimental wearable devices such as the KWatch and Dexcom G5 CGM (Continuous Glucose Meter) (Dexcom, 2015).
- Blood Glucose Meters (BGMs): These devices are typically included in kits and are usually invasive. It is a quantitative test, which means that you will find out the amount of glucose present in your blood sample. The device requires blood for testing and can thus cause some levels of discomfort. CGMDs are typically better in this regard. Invasive BGMs like the Accu-Check may be cheaper than CGMD devices, but are often forgotten and are done at intervals. When seeking trends in data, the tests would need to be done at regular intervals and not be forgotten.

3.7.5 IV Techniques for DM Data

Essentially, these are visualisations that track time series data — the performance of an indicator over a period — also known as temporal visualisations. Temporal visualisations are one of the simplest, quickest ways to represent important time series data.

In the section above, relevant time series data IV techniques include:

- 1D- Linear
- 2D- Planar and
- 3D-Volumetric

Some common graphical representations of these include (Ayalasomayajula, 2016):

- *Line Graph*: This is the simplest way to represent time series data and is shown in Figure 3-7. It helps the viewer gain a quick sense of how a dependent variable has changed over time. For temporal visualisations, time is always the independent variable, which is plotted on the horizontal axis. Then the dependent variable is plotted on the vertical axis. Graphs like this can be used in the proposed system to show increases and decreases in BGLs over time.

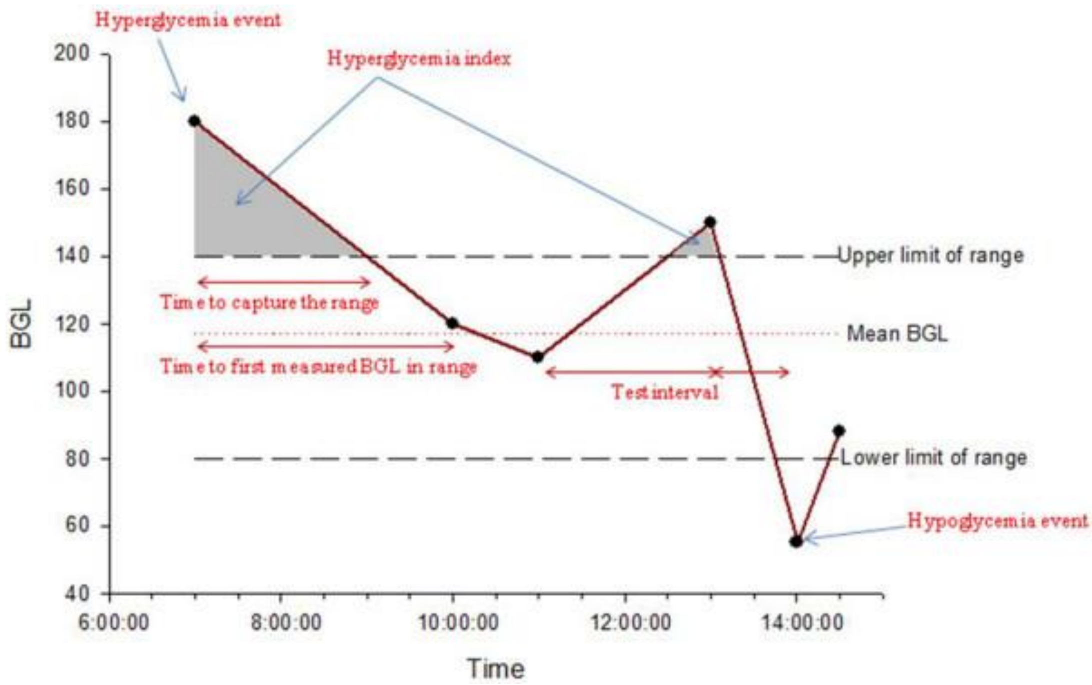


Figure 3-7 : Line Graph Representing BGLs Over Time (Eslami, de Keizer, de Jonge, Schultz and Abu-Hanna, 2008)

- *Stacked Area Chart*: An area chart is like a line chart in that it has points connected by straight lines on a two-dimensional plane. It also puts time as the independent variable on the x-axis and the dependent variable on the y-axis. Figure 3-8 and Figure 3-9 displays this concept. In an area chart, multiple variables are "stacked" on top of each other, and the area below each line is coloured to represent each variable. Area charts can be used in the proposed IV tool to represent overlapping BGLs over separate weeks to directly compare for improvement/ decline in the health of a patient.

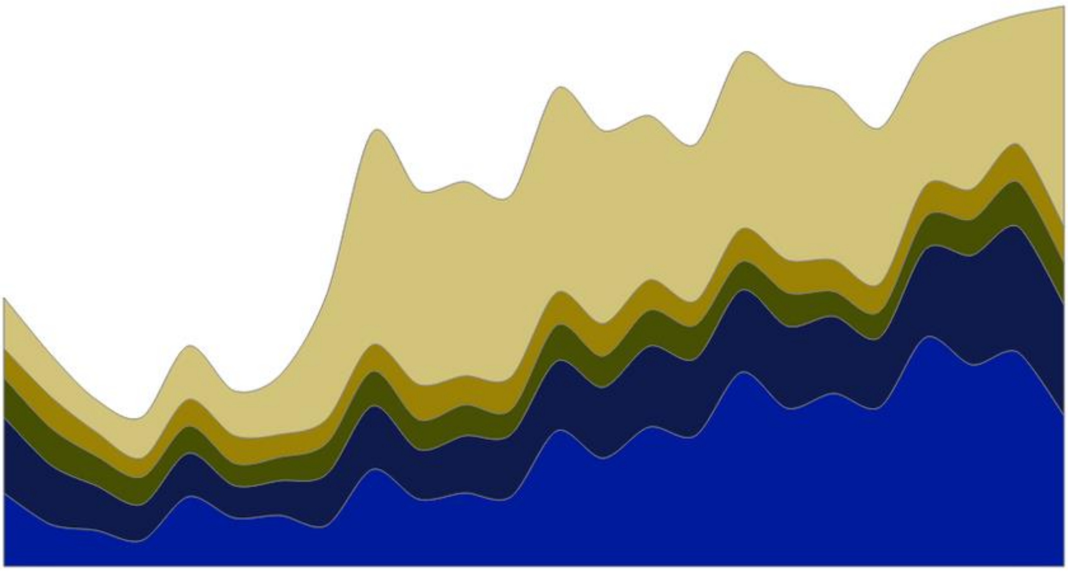


Figure 3-8 Stacked Area Chart (Hall, 2014)

The order in which relevant DM data variables are stacked is crucial because there can sometimes be a difference in the actual plot versus human perception. The chart plots the value vertically whereas we perceive the value to be at right angles to the general direction of the chart. For instance, in the case below, a bar graph would be a cleaner alternative.

Figure 3-9 Error in Captured Stacked Chart (Ayalasomayajula, 2016)

- *Bar Charts*: Bar charts represent data as horizontal or vertical bars. The length of each bar is proportional to the value of the variable at that point in time. A bar chart appropriate for determining how the BGLs change over time or for comparative purposes. Grouped or stacked bar charts combine both purposes.
- *Stream Graph*: A stream graph (shown in Figure 3-10) is essentially a stacked area graph but displaced around a central horizontal axis. The stream graph looks like flowing liquid, hence the name. Figure 3-10 shows a stream graph detailing a randomly chosen listener's last.fm music-listening habits over time.

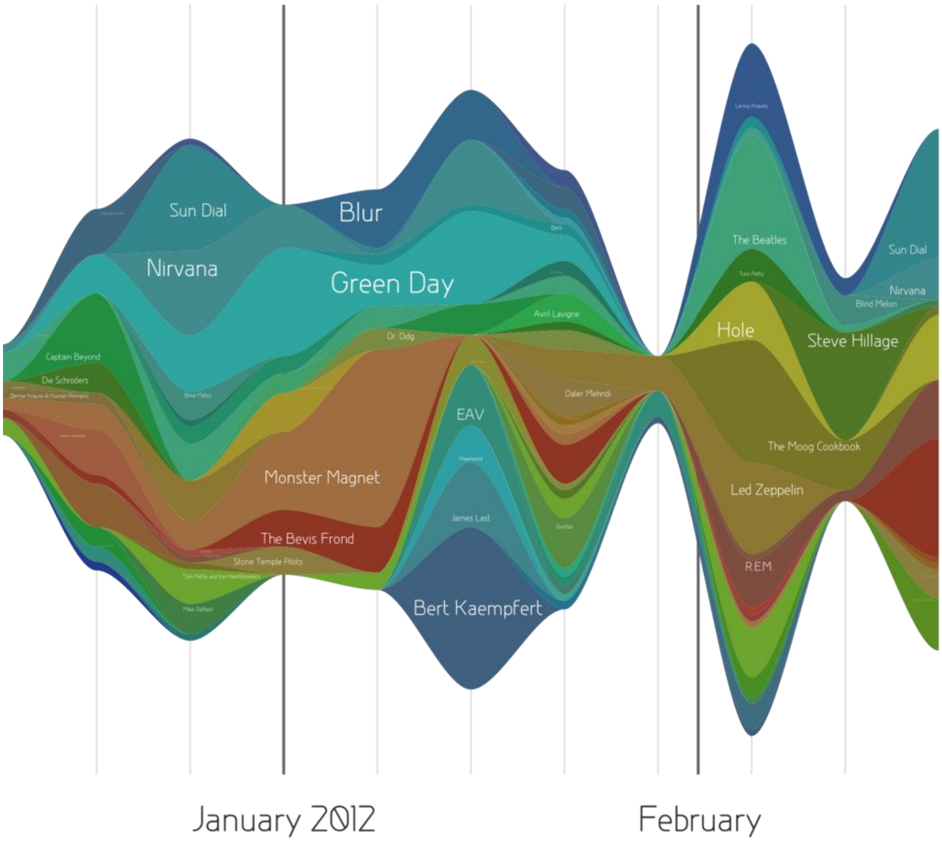


Figure 3-10 Example of a Stream Graph (Ayalasomayajula, 2016)

Stream graphs could be used to represent and compare time series data such as the BGLs over different weeks, or BGLs vs carbohydrate and sugar intake. Stream graphs are appropriate for large data sets like those provided from the use of BGL monitoring devices over time.

- *Polar Area Diagram*: When time series data is seasonal, polar area diagrams can represent the time series data cleanly. A polar diagram looks like a traditional pie chart, but the sectors differ from each other not by the size of their angles but by how far they extend out from the center of the circle.

  This popular polar area diagram created by Florence Nightingale shows causes of mortality among British troops in the Crimean War. Each colour in the diagram represents a different cause of death.

  Polar area diagrams (shown in Figure 3-11) are useful for representing seasonal or cyclical time series data, such as DM data. Multiple variables can be neatly stacked in the various sectors of the pie.

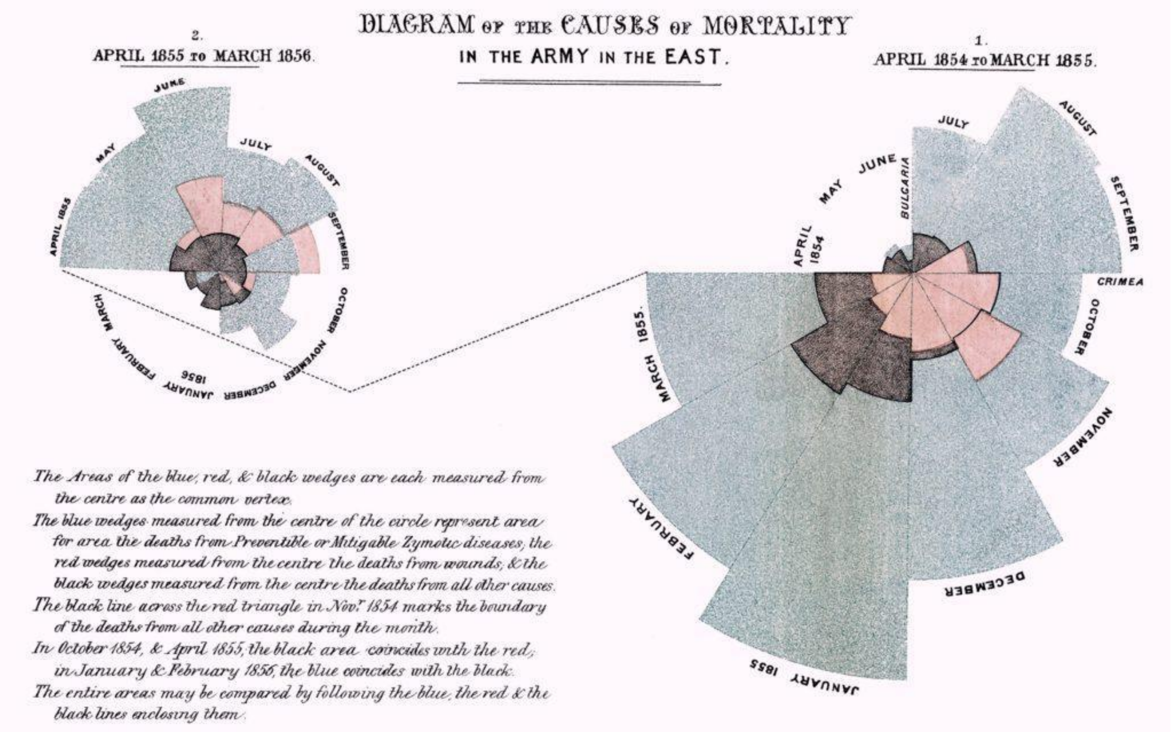


Figure 3-11 Example of Polar Area Diagram (Ayalasomayajula, 2016)

3.8 IV in Medicine

Different IV tools have previously been evaluated outside of the clinical setting and can closely reflect reality. It has been shown that a more detailed tool is necessary for both patients and clinicians to benefit from the creation of targeted systems.

The overall goal of the existing tools (such as Diabetes:M (Sirma Medical Systems, 2021) and MySugr (mySugr, 2012)) was to present user's information contained in a record. It was shown that it improved their ability to recognize patterns for knowledge discovery and following treatment. The introduction of simple visualisation tools, with some including automated computational enhancements, vastly improved patient's ability to take responsibility and gain understanding for their illnesses.

Visual representations take advantage of the eye's broad bandwidth pathway into the mind to allow users to see, explore and understand large amounts of information at once (Smith & Frost, 2003). IV in medicine is the creation of an approach for conveying abstract information in intuitive ways.

The point of IV with respect to this research, would be to reduce the need for sophisticated methods needed to interpret T2DM data and to highlight any health patterns that may emerge.

When properties of data are mapped visually, humans can browse through large amounts of data efficiently. It is estimated that 2/3 of the brain's neurons can be involved in visual processing (How much of the brain is involved with vision, 2015). Proper visualisation provides a different approach to show potential connections and relationships, which are not as obvious in non-visualized quantitative data.

In this way IV can become a means of data exploration. When IV techniques are applied to patient health information, significance is placed on the actions that can be detrimental to their health.

When visualising health information there are five aspects that must be represented to achieve recovery goals for patients (Faisal, Bladford and Potts, 2013):

- *Treatment planning*: This should be communicated to the patient by a medical professional. It includes any exercise routines, practices or medication that the patient must adhere to in order to improve their health situation.
- *Examination of patient's medical records*: Past medical data can provide insight into a patient's current diagnosis and aid in the attempt to provide an effective treatment plan.
- *Representation of pedigree and family history*: Family history can provide insight into a patient's future prognosis. Hereditary problems can affect patient health if they are genetically prone to high/low blood pressure or have a tendency toward weight gain.

- *Communication and shared decision making:* It is important that patients take responsibility for the actions that can lead to degeneration in their health. When communication is open and decisions are made by both the clinician and patient, the responsibility is shared and patients gain understanding into their disease.
- *Life management and health monitoring*: Patients must have a means of managing their lives with diet and exercise and monitoring their diabetes through a strict and detailed plan. Diabetes is chronic and patients are prone to deterioration over time, having a means of managing and monitoring their disease chronically can prevent any further damage and, in some cases, begin to reduce side effects.

This project will attempt to incorporate all five of these points in a manner that can best improve self-management of DM. The focus of the research will be placed on the last point: Life management and health monitoring. The first three factors mentioned rely heavily on a medical professional and are not the focus of this research since the tool will in no way replace medical professional involvement. Communication and shared decision making will remain a part of the initial requirements of the tool, as the tool should aid in this process by communicating vital information to a clinician.

3.9 IV and Time Series Data

The type of data that must be visualized to facilitate this understanding has been discussed and falls under the category of 'Time Series Data'.

Time series data is defined formally as:

If (Ω, ϒ, P) is a probability space, and T an index set. A real valued stochastic process is a real valued function Xt(ω) such that for each fixed $t \in T$, -Xt (ω) is a random variable on (Ω, ϒ, P) (Lamperti. J, 1977). When the index set T corresponds to time indices (discrete or continuous), Xt (ω) is known as a time series.

For fixed t, Xt(ω) is a random variable. For fixed ω, Xt(ω)is a real valued function of t that is called a realization of the time series (Williams & Rogers, 2000). A plot of a recorded time series represents one realization out of the collection of all possible realizations. The ω is typically omitted and Xt is used to represent the time series.

For a discrete time series, the set of times T is a discrete set, and the measurements are typically at successive times spaced at uniform intervals. Continuous time series are obtained when observations are recorded over some time interval, e.g. (0,1). It can easily be deduced that DM data falls into the prior category as devices are unable to read complex DM data points at a continuous rate.

Time series data has a natural temporal ordering (Bosman, Unknown). This makes it distinct from common data problems, where there is no natural ordering of the observations, and from spatial data analysis, where the observations typically relate to geographic locations. A time series model will generally reflect the fact that observations close together in time will be more closely related than observations further apart (Gelman and Unwin, 2013). In addition, time series models will often make use of the natural one-way ordering of time so that values for a given period will be expressed as being derived in some way from past values, rather than future values.

3.9.1.1 Trends in Time Series Data

When identifying patterns in time series data, the initial trends that are identified are either positive or negative trends. Graphical representations with positive trends typically increase in gradient over time and those with a negative trend tend to decrease (Velicer and Fava, 2003).

Variation is another measure for trends in time series data. Peaks and pits in graphed data typically represent the variation in that data set. Seasonal data have regular peaks and troughs.

Cyclic time series diagrams result from variation in the data that is actively a result of events but is not predictable. Changes in these plots do not occur at regular time intervals. Cyclical time series plots can still contain a positive or negative trend.

Time series data can be seasonal, cyclical or random. Random time series plots contain no visible patterns and variation is obscure.

In the case of DM time series data, positive and negative trends may increase or decrease depending on the BGLs and target lifestyle events in a specific target lifestyle event window. The data may become seasonal and BGLs may tend to peak and trough after eating at regular time intervals and may form consistent patterns. The data will not be cyclical or random, as the variation is a result of events, but it is also predictable after an event has occurred.

3.10 IV Requirements for Self-Management of T2DM

To represent DM data in a manner that supports effective self-management and cognition, the techniques used to visualize this specific information should adhere to certain requirements. Only a few applications using IV to represent medical data have been found and so there is a limited amount of information to guide this specific type of application. The field of IV offers little methodological guidance to those who seek to design systems. Many sources describe the foundations of the domain, but few discuss practical methods for solving visualisation problems. One frequently cited guideline to design is the "Visual information-seeking mantra", proposed by Shneiderman in 1996:

- Overview first, zoom and filter, then details-on-demand

The taxonomy divides general visual information seeking into seven data types and seven tasks. This guideline is one of the earliest and most influential contributions to the IV field.

Seven Data Types:

- one-dimensional data;
- two-dimensional data;
- three-dimensional data;
- temporal data;
- multidimensional data;
- tree data;
- network data.

Seven Tasks:

- overview;
- zoom;
- filter;
- details-on-demand;
- relate;
- history;
- extract.

The mantra is discussed in terms of the seven tasks. Any IV technique selected to represent data should support the user's tasks. The following requirements are proposed in terms of the VISM used for IV, adapted to self-management of DM and based on the requirements of the proposed tool:

· **Overview:** The user should be able to view their history of BGLs. An overview window should be provided to allow the user to easily move through specific timeframes of their DM data. Since this project is dealing with the first four groups of data types mentioned above, stack zooming strategy could assist the user in navigating to a position in the graph that is of interest. The user should also be able to easily navigate through time with pan or scroll controls. The use of an overview is an important research aspect in IV (Hornbæk and Hertzum, 2011). The overview will provide users with a general idea of the DM data. It is suggested to provide an overview for satisfaction rather than for the objective of performance.

· **Zoom:** The user should be able to effortlessly zoom in on specific events, meals or points of interest of the DM data that are significance. A user would zoom in to focus on a section of the data or to view more detail graphically (Carr 1999).

· **Filter:** A user should be allowed to remove the items that are not of interest to him at any point in time allowing the user to concentrate on interesting factors. A user should be allowed to search for aspects of data based on their goal. A search facility should be provided by the system to allow the user to navigate through the tool and find useful information, especially because of the large nature of the data. If the user has a specific query in mind, they should be able to manipulate the data in this manner. Only data which meets the search criteria should be highlighted or colour coded in some way to differentiate the relevant search results from the rest of the data. Category linking should be possible

· **Details-on-Demand:** A user should be able to select sections of the graphics and obtain details or be able to find more information about the represented data when required. A user should be able to expand or contract segments of the data when needed. An example of this would be expansion of points which indicate that food was eaten, to view which foods were consumed and details of those foods.

· **Relate:** Users should be able to connect the data and relate different aspects of the data to each other easily. The filter aspect should be used for relational advantage, so that impact of independent variables on the dependent variables can be identified and understood.

· **History:** The user should be supported in reversing and re-doing actions performed to assist in the exploration process.

· **Extract:** No traditional exporting of files is necessary in this application, but it should be possible for an extracted viewpoint to exist. As an example, extraction implies that the information can be seen externally or provided to other individuals. Practitioners must be provided with an external view point and not simply log in as the user to view critical DM data.

3.11 Existing Systems and Experimental Work

A diabetic can use three major pieces of technology in the treatment and regulation of their disease; an insulin pump, continuous glucose monitor, and blood glucose meter. The readings from these devices are recorded to medical software that can be accessed by medical professionals and the patient for a greater understanding of the patient's daily blood sugar levels. The insulin pump controls bolus and basal insulin rates (Boucher-Berry, Parton and Alemzadeh, 2016). Bolus insulin is given generally after meals to compensate for sugars ingested, whereas Basal insulin is small increments of insulin given at the start of an hour for long-acting results. Combined, basal and bolus rates generally emulate the normal rise and fall of blood sugar levels of a healthy human.

This research aims to determine when these rates are too high and low for the patient, to help guide their behavior and highlight trends. The patients, once speaking to a medical professional, will be able to make decisions that are more informed because of increased understanding due to the visualisations displayed. Currently, the graphs used by medical professionals are cumbersome and hard to understand. To determine a better standard for the artefact to be developed, existing or experimental systems must be examined to determine fitness and improvement factors.

One such system was developed using a tool called Base SAS. Through the creation of multiple datasets and execution of SAS graphing procedures, the study used a months' worth of diabetes data to develop easier to use visualisation to better understand the 24-hour trends seen in daily life.

3.11.1 Methods Used

The data for the abovementioned study came from Medtronic CareLink, a personal therapy management software for diabetes. The software retrieves information from an insulin pump, CGM and BGM and condenses it into several reports. The information is reorganized in a time series data according time of relevance.

When downloading the data from CareLink, the dataset includes 40 variables and 10,896 observations. The CGM takes blood glucose readings every five minutes and requires a calibration based off the BGM every 12-hours. The BGM takes readings four to six times a day, generally before meals and evening times. Several observations are duplicates or provide no useful information for new graphical representation.

For the analysis, only the variables Date, Time, Hour, Sensor Reading, and Blood Glucose Reading were used. Additionally, any observations that do not contain any blood glucose reading or sensor reading were deleted.

Figure 3-12 represents CareLink's visualisation of the CGM. This visualisation's colour scheme is misleading and the average BGLs, as indicated by the dotted line, is unreadable to the average person

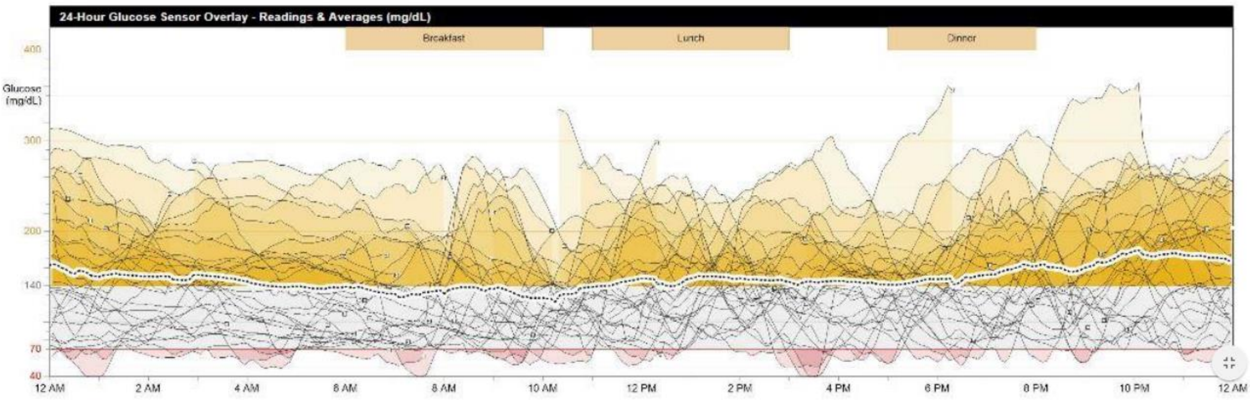


Figure 3-12 Medtronic CareLink 24-Hour Glucose Sensor Overlay (Bell, Larkin and McManus, 2017)

Using PROC SGPLOT, a visualisation replication was created that matched CareLink's graphs for medical professionals in Base SAS, as shown in Figure 3-13. The data is currently presented in a format which would confuse or overwhelm patients. To understand these data points, a graph of the min, mean, and max for 30 days' worth of blood sugar readings, along with the mean and one standard deviation, was produced to look at trends. These graphical representations can better indicate when insulin intake is in deficit.

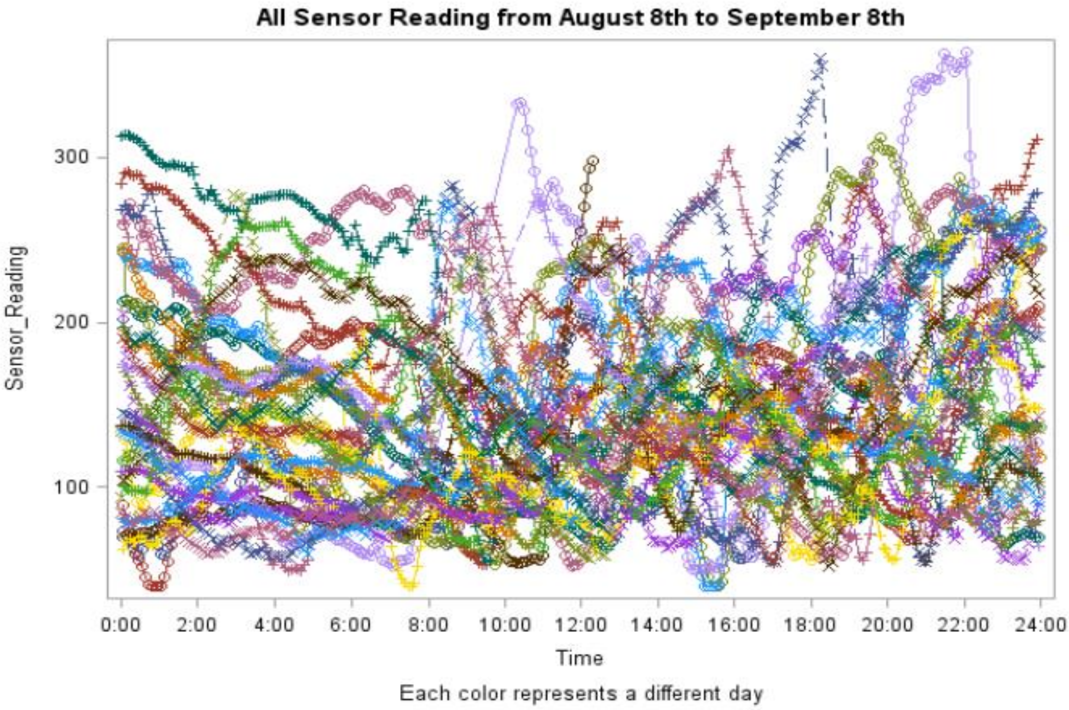


Figure 3-13 SAS Graph of CGM Readings (Bell, Larkin and McManus, 2017)

To create easier to read visualisations, the first graph displays the min, mean, and max of every 5 minutes in a 24-hour period. This can be seen in Figure 3-14. Averaging a month's worth of data can show trends of too much or too little insulin in the body. Figure 3-14 indicates that too much insulin is in the system or low blood sugar occurs during 7AM to 9AM and again at 2PM to 4PM. This could indicate that too much insulin is being given before meals. Another observation to mention is the high blood sugars towards the end of the day and the low blood sugar at the beginning. Since this is personal data, it should be noted that this anomaly is due to evening exercises. This evening exercise results in higher blood sugar at night, due to the reduction on basal insulin to account for burning sugar during the exercise. The lower blood sugar in the morning is a combination of insulin and exercise reducing the blood sugar to a low point.

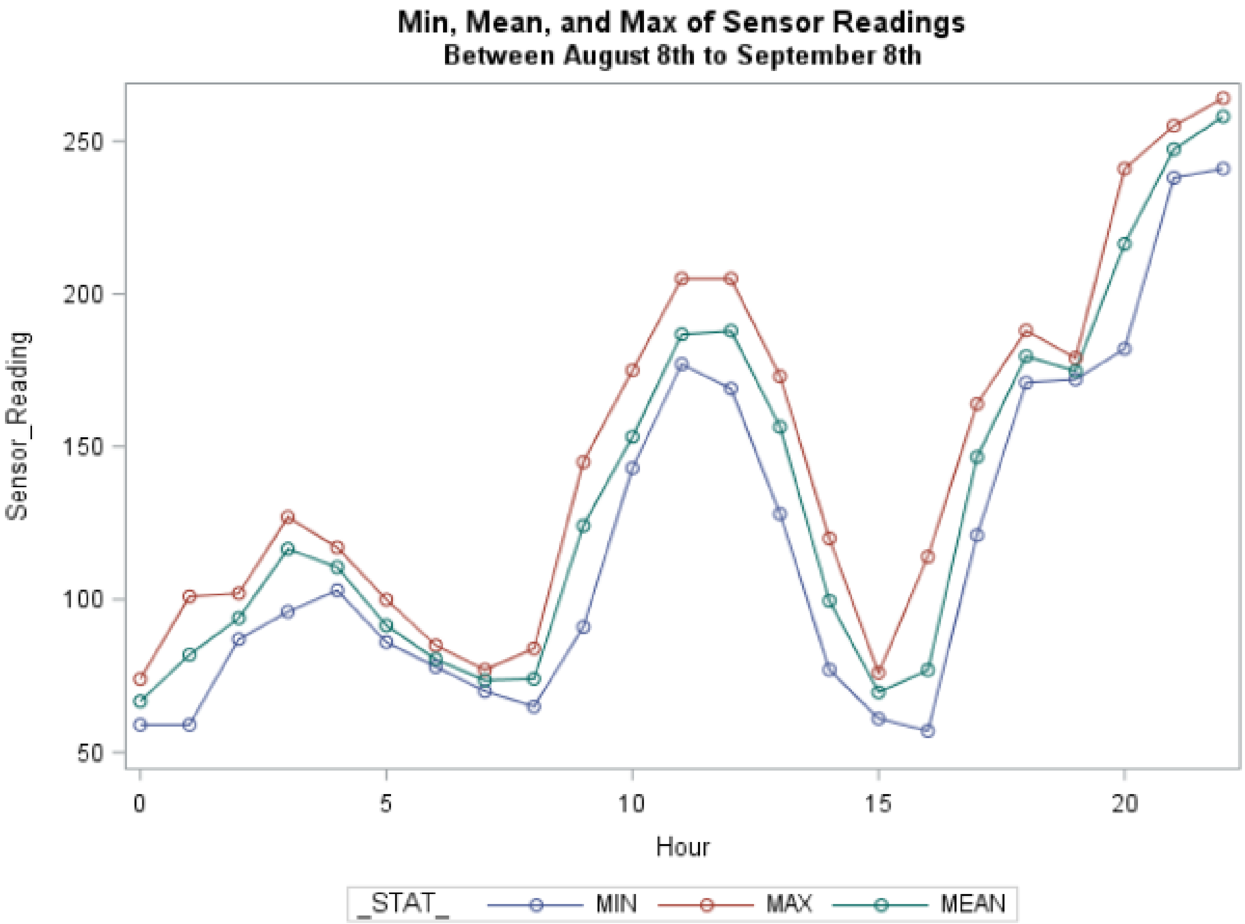


Figure 3-14 Min, Mean, and Max of CGM Readings (Bell, Larkin and McManus, 2017)

Additionally, the standard deviation was calculated for a month's worth of data, Figure 3-15. The goal here was to decrease the influence of outliers and see if the trends continue as previously seen in Figure 3-14. The upper and lower standard deviation seem to run almost parallel to the mean. This further solidifies that the downward blood sugar trends seen after breakfast, lunch, and the after-dinner spike. A medical professional would be able to spot these trends and make the necessary adjustments to the diabetic's basal rate to prevent extreme blood sugar occurrences.

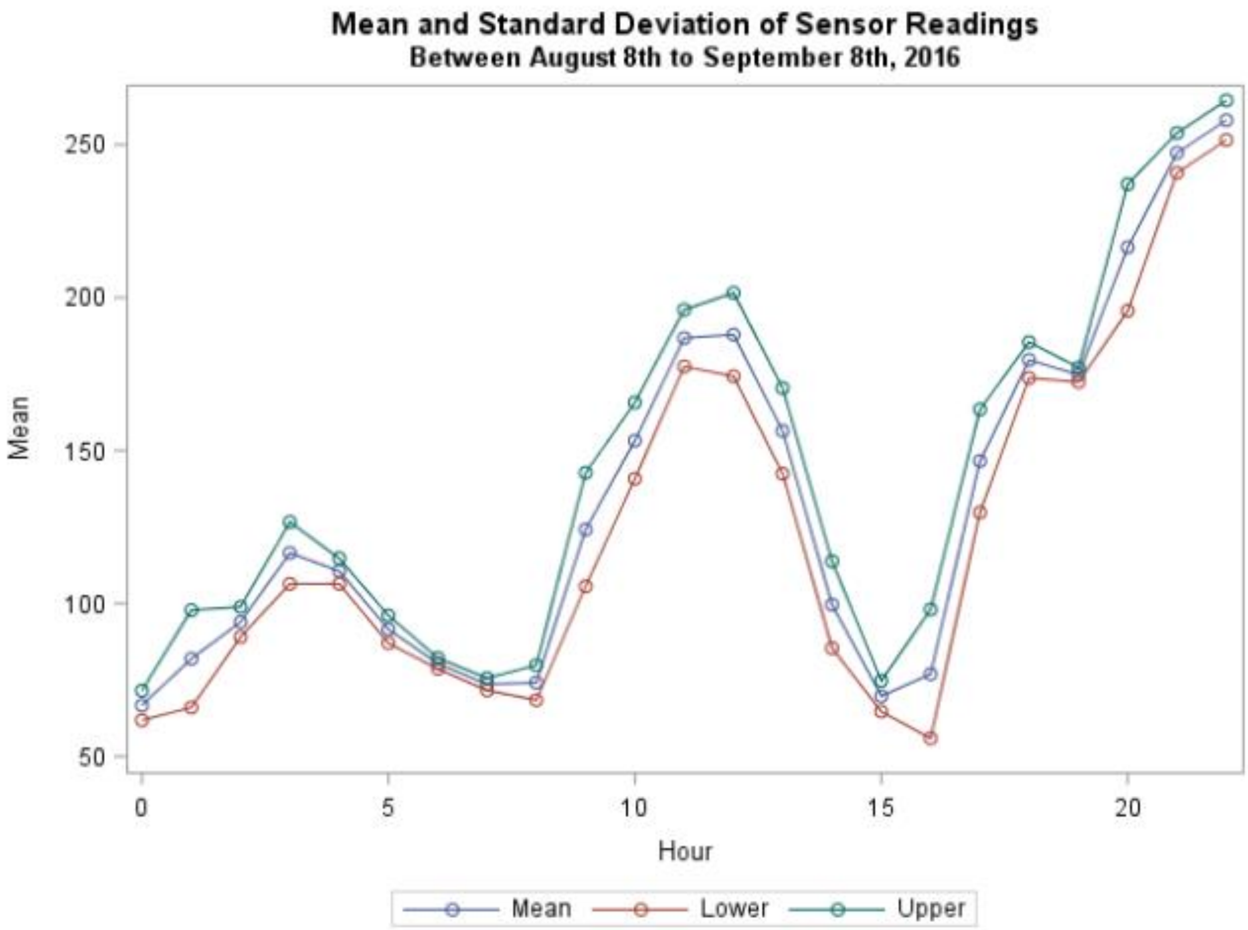


Figure 3-15 Mean and Standard Deviation of CGM Readings (Bell, Larkin, & McManus, 2017)

The techniques shown in Figure 3-15 exhibit that SAS users (or users taking advantage of software which can create sleek, tidy looking clear imaging) paired with their health data can make informed observations and start knowledgeable conversations about their health.

Simplifying a month's worth of data into averages rather than daily totals can show trends that otherwise cannot be observed. After concluding the analysis, the data was presented to a local endocrinologist. Certain adjustments were made to lower the basal rate for midmorning and late afternoon to counteract the downward trends. After changes were made, low blood sugar instances reduced, which helps maintain stable blood sugar readings throughout the day.

This study serves as evidence that the use of cognitively pleasing graphics can bring about cognition and recommendations that can improve health and lifestyle.

3.12 Conclusion

This chapter aimed to address the second research question:

"What possible IV techniques could be used to support the self-management of DM?"

Suitable IV techniques were identified by determining the type of data that required visualisation. The applications analyzed in Chapter 2 as existing systems typically used IV techniques which are adequate for analysing time series data. As discussed in Section 3.7.4, time series data (like T2DM data) can be visualized in numerous ways. While tables and pie charts can represent this data, line charts and bar charts are the most effective at displaying time series data. The answer to the second research question is temporal charts i.e. The Bar, Pie and Line Chart as well as heat maps.

Requirements of the IV for DM data was proposed according to the functionality identified in Section 2.7 and 3.10 and the tasks defined by the VISM. The user tasks that should require support by the system include overview, zoom, details-on-demand, filter, relate, history and extract tasks. Colour and highlighting will be used to support this.

The next chapter will discuss the design and implementation of an IV prototype used to visualize DM data. The system will be designed and implemented according to the requirements of IV for the support of DM self-management. A prototype will initially be used to identify how the system will support the requirements of IV and then progress to a functional prototype to meet the requirements identified in this chapter and evaluated in the subsequent chapter.

4 Design and Implementation

4.1 Introduction

Chapter 3 highlighted the requirements of IV for use in the self-management of T2DM. This chapter aims to discuss the design and implementation of an IV prototype to visualize T2DM data with the selected IV techniques from the previous chapter. This chapter addresses the fourth research question identified in Chapter 1: How *can IV techniques be applied to support the self-management of DM?* This question will be answered through the design of an IV prototype.

This chapter includes the design of a prototype visualisation system, it's functions and the techniques that will be used to guide the visualisation. An implementation overview is provided after the design of the system. The implementation section includes comparisons of various tools and frameworks that could be used to build the initial prototype. The data and visualisation techniques are discussed once more, specifically in terms of implementation.

A brief discussion is included to determine whether the identified tools can be used to implement the designed prototype.

4.2 Design

The artefact that requires development must visualize T2DM data. This section describes the data that is to be used for the implementation and the interpretation of that data. This section will also describe the necessary transformations that were required for the data to be useful in the prototyping process and the format of the data that was used. The user tasks outlined in Chapter 2 as functional requirements are discussed in terms of the requirements of IV identified in Chapter 3.

The IV techniques that will be used for the prototype are then outlined and motivated. In addition to this, substantial evidence will be provided to motivate the reasoning behind all suggested changes to existing visualisations. The aim of the visualisation designs is to reduce the cognitive effort required by a user to interpret their T2DM. A measurable success in the design can be determined by the reduced time it may take for a user to determine differences in their BGLs and the causes of any volatility in the BGL levels.

4.2.1 Application

Designs were created using the ReactNative (React Native · Learn once, write anywhere, 2022) framework. The purposes of these designs were twofold. First, the application design is necessary in order to integrate the necessary functionality seamlessly. Second, ReactNative is a framework that can be used to create pleasing application user interfaces (UIs). The use of ReactNative could serve as an evaluation of the framework for full implementation of the IV prototype.

Welcome Screen

The application would make use of OAuth 2 for security purposes and users are required to log in to the application using their existing Facebook, Google or Twitter account. The first screens that the user should see when opening the application is a brief explanation of what they will be required to do with the application, as shown in Figure 4-1.

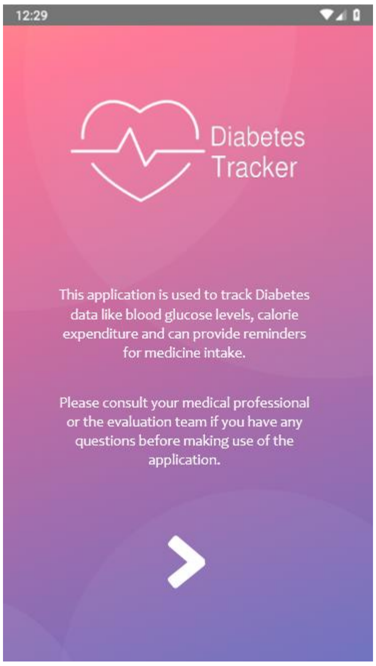


Figure 4-1 Design of the Tutorial Screen Displayed when MedicMetric is Opened for the First Time

Log-in Screen

The user might either need to register or login upon first opening the application. Figure 4-2 displays the next two that they might be expected to navigate to.

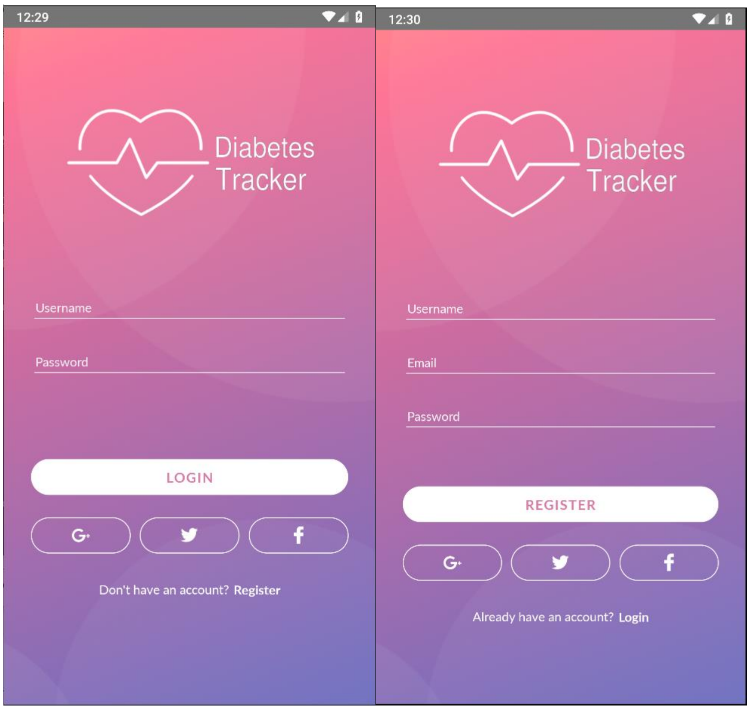


Figure 4-2 Designs for the Login and Register Screens in MedicMetric

Navigation

From here users are provided with a navigation screen (shown in Figure 4-3) so that they are capable of viewing the other facets of the application.

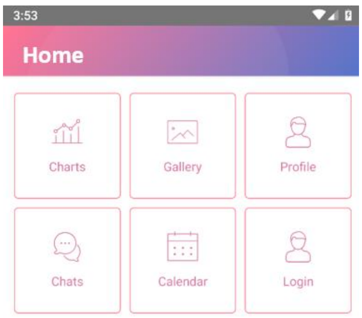


Figure 4-3 Design for the MedicMetric Navigation Screen

User Profile

Users should be capable of selecting to set alarms in their calendar as reminders, view their own profile, open a chart with one of their contacts on the application and to view the charts. These screens are shown in Figure 4-4.

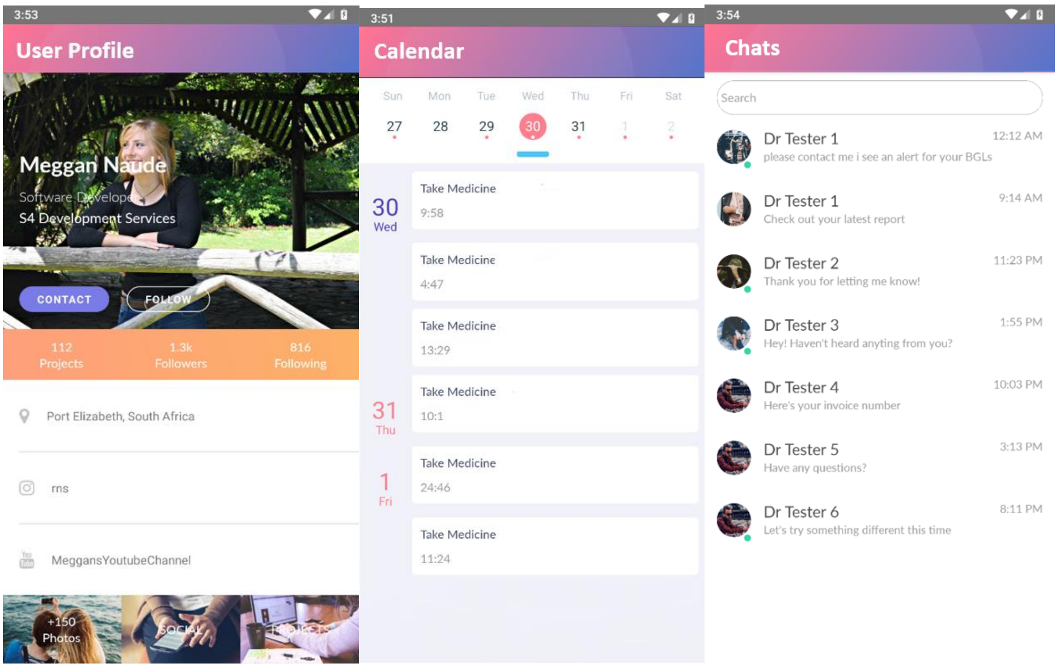


Figure 4-4 Design for User Profile, Calendar and Chat Screens in MedicMetric

Should a user select to view a chart they should be able to more precisely view the DM data within the application (Drill-down).

4.2.2 Data

In order to develop a prototype to determine to what extent IV can be used to support the self-management of T2DM, and that accurately represents T2DM data using IV, a collection of accurate, real-life DM data should be used as a test set for implementation. The Dexcom sandbox diabetes data, and Fitbit test data sets were selected as the sample data for this prototype. The techniques used for obtaining and refining this data will be discussed in this section.

4.2.2.1 Data Source

Three data sources were identified for potential use in the development of a prototype application, namely the Dexcom sandbox data, the Fitbit test data and the Medtronic exported data. These sources are discussed and limitations of each will be noted.

Fitbit API

Fitbit produces products such as activity trackers and wireless-enabled wearable devices that measure data such as the number of steps walked, heart rate, quality of sleep, stairs climbed, and other personal metrics involved in fitness.

Fitbit provides a Web API (Application Programming Interface) for accessing data from Fitbit activity trackers, the Aria scale, and data, which is manually added by users within the accompanying Fitbit application. The Web API is open-source and provides in-depth data about the physiology of individuals who use the Fitbit devices.

The Fitbit API is extensive. Only a few endpoints will be used in the creation of the application so only necessary endpoints will be discussed. The endpoints discussed will be relevant to one of four main areas detailed below:

- **Activity** - Kilojoules, steps, distance, elevation, floors etc. can be obtained by adjusting an API call appropriately. This information can also be extracted by the times that specific activities were logged within the application. For the purposes of developing the IV tool in this research, this API request will be limited to only return steps as it is important for individuals with T2DM to monitor their activity throughout the day, and how it may be affecting their BGLs.
- **Body and Weight** - The 'Get Body Fat Logs API' retrieves a list of all user's body fat log entries for a given day in the format requested. Body fat log entries are available only to authorized users. Since a device like the Fitbit Aria is available for use, this API call can be used to obtain body fat percentages and display them to the user so that they are able to track their weight over time and adjust their diet if needed to meet specific goals.
- **Heart Rate** - Heart disease is the largest risk factor that individuals with diabetes face. Relaying information pertaining directly to the heart has benefits that are two-fold: the user can notice a correlation between behavior, which affects their heart rate, and their diabetic data, and users are better able to track a highly at-risk organ within their body.
- **Sleep** - Sleep plays a large role in the excretion of sugars, which are stored in the bloodstream. For this reason, it is imperative for end users to see a correlation between sleeping habits and their BGLs. The 'Get Sleep Logs by Date' endpoint returns a summary and a list of a user's sleep log entries as well as detailed sleep entry data for a given day.

Limitations

Up to 150 API requests can be made, per hour, for each user that has authorized the application to access their data. This rate limit is applied when API requests are made using the user's access token. This means that the application will become restricted the more the user base grows. Since only a maximum of 20 users will be able to make requests, this does not pose a problem.

The application can also make 150 API requests per hour without a user access token. These types of API requests are for retrieving non-user data, such as Fitbits general resources like food specs from their database.

When a request is not fulfilled due to reaching the rate limit, the application will receive a HTTP 429 response from the Fitbit API. A Retry-After header is sent with the number of seconds until the rate limit is reset and the application can begin making calls again.

Due to the limitations placed on the amount of API requests that can be made, the heart rate information will not be visualized in the initial prototype until further speed tests can be run and it can be determined that the application is capable of supporting multiple users without receiving an error response.

Dexcom API

The Dexcom API was created by Dexcom. Dexcom is a company that develops, manufactures and distributes CGM systems for DM management, like the Dexcom G5 and G6, discussed as existing systems in Chapter 3.

The Dexcom API, retrieved by registering as a Dexcom developer, gives developers access to an archive of datasets that are open source and free to use. Developers can leverage the Dexcom platform to create applications with Dexcom CGM data including estimated glucose values, events and statistics. The API is RESTful and utilizes the OAuth 2.0 standard for authentication, providing individuals with a secure authorization for their Dexcom CGM data for use in third party applications.

At the time of this research, the Dexcom API is the only publicly available API that allows developers to interface with a CGM. The Dexcom API enables the creation of an application for any Dexcom user, thus supporting choice in DM management.

There are currently two data environments that can be accessed using the Dexcom API, the sandbox and production environments. The sandbox environment contains a small set of simulated user accounts that do not correspond to real users. The production environment holds Dexcom user data, which is automatically uploaded from the Dexcom G5 and G6 mobile applications. This data can also be manually uploaded from a receiver using the Dexcom CLARITY uploader.

The five scopes of data access using the Dexcom API are:

1. Estimated Blood Glucose Levels
2. Calibration Data
3. Events Entry Data
4. Device Details
5. CGM Statistics

Limitations

The Dexcom API enables developers to connect their applications with Dexcom CGM data, but it does not automatically grant the applications access to Dexcom user data. Within the application, it is necessary for users to connect their Dexcom account to the app, which requires user authentication and HIPAA (Health Insurance Portability and Accountability Act of 1996) authorization (via OAuth 2.0) for data access to occur. Currently, the Dexcom API used in a production environment for real-time data requests, is limited to use in the United States of America. For this reason, the Dexcom API will be used in order to create a proof of concept, using the sandbox data as an initial dataset.

Each application created has the ability to make API requests to both the sandbox and production data environments. For the production environment, applications are initially granted limited access, allowing them to have up to 20 authorized users. Since 20 authorized users is enough to complete the study, this will suffice. This API will allow prototype building immediately.

Request frequency is limited to 60,000 calls per app per hour. If the limit is exceeded, an HTTP 429 response will be returned. If 20 users have 150 requests per hour then the 3000 requests will not exceed the limit provided. Data is also significantly delayed for upload, so users will only be asked to open the app (and make requests) 3 times a day.

Not many individuals, living in South Africa, currently make use of the Dexcom G5 and G6 as it is expensive and requires a medical prescription. For this reason, when the field study was conducted, there is a potential that not enough participants will be found who are able to make use of the system as intended.

Medtronic Data

Medtronic, like Dexcom, is a company that develops, manufactures and distributes CGM systems, among other health management tools. Medtronic produces a sensor known as the Guardian Sensor 3, which can connect to the Guardian Link 3 Transmitter.

The Guardian Sensor measures the interstitial cell fluid just below the skin. This can be used to generate an accurate reading of BGLs, with a MARD of 8.7%, when worn on the arm. The Guardian also contains a diagnostic chip in order to monitor the sensors health and improve its performance, and can be worn for up to seven days at a time.

Guardian, like Dexcom also provide users with a transmitter and a mobile app known as Guardian Connect. The application can display recent glucose data (as shown in Figure 5-4) and glucose trends over time, as well as the status of the sensor and the transmitter. Like the Dexcom application, the sensor does not track other events like heart-rate, kilojoule expenditure, but alerts in the application happen in real time. This means that when the end-users BGLs drop below a healthy range or rise above a healthy range, an alert is sent to them.

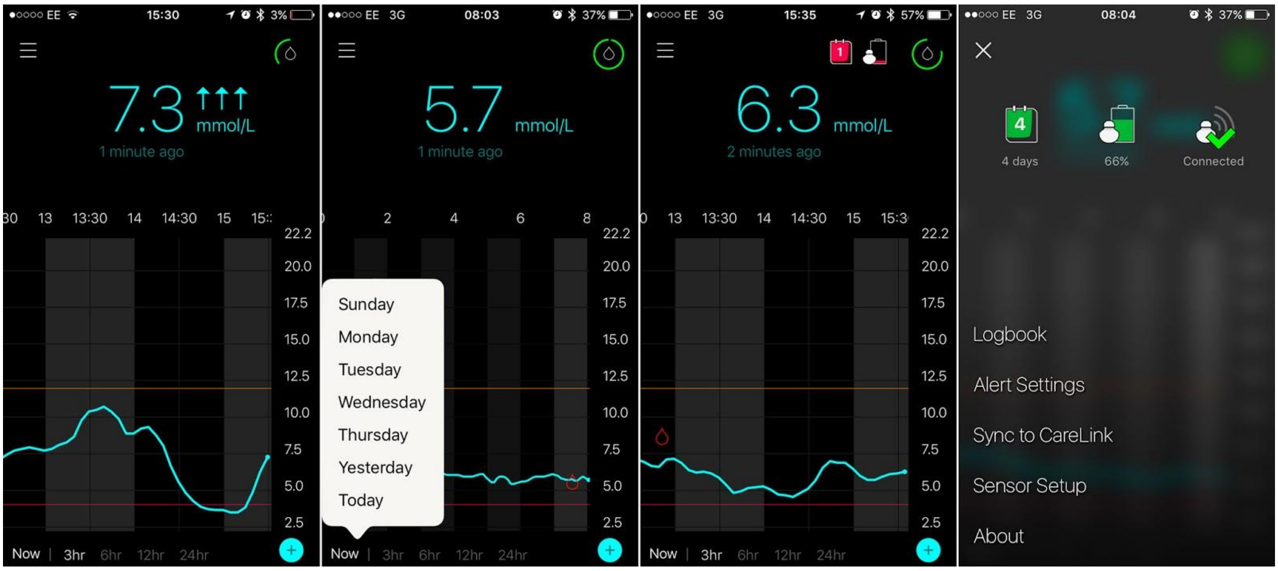


Figure 4-5 Medtronic Screens in Medtronic Guardian Application (Medtronic Guardian Connect Review - iPhone CGM in the cloud, 2022)

Data from the Guardian Sensor is not publically available, but because Dexcom users in South Africa are not common, it is necessary to ensure that the application is capable of working with more than one sensor. For this reason, a Medtronic technician was contacted in order to obtain sample data from the Medtronic Guardian Sensor.

User data can be exported from the Medtronic Guardian to a .csv file. This information can then be transformed and sent to the database. When the widgets in the developed IV prototype are refreshed and information was added to the database, the information will be displayed. The .csv file will contain calibration information, sensor BGL readings, alarm events and event markers, which are discussed in detail below:

- Calibration Information – In order for the Guardian Sensor to be calibrated correctly, a series of manually measured BGL values must be added via input to the application. This is done in order for the Guardian Sensor to add corrections for errors that may arise over time.
- Sensor BGL Readings – The Guardian Sensor will automatically measure the BGL of it's wearer in five minute intervals.
- Alarm Events – The Guardian system can produce multiple alarm events, which can send alerts to the wearer. These notifications include reminders to re-calibrate the sensor, high specific-gravity levels (indicating that users should drink water), and various prediction events like predicted low BGLs.
- Event Markers – These markers are manually inputted by the wearer of the sensor and in the .csv that was provided to the investigator, this field contained administered insulin measurements.

Limitations

No open source, publicly available API exists for the Medtronic CGM and thus no real-time data can be sent to the prototype application at this point. Instead, a .csv file must be exported to the investigator nightly in order for the data to be uploaded timeously to the database. This means that the prototype application does not support real-time analysis of BGLs and affecting factors. For the purposes of the evaluation, this should suffice, as participants will also be provided with an input option, where they are capable of measuring their BGLs using any glucose monitor and having it displayed within the application shortly after.

Not many individuals, living in South Africa, currently make use of the Medtronic CGM as it is expensive and requires a medical prescription. For this reason, when the field study is conducted, there is a potential that not enough participants will be found who are able to make use of the system as intended.

4.2.2.2 Format

This section will discuss the formats of data retrieved when using the Dexcom and Fitbit APIs. The Medtronic data is parsed separately using a typescript file reader component in order to convert the .csv file into a JSON object, from which relevant data can be extracted. Once the data is in an acceptable JSON format it can be converted into an object in typescript and used within the application relatively easily.

Because the Dexcom and Fitbit API return responses as JSON object, they are already in a useable format, and no further parsing of data is needed. If information must be ignored a model of the standard response can be created in typescript and all necessary attributes can be set from the JSON response data. This section will focus on other data formatting specifics of the JSON data, such as time formats, units and JSON formatting.

Time

There are several forms of time to understand when handling and processing the CGM data using the Dexcom API. Dates and times are formatted according to the ISO 8601 standard.

For the /egvs, /calibrations, /events, and /dataRange endpoints, two separate fields describing time are provided: systemTime and displayTime. systemTime is the UTC time according to the device, whereas displayTime is the time being shown on the device to the user. Depending on the device, this time may be user-configurable, and can therefore change its offset relative to systemTime.

All requests, except those made to the /dataRange endpoint, require two query parameters, startDate and endDate, which specify a time window. This window can be a maximum of 90 days, and any request with a time window greater than 90 days will return a 400 (Bad Request) error. These are ISO 8601-formatted UTC timestamps, and therefore queries are executed against the systemTime field in the corresponding endpoint. The time component may be specified down to milliseconds. Queries are inclusive of startDate and exclusive of endDate.

The Fitbit API returns all date and time-related fields in local time of the resource owner's time zone. A user's current time zone and UTC offset in milliseconds is retrievable.

Units

Where applicable, units are specified within the responses. All glucose values are reported in units of mg/dL and trend rates in units of mg/dL min. Conversion of these values into user-preferred units, such as mmol/L, is required in the application as it is the recognized measurement by most users.

The conversion from mg/dL to mmol/L is straight forward. The formula is:

(mg/dL * 10)/ molecular weight = mmo/L where the molecular weight of glucose is approximately 180. For simplification purposes the formula will be restructured as mmo/L= mg/dL / 18

Fitbit API calls reveal and log resource values in one of the unit systems based on the value of the Accept-Language header. Since most users in South Africa will register with 'Metric' settings, the units for the application will be that of the metric system.

Data Availability

Data from the Dexcom API is available with a three-hour delay. This delay is enforced on the data upload time, not on the timestamps of individual data points. The G5 and G6 Mobile applications upload once per hour, so the data will be 3.5 hours delayed. Data uploaded directly from a receiver over USB (via the Dexcom CLARITY uploader) is available immediately because it is viewed as an active, rather than passive, upload. This means that if the Dexcom API was used, the application would not be able to operate in real-time.

Using the Fitbit API, up to 150 API requests per hour can be made for each user that has authorized the application to access their data. This rate limit is applied when API requests are made using the user's access token. This means that the application will become restricted the more the user base grows. Since only a maximum of 20 users will be able to make requests, this does not pose a problem.

4.2.3 Functions

The tasks that require support by the prototype were defined according to the requirements of IV for self-management of DM at the end of Chapter 3 (Section 3.10). The functions provided by the prototype should support the VISM tasks that were used to identify the IV requirements.

A low fidelity prototype was created to identify initial ideas for visualisation, and how the prototype should support the proposed requirements for IV as well as support for self-management of DM requirements identified in Chapter 2. The low-fidelity prototypes for IV were designed first, as the design of the IV could impact the choice of platform, framework and tools that should be used to create a working prototype.

The prototype IV tool was called “MedicMetric”, as it acts as a medical IV tool for self-managing T2DM.

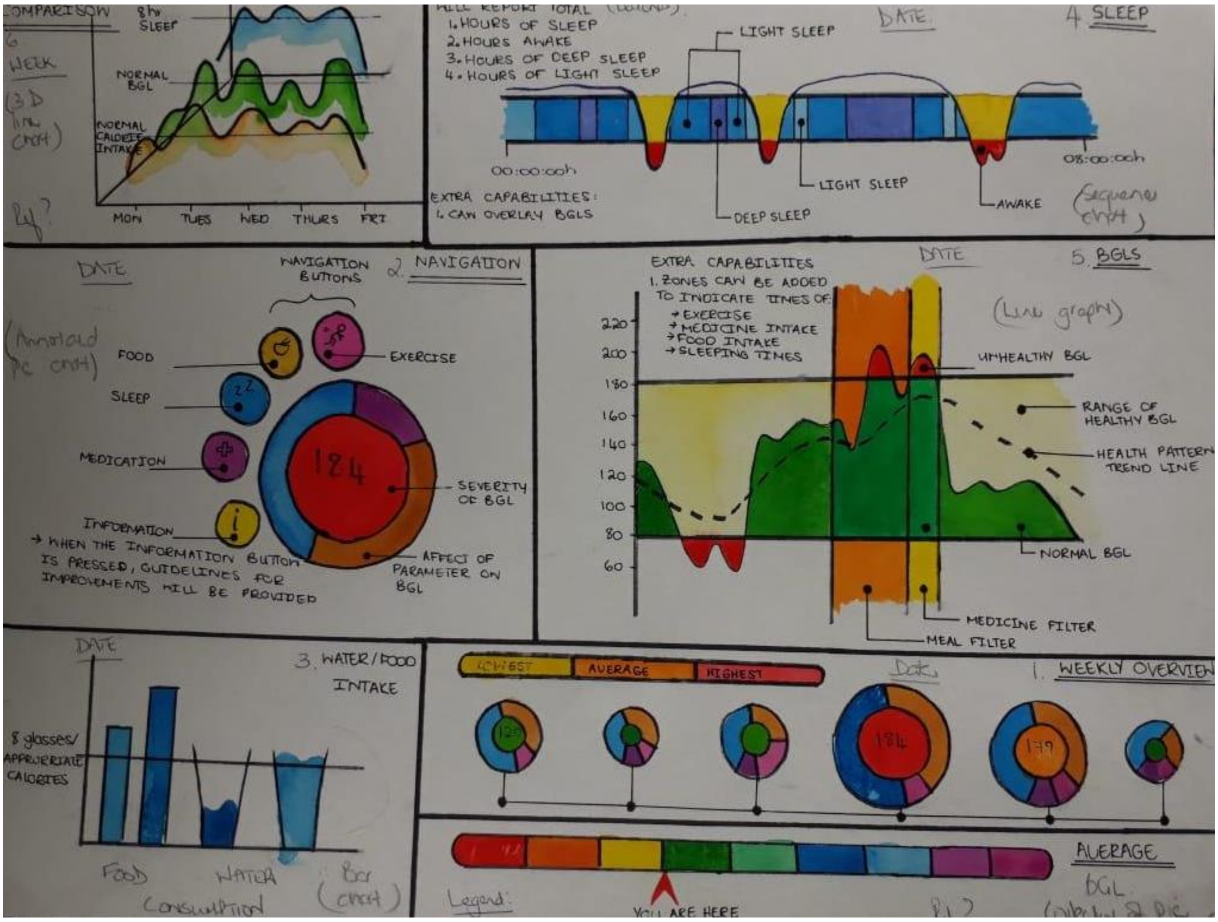


Figure 4-6 Low Fidelity Initial Prototype Design

The prototyped diagrams shown in Figure 4-6 should aid the cognition of DM patients, and allow them to connect their personal behavior with the resultant BGLs display. The prototype must also fulfill the visual information-seeking mantra.

Table 4-1 indicates the tasks that must be supported by the prototype and how the initial designs must fulfill the VISM according to each category.

Table 4-1 Visual Information Seeking Mantra and the IV Tasks that Support it

Category	Explanation	Principle Fulfillment Explanation
Overview	A view of user historical data.	● View DM data for a specified date range or (as a default) the weekly overview of DM data. ● Make use of the minimized interactive overview of single days DM data to navigate to other sections of DM data. ● Navigate through the weekly or daily data using tabs.
Zoom	The ability to zoom in on events and obtain more data.	● Expand or contrast the DM data to view detail as required. ● Filter the data on various parameters i.e., date, time, sleep zones etc. ● View subsets of data by ruling out parameters. ● View adjusted effects of data on BGLs by filtering on parameters.
Details on Demand	The ability to select sections of the graphics and obtain details or be able to find more information about the represented data when required.	● View details of a BGLs. ● Hover over the BGL to display the time it was taken and whether it is average, above or below a healthy range. ● View details of sections of the chart by displaying tooltips on click events.
Filter	The ability to remove the items that are not of interest.	● Search for the DM data relevant to a specific date or time. ● Filter the data to include effects of specific parameters such as exercise, food intake, awake hours on BGLs.

		● Choose to exclude/ include parameters.
Relate	The ability to connect the data and relate different aspects of the data to each other easily.	● Cleary view the relationship between the BGLs and factors which affect the BGL value. ● Share an overview of patient data with a practitioner for further relation. ● View search results in combination with the filtering results.
History	The ability to reverse and re-do actions performed to assist in the exploration process.	● Undo / redo graph navigation actions. ● View and manage a history of searches and filters.
Extract	Extraction implies that the information can be seen externally or provided to other individuals.	● Bookmark (or select) a set of filters to be used. ● Create a report and share it with a practitioner.

4.2.4 Visualisation Techniques

The most appropriate IV techniques to be used to support the self-management of DM were identified in Chapter 3 as temporal charts i.e.: The Bar, Pie and Line Chart as well as heat maps. These charts all do a good job of representing time series data in a manner that is easily interpretable. Since the users of the system may not all have the same background or knowledge about visualisations, these three visualisations (also serving as the most popular visualisations), are the most likely to provide some form of familiarity.

Annotated Line View

As discussed in Chapter 3, existing T2DM IV tools make use of line charts to represent T2DM data. These line charts are used so that individuals trying to interpret their time series T2DM data will be able to explore the data with ease and focus on their BGLs while doing so. All existing systems provided users with a line chart. This chart typically focused only on BGLs and had markers to indicate when relevant events had occurred. For this reason, a line view was implemented in order to compare the existing techniques used for self-management of T2DM and a new proposed technique to be used.

The line view was implemented, but detailed events were placed on the chart. In typical applications, events are noted on the chart as icons and must be clicked in order to provide users with details about what the icon represents. By creating blocks of colour in the background of the chart, an entire zone is allocated to denote that something had occurred in that time-period. If a point in the chart is selected, detailed information about that point will be displayed, but information relating to events is present at all times.

Adding filtering to an already existing bar chart so that zones of the chart are easier to see can increase cognition for users, making interpretation easier and links between behavior and BGLs more obvious. The initial low fidelity design for this chart is displayed in Figure 4-7.

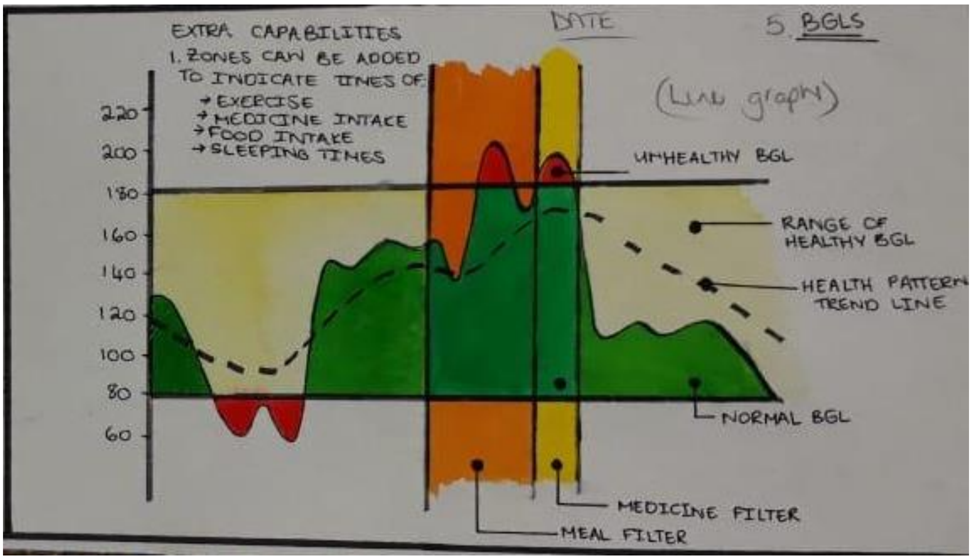


Figure 4-7 Low Fidelity Design of the Annotated Line View

A line denoting the upper and lower limits of BGLs was also implemented in the chart. These enhancements to the simple line chart create a new visualisation technique for visualizing T2DM namely, the Annotated Line View. This chart will be performance tested against two other alternative views to determine which view relays information best. It will also undergo performance tests against existing systems to determine if the typically implemented line views are better.

Change Rate Line View

Another change was added to a different line chart, which can display multiple lines representing different factors affecting BGLs. The rate of change (ROC) for each factor was calculated in order to create a view, which could display trend information about BGLs and the factors which affect it. By evaluating this view against the Annotated Line View, it can be determined which chart supports effective self-management of T2DM. The goal of using a chart like this would be to stabilize the ROC for BGLs, this would mean that the BGLs do not vary a great deal throughout the day. Fluctuations in other variables would also be clear, and a relation can be seen if another variable and the BGL fluctuate at the same time. However, it would be difficult to determine if the BGL increased or decreased rapidly during the fluctuations as change rate does not indicate this type of information.

Radial Progress View

The data relevant to DM can become quite large but ultimately BGLs (the dependent variable) are affected by several other factors and can increase or decrease because of these factors, over a given period. The bar chart is valuable as variables can be plotted against time and it is useful for viewing changes in a variable over time. It is also a good comparative tool for multiple variables over time. Grouped or stacked bar charts can be used to combine both purposes and result in an intuitive way of comparing variables to each other and their change over time.

In order to give the user a sense of purpose and a goal to achieve, a chart was developed in order to display progress over time. A bar chart representing how much water a user should drink, how much sleep they should get, and other health goals that should be achieved, was created. Initially this chart was a bar chart, but it was discovered that a radial bar chart could mimic a progress gauge.

The Radial Progress View is a radial bar chart which displays how close users are to meeting behavioral goals. When compiled into a weekly view, with one stacked radial bar per day, this chart is also capable of relaying information about the effects that behavioral patterns can have on BGLs.

Since all three charts need to be evaluated, it makes sense to evaluate them against each other, to determine which chart is best at reducing the user cognition required to interpret T2DM data effectively. The views will also be evaluated against the standard line charts which are displayed in the existing systems discussed in Chapter 3.

Other Views

Other views need to be implemented in order to support the annotated line, normalized line and Radial Progress Views. One such example is a bar chart designed to display sleep stages throughout the night. This chart will represent data horizontally in segments. This chart can also be used for any data that can be split into definite categories. For sleep it will represent light, deep and REM sleep times.

In much the same way, steps, kilojoule expenditure and water intake will be displayed in bar charts. The initial design for the bar chart for displaying water was a series of glasses of water, one for each day, which would fill up more based on the amount of water drunk during that day.

4.2.4.1 Visualisation Technique Initial Review

The initial design was critiqued by a design expert in the Computing Sciences Department of NMU with 21 years of experience in design and multimedia modules as well as concluded research in the field of digital learning and creativity. A second reviewer with 43 years of experience and multiple publications in the IV domain was also asked to critique the designs. Both reviewers obtained their PhD’s in Computing Science. The following were the initial changes that were suggested:

1. The bar chart representing water intake should become a more intuitive and measurable visualisation. The chart in the form of a glass does not represent measurements accurately to the user without an axis. The glass should become a measuring jug or a glass, which has measurements to aid in the process of understanding the level of water drunk quickly and without the aid of the legend.
2. The chart displaying sleep (stacked bar chart) should contain a more accurate date/time measure so that users are aware of the day that they are looking at.
3. Legends are required so that users can see the variables that they wish to filter on.
4. The designs require a more refined visualisation for further input.

4.2.5 Visualisation Techniques Second Iteration

The first iteration of IV designs were created for a preliminary evaluation to take place. The designs were basic, conceptual and subject to change. This section will explain the procedure involved in the first iteration of their evaluation and changes.

Annotated Line View

The line chart displayed in Figure 4-8 will be used to plot BGLs over time. To assist in the comparison process, users can select different parameters that will be highlighted on the chart. These sections will display as similarly coloured zones and will be present as an overlay in the diagram. In addition to this graph a progress bar will display indicating the safety of the patients current BGL. Warnings will be sent to users to alter behaviors when these readings are dangerously low or high.

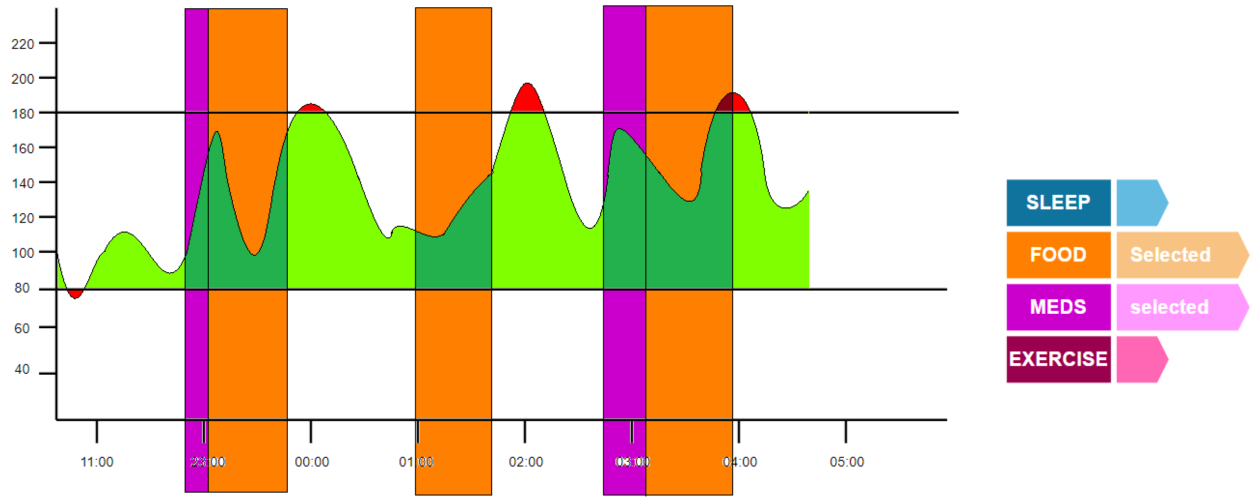


Figure 4-8 Design of the Annotated Line View

Radial Progress View

The initial Radial Progress View diagram, shown in Figure 4-9, would be a series of 'loading bars' to indicate progress in different self-managed aspects of a patient's life. This would assist the patient in drawing comparative conclusions between behavior and BGLs. The central point would indicate one of three configurable settings, i.e. highest BGL for the day, lowest BGL for the day, or average BGLs throughout the day.

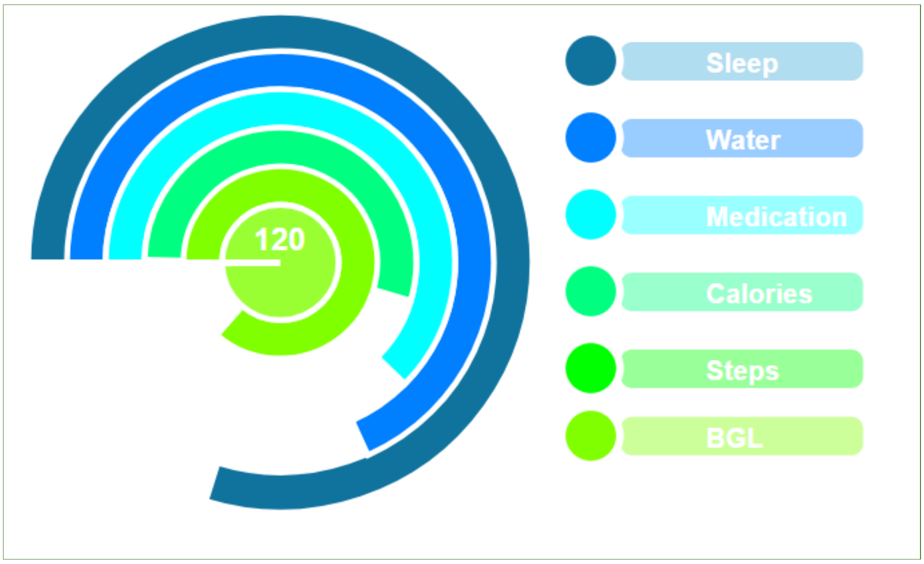


Figure 4-9 Design of the Radial Progress View with Legend

As the progress bars progress throughout the day, their colour will become brighter, indicating a good progression. This is shown in Figure 4-10. Shorter darker bars will indicate that the individual using the application is not on schedule to have a 'healthy' day. The side legend will serve three purposes, namely: it will act as a form of navigation so that a user can view more data, it will allow the user to hide or show different bars within the graph, and thus alter the effect of those parameters on the graph, and it will act as a legend.

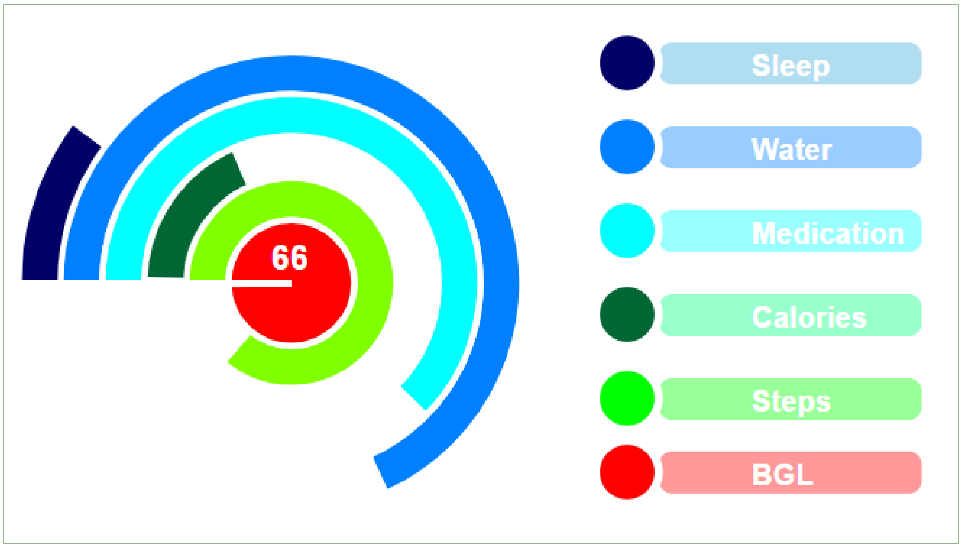


Figure 4-10 Radial Progress View Displaying Colour Variance Based on Performance

As an alternative to the legend categories in the overview chart, each bar can be shown with an individual icon. This is shown in Figure 4-11. The icon will serve the same three purposes as the legend but will appear in a more compact view, to allow space saving on a dashboard or be used for a mobile view.

Figure 4-11 Radial Progress View with Filters and Tag Icons Initial Design

As shown in Figure 4-12, this diagram can be used to effectively show, at a glance, which factors influenced the BGL negatively and in doing so, highlight behaviours to the patient that can cause them to have problems. They can also be used in weekly views for each day of the week to indicate an average or overall progress for that day.

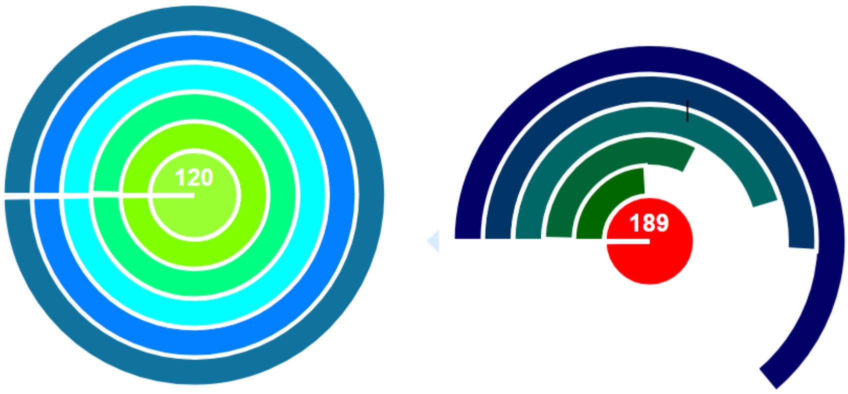


Figure 4-12 Progress Gauge View in Perfect and Worst Conditions

Alternative Overview Visualisations:

Figure 4-13 shows a shortened half circular set of bars and a set of bars with a guiding line will serve as an alternative to the aforementioned visualisations as they can show progress in much the same manner but are provided in different styles. The guiding lines in the chart can be better suited to show how far progress is expected to go whereas the left images save screen space while providing the same behavior as before.

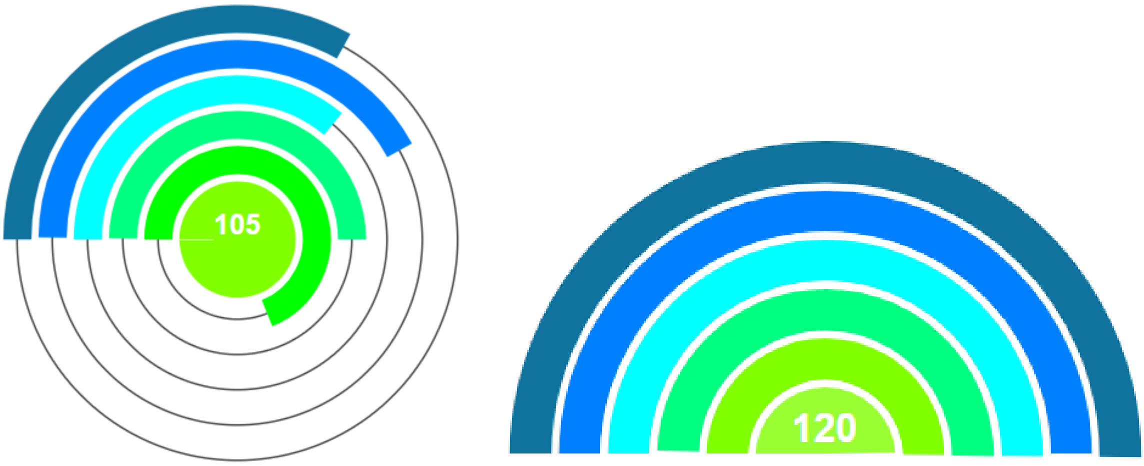


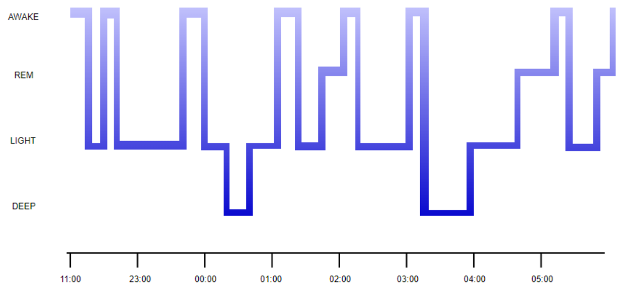
Figure 4-13 Alternative Designs for Progress Bar to Improve Screen Real-estate

Change Rate Line View

The Change Rate Line View did not generate any points of contention upon its initial review and was therefore not redesigned in the second iteration.

Sleep charts

The bar chart indicating sleep throughout the night are not limited to representing sleep. Any of the aforementioned parameters can be mapped against time or type and shown in the same way. Tooltips will be provided when sections of the graphs are hovered over, allowing for more detail to be displayed. This is true for all diagrams previously shown.



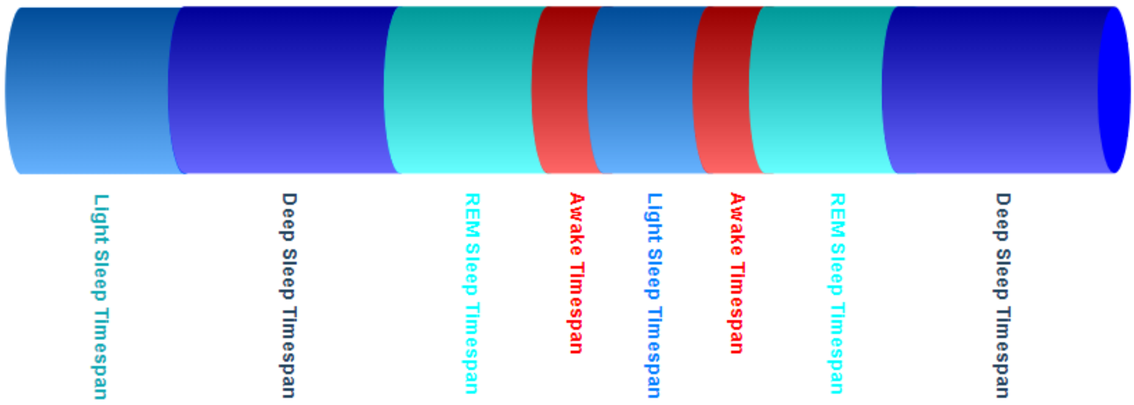


Figure 4-14 Design of the Weekly Sleep Chart

In a similar manner as Figure 4-14, Figure 4-15 could be used for multiple parameters, but will be discussed in the context in which they were visualized. The top two images represent water consumption throughout the day. As a user drinks water, bars will increase to indicate an accurate measure of water consumed.

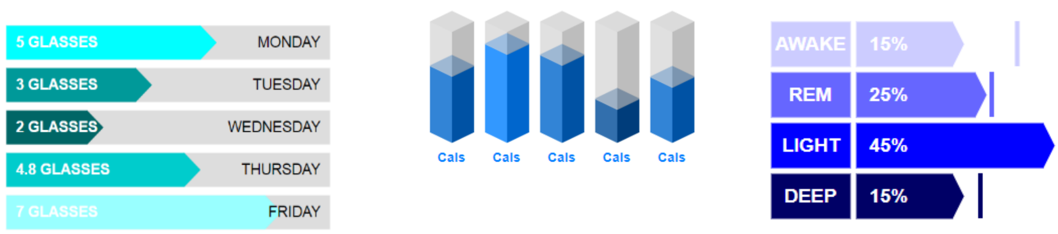


Figure 4-15 Alternative Stacked Chart Designs for Representing Water Intake, Kilojoule Expenditure and Sleep Categories

In addition, a 3D view of all parameters mapped against time was designed (Figure 4-16) with an expected maximum value per day and the amount achieved in the given time.

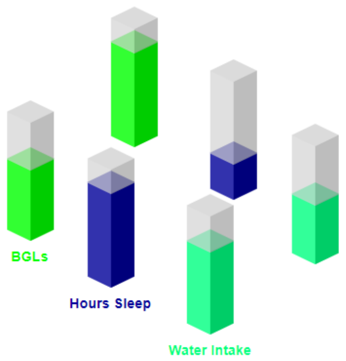
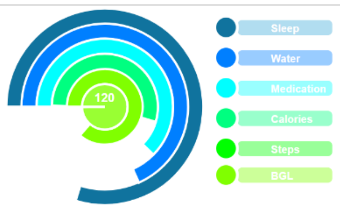


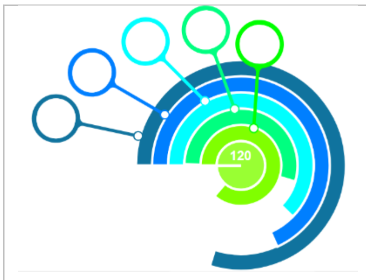
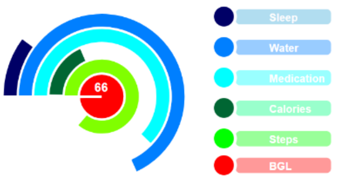
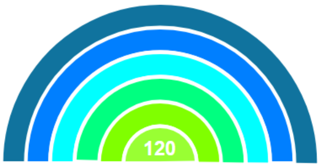
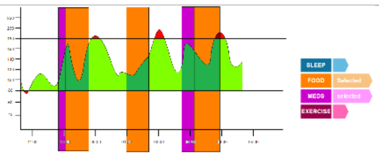
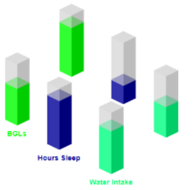
Figure 4-16 Initial Design 3D Comparative Chart

4.2.5.1 Visualisation Technique Second Evaluation

As part of the evaluation process three lecturers within the Computing Sciences department of NMU were consulted about the designs. One of the previous assessors was accompanied by two new evaluators. Both were senior lecturers with PhDs in Computing Science and more than 20 years of experience lecturing and supervising students. Both lecturers had published work in the field of IV. Each diagram was shown, and a statement was made to describe the function of each design. The lecturers were then asked to comment on the design. Table 4-2 below shows the comments collected for each design:

Table 4-2 Feedback Provided for Each Chart Designed

Design	Comment
	The legend seemed unnecessary for navigation. It might be better to navigate by clicking on the bars in the chart.

	Like above, the icons seem unnecessary. It could be better to simply navigate using the bar.
	The colour changing was considered good and should be kept going forward
	This was chosen as the best circular bar chart design as it takes the least screen space.
	The graph is very useful but individuals suffering from red-green colour blindness will struggle to differentiate between different colours and levels.
	The application of the three-dimensional graphing seems unnecessary. Something simpler like a line chart or stacked bar chart could be much more effective, especially considering the similar colours used in the display.

4.3 Implementation

In this section the implementation tools that were used to create the prototype system are discussed. Reason for choosing each library/ framework and extensive comparisons are supplied.

4.3.1 Implementation Tools

The crucial choice in the development of the prototype must be made in the development planning phase - should the application be developed natively or should it be developed as a hybrid or web-based application? The answer to this question impacts the amount of work to be done.

Because users require reminders and notifications for dangerously high or low BGLs, it is most useful to develop an application, which can be used on a smartphone with push notifications. Smartphones are widely accessible and can notify users of important information even when they aren't at home or when the application is open in a web browser tab. The same cannot be said for a desktop applications or web applications.

For the above reasons, the prototype should ideally be cross platform compatible for all mobile devices - to enable as many users as possible, ideally with a variety of operating systems and device capabilities. For this reason, the application should be a native application that can run on Android and iOS.

4.3.1.1 NativeScript

Initially, ReactNative was used to create the screen designs, but it was not as intuitive as a framework for use and had little documentation. ReactNative is also based on React.js which was a framework unfamiliar to the developer. As a result, it was replaced with NativeScript which can work with the a more familiar framework, Angular.

NativeScript (NativeScript, 2022) is a cross-platform JavaScript framework that allows for the development of native iOS and Android apps from a single code base. The framework provides JavaScript access to the native APIs, user interfaces, and rendering engines of iOS and Android. NativeScript can also leverage other web application frameworks like Ionic and Angular.

The principal investigator developing the IV prototype is a Senior Angular developer. Using NativeScript with Angular can expedite the development of the IV prototype.

There are many factors to consider such as features, requirements, cost, time, size, and platforms while deciding the best framework. Since the artefact to be developed must run on smartphones and is to be primarily used in this regard, an ideal approach would be as close to a native app as possible. In order to provide participants with a look, feel and performance that they are used to, NativeScript is the best choice.

The platform can provide a fast-paced development option for both Android and iOS, the two platforms which must be supported. It also has a vast support community and large number of plugins and libraries which are available. The stability of the platform and code reuse functionality are also massive benefits in regards to using NativeScript.

NativeScript provides speed to market, one source code, easy updates, availability of resources, and lower budget costs in terms of implementation time.

4.3.1.2 Firebase

Firebase (Firebase, 2022) is a Backend-as-a-Service (Baas). It provides developers with a large range of tools and services in order to create quality applications quickly. Firebase is categorized as a NoSQL database program which stores data in JSON-like documents. Firebase supports authentication using passwords, phone numbers, Google, Facebook and Twitter. The Firebase Authentication (SDK) is also available for integration into mobile applications.

Firebase is considered great for quick prototyping but not excellent when complex querying is required. Since APIs are used in the application to retrieve data from Fitbit and Dexcom, the database doesn't need to store large quantities of user data and will mostly be used for authentication and configuration purposes.

A benefit of making use of Firebase as a NoSQL database is that it does not need the support of a back end to build the application as it comes with an SDK for various platforms, including Android, iOS and Web.

Firebase will be used as the database for storing and accessing user information during the application reviews.

4.3.2 Charting Tools

Another important aspect of implementation that requires consideration is the library that must be used for the visualisations, which must be implemented for the artefact. Since a JavaScript framework is being used to develop the application, a JavaScript library must be used to create the charts. In order for optimization of the visualisations to be achieved, a few libraries must be evaluated.

NativeScript (NativeScript, 2022) is still relatively new and gaining popularity. This means that developers are still creating new libraries to solve common problems like charting. No one library is a clear superior to its competitors when it comes to charting. For this reason, a comparative study is necessary for all alternatives within the charting field for NativeScript (NativeScript, 2022).

4.3.2.1 HighCharts

HighCharts (Usman, 2022) is a charting library built on JavaScript and TypeScript and is compatible with Android and iOS when used with a wrapper in the correct framework. The library provides a large amount of charting options and supports drilling down data within its charts. HighCharts offers wrappers in order to use the library in the most popular programming languages (.Net, Python, Java etc.).

The features provided by HighCharts depend on the wrapper with which it is used. This charting library was not designed for mobile use. This means that the wrapper used with the library is solely responsible for adapting it for the environment and interpreting input.

Features

- Adds a chart using a single component
- Requires a wrapper for mobile use
- Exporting can be enabled so that charts can be converted to PDF format
- Advanced, pleasing animations
- Higher level of customization

For the purposes of testing each charting library, a simple bar chart was created. This will act as an indicator and evaluator of the ease of use, effectiveness and customizability options provided by each framework.

The steps provided to render a chart by the HighCharts (Usman, M., 2022) site were helpful, but an additional wrapper was needed in order for it to work in a mobile environment. The rendered chart was detailed and had better tooltip functionality, as shown in Figure 4-17. The timelines were more dynamic and changes were very simple to implement once the chart had been rendered.

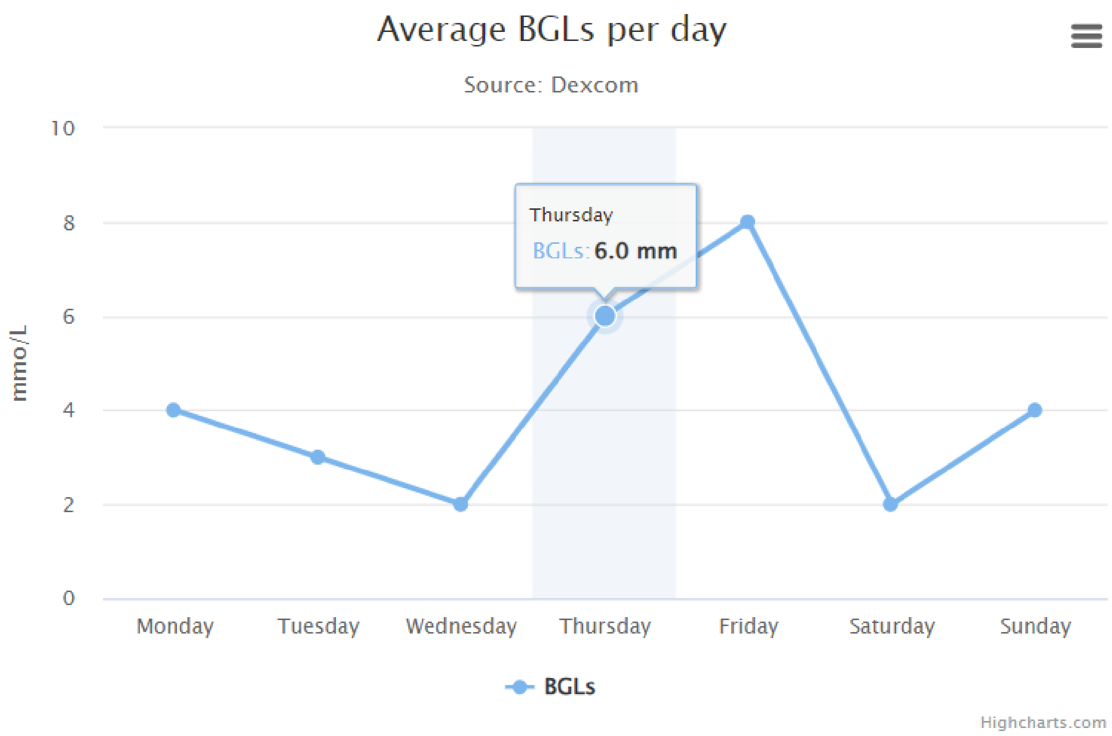


Figure 4-17 Initial Test Implementation of Line Chart with HighCharts Charting Library

4.3.2.2 FusionCharts

FusionCharts (Easiest JavaScript charting library for web & mobile, 2022) is a charting library which is compatible with Android and iOS applications. Among 150 alternatives, the charts and graphs supported by FusionCharts are the area, bar, donut, line, Marimekko, radar and stock charts. This library can provide charts which support interaction, zooming, panning, APIs, animations, drill downs, real time updates and full exporting of charts and dashboards.

The features provided by FusionCharts (Easiest JavaScript charting library for web & mobile, 2022) also include the support for touch and swipe, which can enable the charts to be more reactive during their lifecycle phases in the application.

Features:

- Adds chart to Android/iOS app.
- Adds a chart using a single component.
- Auto-updates the chart object when the data source is updated.
- Allows interactivity between JavaScript charts.

- Adds control to fusion charts chart instance using various APIs and event methods.

For the purposes of testing each charting library, a simple bar chart was created. This will act as an indicator and evaluator of the ease of use, effectiveness and customizability options provided by each framework.

The steps provided to render a chart by the Fusion Chart site were easy to follow and a chart was easily rendered in a few hours, as shown by Figure 4-18. This charting library was easy to set up and use. It boasts a large support base as well as a large repository of customizable charts for use. The chart styling is aesthetically pleasing and the charts are detailed.

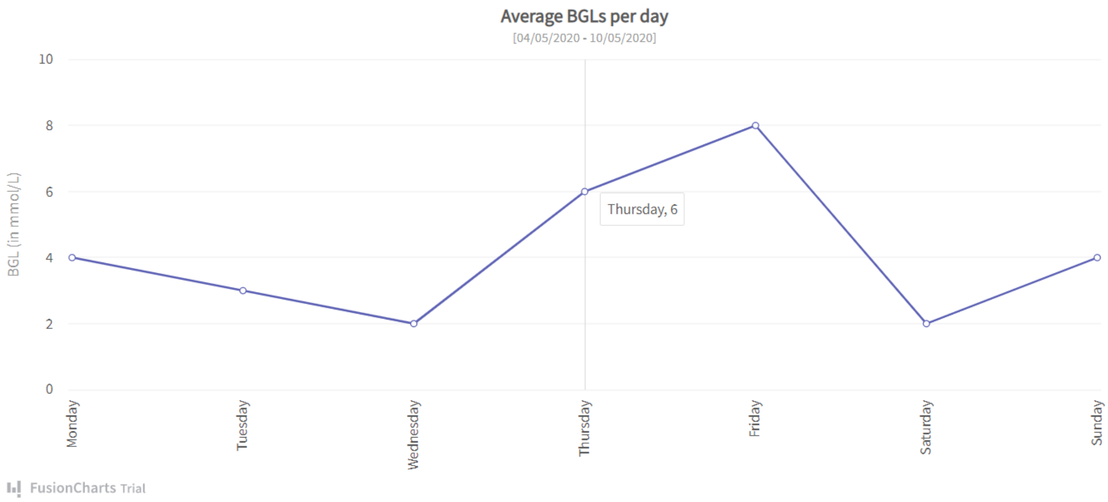


Figure 4-18 Initial Implementation Test Using the FusionCharts Charting Library

4.3.2.3 Comparison of HighCharts and FusionCharts

A basic bar chart was implemented using HighCharts (Usman, M., 2022) and FusionCharts (Easiest JavaScript charting library for web & mobile, 2022) to compare the capabilities of each charting library. The purpose of the comparison was to determine which of the implementation tools provided the most support for the requirements of MedicMetric.

The tools provided the following functionality:

- Extensive libraries of chart options for visualisations
- Tooltips for examining details

- Export functionality for downloading and saving reports of data
- Various labelling capabilities
- Filtering of parameters i.e. removing plotted data

These basic tasks allow for comparison of the two toolkits. The following tasks were completed in the comparison for each toolkit:

1. Identify a chart that is closest to one designed in this section and implement it
2. Add a tooltip to the chart
3. Add export functionality for downloading and saving reports and download the data in the chart
4. Add axis labels, a legend and a title to the chart
5. Remove a plotted parameter from the chart

The functionality implemented in the toolkit was not necessarily the most appropriate functionality to be used for the prototype and was improved once the most suitable charting library was identified. The above-mentioned tasks were implemented as follows.

1. Identify a chart that is closest to one designed in this section and implement it

Once a selected chart was implemented for each charting library the applications were opened side by side. The chart rendered in FusionCharts (Easiest JavaScript charting library for web & mobile, 2022) was faster, but the animation glitched causing it to have an unpleasant jerk before rendering. The chart rendered instantly in HighCharts (Usman, M., 2022), and the animation was aesthetically pleasing. HighCharts also provided a three potential base radial bar charts, which could be edited to create the Radial Progress View, whereas FusionCharts supported standard charts like line, bar and pie charts. This task was simpler to complete using FusionCharts.

2. Add a tooltip to the chart

Changing one parameter in both charts resulted in a tooltip being displayed. The tooltip was simpler in FusionCharts and more detailed in HighCharts. It is worth noting that HighCharts cut off the unit of mmo/ L which resulted in the incorrect unit of mm being displayed. No unit was displayed for FusionCharts, despite one being provided. After expanding the tooltip in HighCharts the correct unit was displayed (Figure 4-19).

Figure 4-19 Tooltips as Shown by HighCharts and FusionCharts Respectively

3. Add export functionality for downloading and saving reports and download the data in the chart
4. Add axis labels, a legend and a title to the chart

Adding labels and export functionality to both charts was also simple. Both charts exported the data with no problem to the correct format selected (either .PNG, .JPG, .SVG or PDF).

5. Remove a plotted parameter from the chart

Both charting libraries provide this functionality when a legend is added. In HighCharts (Usman, M., 2022) the animation leads to a smooth transition when a parameter is removed from the chart. Because of FusionCharts (Easiest JavaScript charting library for web & mobile, 2022) animation issue, the chart is not rendered smoothly when a parameter is removed.

Other criteria to consider include performance when visualizing large data-points, product support, which is easiest-to use, customization and variety of animations as well as variety of charts.

Performance on large data-points

Both products are capable of rendering thousands of data-points easily. FusionCharts provides a ZoomLine chart to handle datasets with more than 10 000 points. HighCharts provides a demo line chart with 500 000 points. Since the application should not need this level of performance during testing, either library would suffice.

Product Support

HighCharts provides the most extensive documentation about their APIs and charts that are available. FusionCharts provides dedicated customer support and are capable of changing configurable parameters in order to provide the best solution quickly. For the implementation of the

IV prototype, it is unlikely that a license for FusionCharts will be bought. This means that the documentation is the largest source of support for the development using these libraries.

Customization and Variety of Animations

HighCharts has more customizable animations when compared to FusionCharts JavaScript charts.

Variety of Charts

HighCharts (Usman, M., 2022) provided a larger number of charts, which are closest to the designed charts present in this chapter. This means that using HighCharts, the effort required to edit a chart in order to obtain the needed design is lower than the effort required using FusionCharts (Easiest JavaScript charting library for web & mobile, 2022).

Both charting libraries are capable of rendering chart in an Android/iOS environment. Each chart was easy to implement and the time from initial implementation to rendering a chart were both short. The styling provided by HighCharts is far more aesthetically pleasing and the documentation for HighCharts are more extensive.

The community support provided by the HighCharts library specifically for application developers is also far more extensive.

Because HighCharts provides highly configurable charts, which are similar to the ones designed in this chapter, it would be beneficial to make use of HighCharts. The set-up procedure for HighCharts was more difficult than that of FusionCharts but once a suitable wrapper was identified, the library was easy to use and provided all the functionality needed. For these reasons, HighCharts was selected for use in the development of MedicMetric.

HighCharts is a JavaScript library typically used for the development of web applications, so the charts are capable of a lot more than alternative libraries which are designed for mobile use, like the FusionCharts library.

4.3.3 Visualisation Techniques

Three visualisations, capable of providing users with the ability to view and correlate behaviors with BGLs were implemented using the HighCharts (Usman, M., 2022) library in MedicMetric. These charts were implemented for comparison purposes and all three support the tasks listed in Section 4.2.3. Users can navigate between the views by using a chart navigation screen. The chart data is a combination of sandbox data and purposefully generated data. The generated data was used in order to highlight aspects of the IV techniques more clearly.

4.3.3.1 Radial Progress View

The Radial Progress View was implemented using HighCharts (Usman, M., 2022) radial bar chart. The chart contains all tracked variables. The radial line meets the end of the track when participants have fully met their goal for the day. For instance, if a participant sets a reminder to take their medication, and selects that they have completed the task when the reminder is sent, then they have met their goal for medicine intake. If a participant sleeps for 8 hours a day, and drinks a minimum of six glasses of water in a day then those bars will also be full.

The weekly overview (Figure 4-20) shows all of the same information that is shown in the day view, but it is represented using stacked bars. This way, the user performance can be compared to the other days in the current week, in order to determine which days they performed their worst. It is worth noting that in order for a participant to meet their goal for the BGL category, their BGL must remain within the acceptable range for the day (between 4 and 8 mmo/L). If the participant does not achieve this goal, then it is calculated as the percentage of the day for which they were outside the acceptable range.

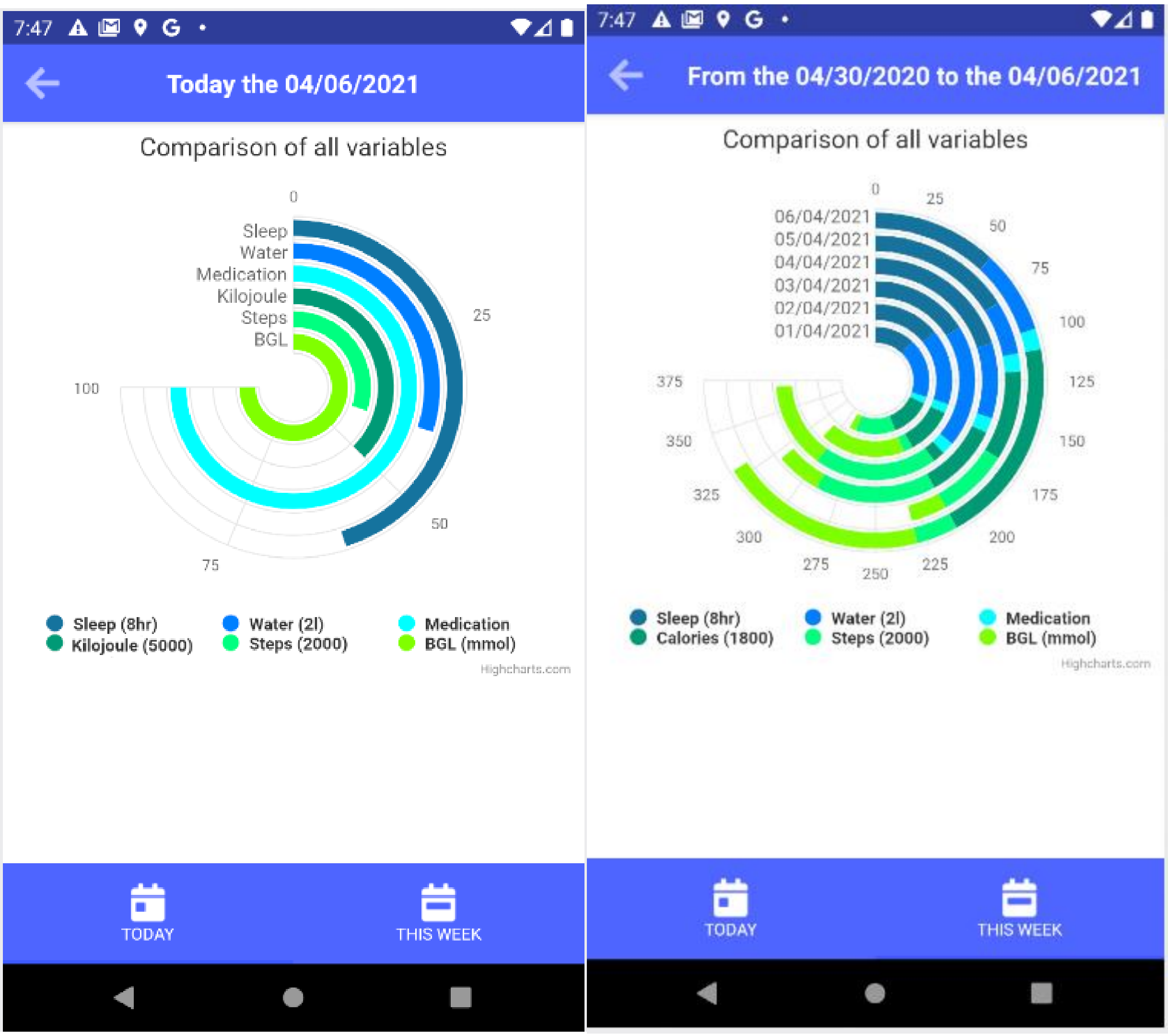


Figure 4-20 The Radial Progress Daily and Weekly View

Users are also able to filter the chart completely down to one criterion and compare their individual goals throughout the week. For example, users can click on the legend at the bottom and remove all factors except water. Now they will see a Radial Progress View with only water, and they can compare their progress throughout the week specifically in relation to water.

4.3.3.2 Annotated Line View

The HighCharts (Usman, M., 2022) Annotated Line View was edited in order to display events as zones on the line chart. This process produced the Annotated Line View. The title of the event is shown and upper and lower limits of BGLs can be seen on the chart. By showing events as zones, it becomes easier to associate the event to the BGL, and therefore to associate a behavior to the BGL.

The daily and weekly view of this chart (Figure 4-21) can be seen below. From the data below, it would be relatively easy to determine that medicine intake and exercise cause BGLs to drop. This has been exaggerated in the figure for this example.

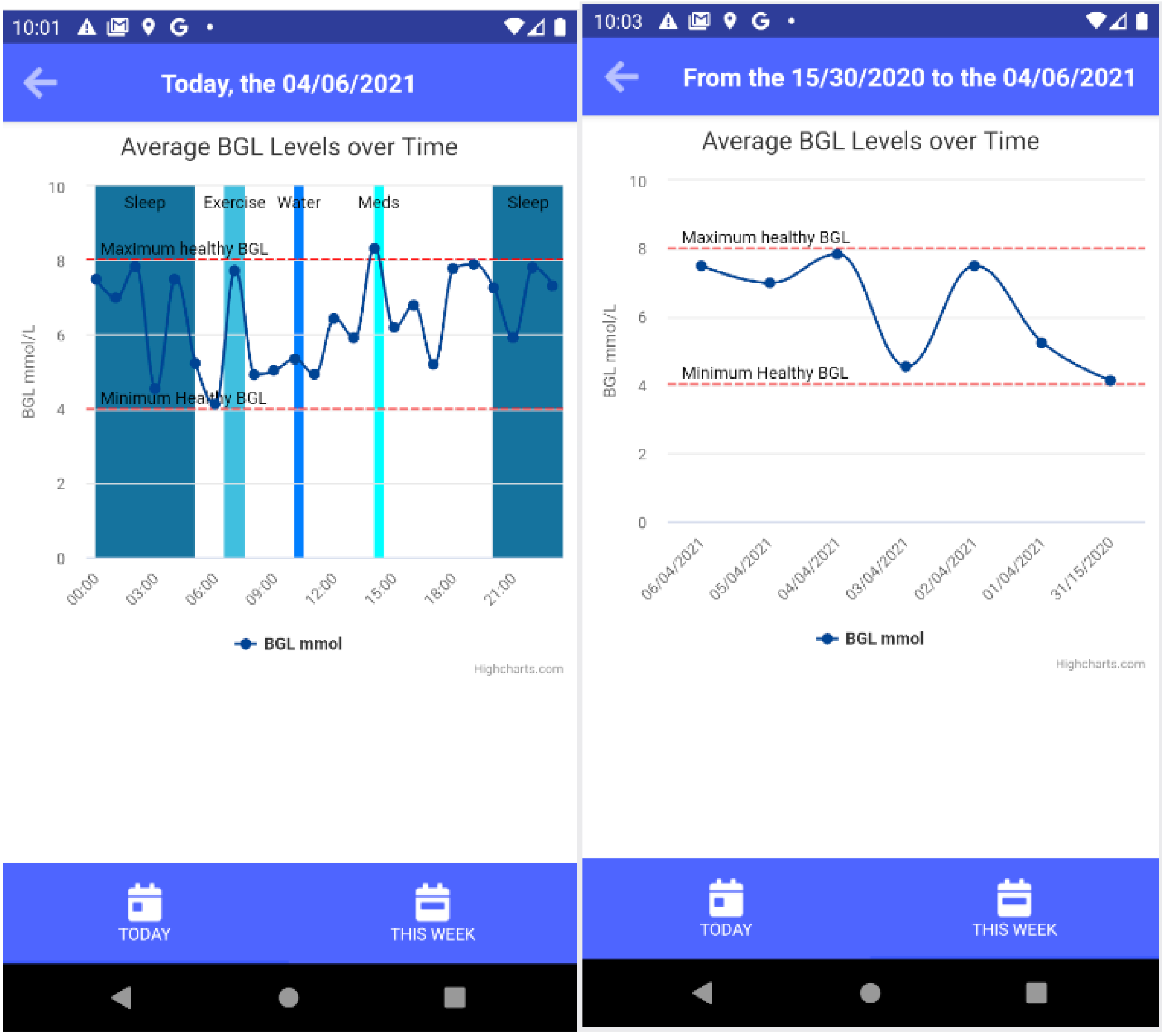


Figure 4-21 Annotated Line Daily and Weekly View

4.3.3.3 Change Rate Line View

In order to highlight trends in the data, a ROC line for different variables was calculated. The calculation for ROC is simple in that it takes the current value for a variable and divides it by the value from an earlier period. One is then subtracted from this amount and the remainder is multiplied by 100 to give it a percentage representation.

This results in Figure 4-22. This chart would be useful in determining if one factor would have an effect on another, but it would be difficult to tell if that effect would be negative or positive as ROC does not relay that kind of information, however, BGLs should be stable over time and not fluctuate rapidly. Any behavior which negatively effects BGLs but causing both to fluctuate at the same time would be easy to notice using this view.

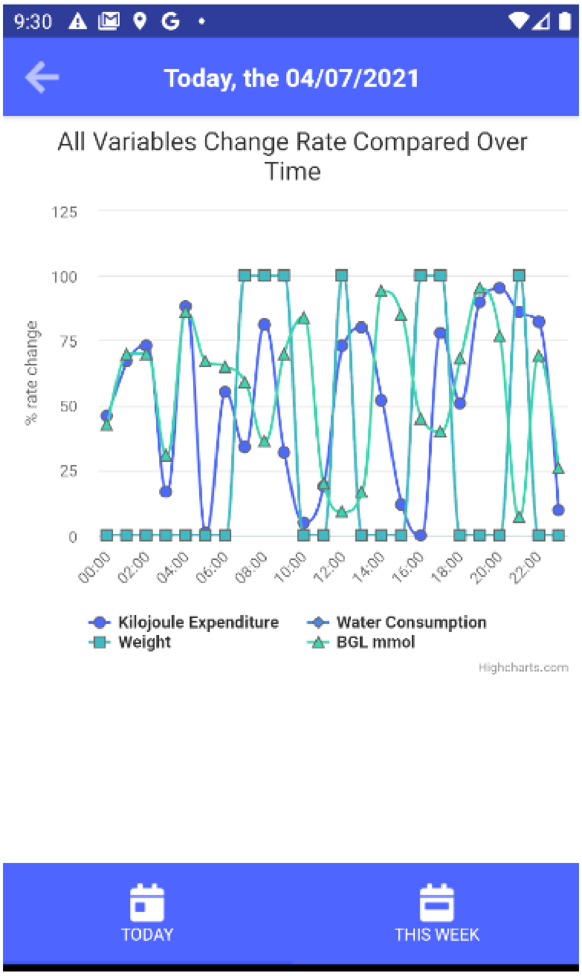


Figure 4-22 Change Rate Filtered View

4.3.4 Application Implementation

The designed application was implemented using NativeScript (NativeScript, 2022) and the HighCharts (Usman, M., 2022) library. This section will describe how the application implementation differs from the design outlined in Section 4.2.1.

Login Screen

The log in screen (Figure 4-23) was implemented as planned in Section 4.2.1. The signup button was placed above the log in button as opposed to as a text line below the button as it is clear now where the signup functionality is.

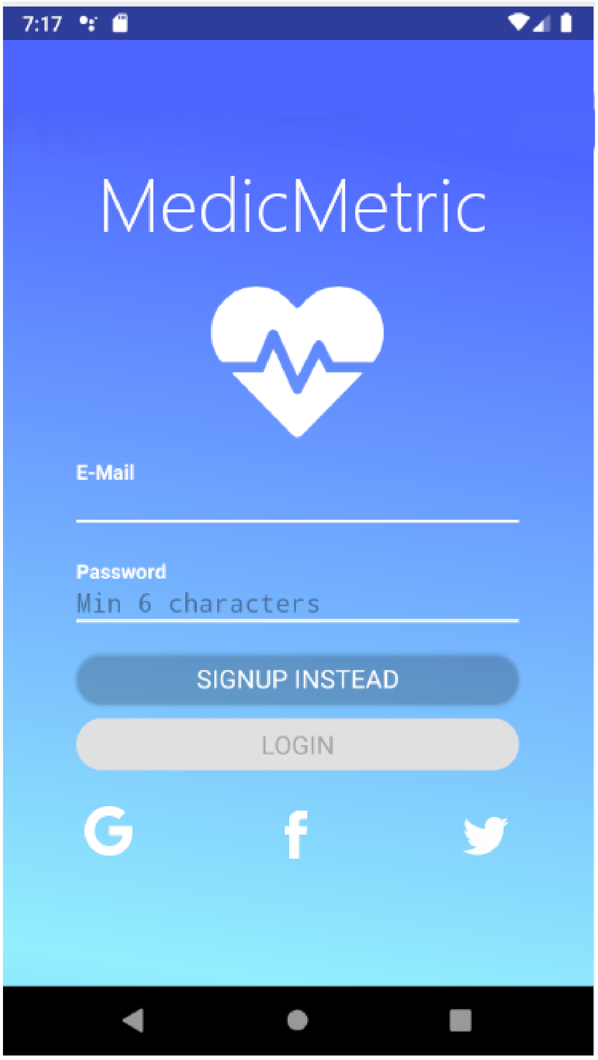


Figure 4-23 MedicMetric Login Screen

The login button is greyed out until an email and password is provided, or the user clicks on the Google, Facebook or Twitter icons in order to use OAuth 2.0. The signup screen is almost identical, but the 'Signup Instead' button will have 'Login Instead' written on it. If the password is entered incorrectly or is shorter than six characters, the login button remains disabled.

Navigation

Navigation within the application can be performed using a side drawer menu which is activated by the hamburger menu displayed on the top left of the screen. Navigation can also be done using the tabs at the bottom of the screen. Navigation between charts must be done by selecting the card on the screen (Figure 4-24) with the name of the chart that the user would like to view.

Figure 4-24 Medic Metric Navigation Screen

User Profile and Calendar

Implementation of the user profile was limited, as profiles and sharing were not in the scope of the research. Users are able to create a profile with their details (Figure 4-25), but no additional information is displayed at this time. The contact and follow buttons do not currently have functionality, however users are able to edit their profile picture by holding down on it and selecting a new image from the gallery.

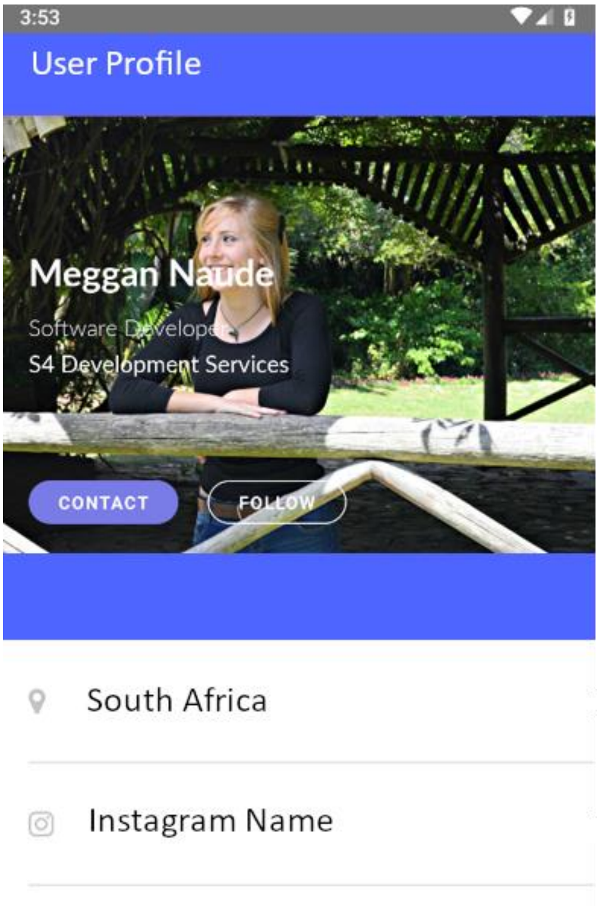


Figure 4-25 Medic Metric User Profile Screen

The calendar view (Figure 4-26) can be used to create events manually, which will be displayed within the Annotated Line View. Events can be water consumption, medicine intake or a note/reminder that the user is interested in.

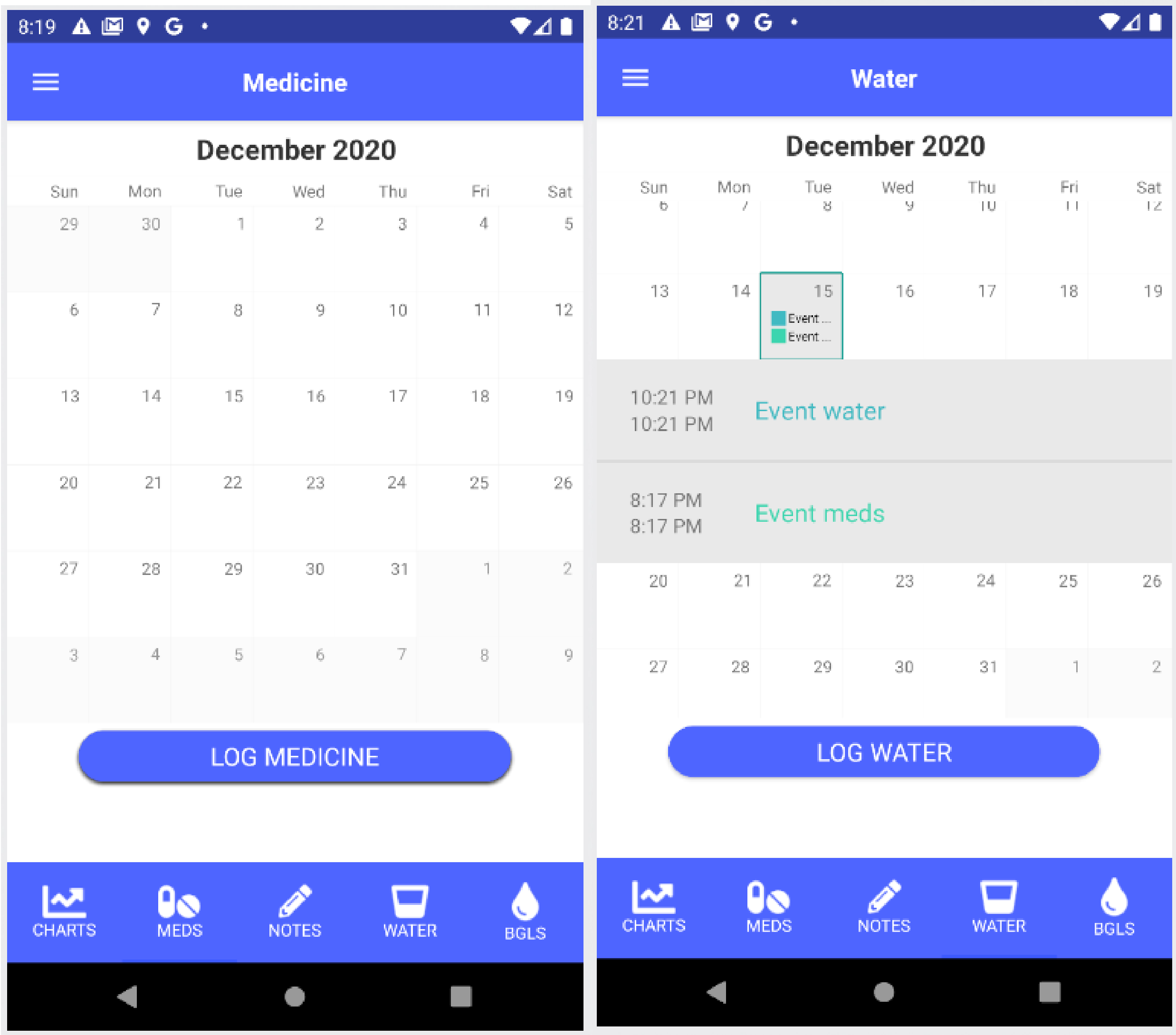


Figure 4-26 Medic Metric Calendar Input Screen

Additional Charts

Extra charts were created to allow users to explore the data more extensively within the applications. These charts will not be evaluated to the same extent that the Radial Progress View, Annotated Line View or Change Rate Line View will. Nevertheless, these charts show important information and details that user may be interested in viewing. A sleep chart (Figure 4-27) was created in order to represent the stages of sleep (REM, deep, light and awake) throughout the night. This data was captured using the Fitbit Charge 2 which is capable of identifying stages of sleep and sleep quality throughout the night when worn.

Figure 4-27 Sleep Chart Daily and Weekly View

A chart representing kilojoule expenditure (Figure 4-28) was also implemented so that users are able to see their general activity throughout the day and over their average activity per day throughout the week.

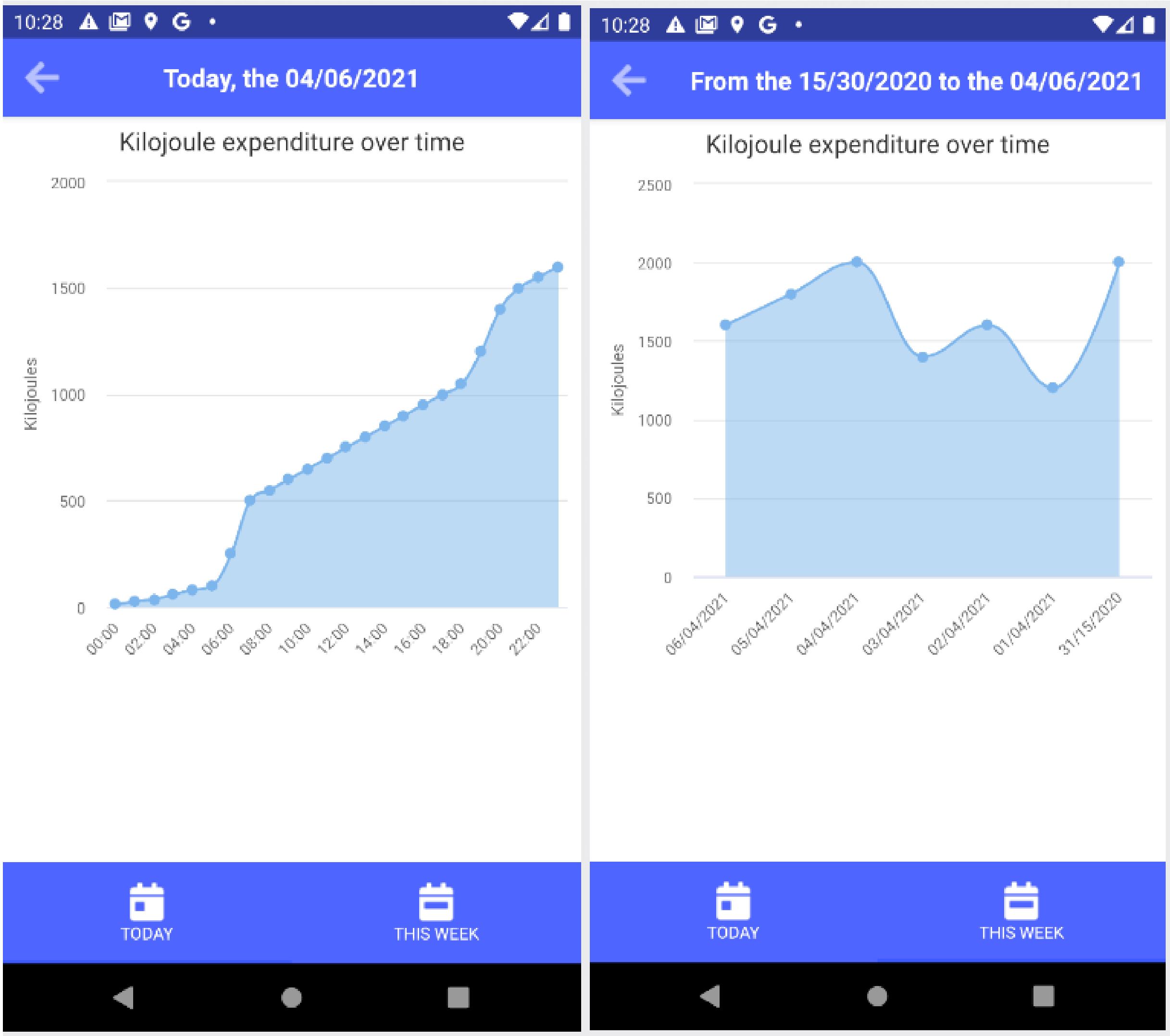


Figure 4-28 Kilojoule Expenditure Line Chart Daily and Weekly View

A third chart was created in order to display water consumption (in glasses or 250ml increments), so that users could track their water consumption throughout the day and week (Figure 4-49).

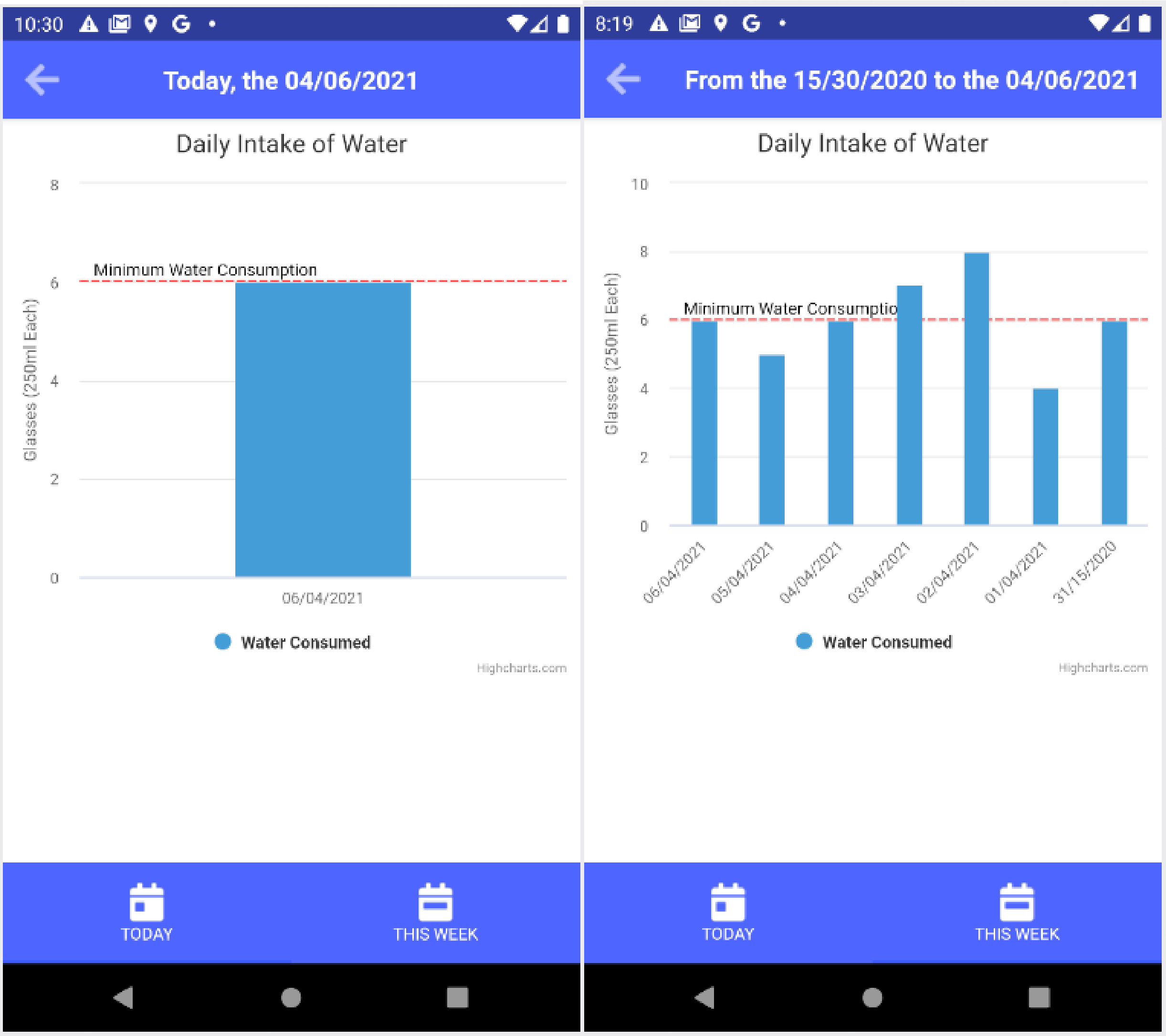


Figure 4-29 Water Consumption Bar Chart Daily and Weekly View

4.4 Discussion

MedicMetric was developed in NativeScript (NativeScript, 2022) using Angular. It was written in TypeScript. HighCharts (Usman, M., 2022) was the charting library used to develop MedicMetric. According to the requirements of IV for the self-management of T2DM as identified in Section 3.10, MedicMetric supports all the tasks outlined in Section 4.4.2. MedicMetric implemented three views of T2DM data, namely the Annotated Line View, the Change Rate Line View and the Radial Progress View.

None of these three charts are currently used in T2DM self-management IV tools, but the Annotated Line View is a new version of the line charts that are currently used in IV tools. A comparison is needed in order to determine which IV tool (and therefore which view) provides better support for the self-management of T2DM. A study is also needed in order to determine which of the three developed views provides the best support for the self-management of T2DM.

HighCharts provides extensive support for interactive data visualisation. The process to convert the data to be visualized into the IV technique is relatively simple. All tasks listed in Section 4.2.3 could be implemented using the HighCharts library. The animations and aesthetics of the chart defaults are pleasing and the chart rendering is fast.

4.5 Conclusion

Chapter 4 aimed to answer the fourth research question identified in Chapter 1: How *can IV techniques be applied to support self-management of DM?*

In the design process, a method for acquiring test data was discovered through the use of the Fitbit and Dexcom APIs. The visualisation which were designed made use of relevant IV techniques. It was discovered that IV techniques can be applied to support the self-management of DM by helping to refine new IV designs which reduce the user cognition required to retrieve and interpret useful data from a visualisation. The most useful IV techniques were used to create and evaluate, through two design iterations, a new set of visualisations, which will be used in the implemented application.

In the implementation section, HighCharts (Usman, M., 2022) was selected as the library to be used to create the visualisations as it easily rendered aesthetically pleasing charts, which are most similar to the designed ones.

5 Evaluation

5.1 Introduction

Chapter 4 detailed the procedure for planning, designing and implementing the proposed application that would be used as an IV tool to aid the self-management of T2DM. This chapter aims to discuss the evaluation of the IV prototype, and its general effectiveness according to the individuals who evaluated it. This chapter addresses the fifth research question identified in Chapter 1: *How effective are the identified IV techniques in supporting self-management of T2DM?* This question will be answered through the evaluation of the designed IV prototype, and a comparison of the prototype to alternate tools.

This chapter includes the research design and results of the usability evaluation. This will be used to compare existing tools' visualisation techniques to those provided within the developed prototype. Any identified usability issues will be rectified. A discussion is provided after the evaluation as well as suggested modifications for future work.

5.2 Usability Evaluation

A usability study was conducted to determine if the developed IV tool, MedicMetric, is adequate for daily use in its intended environment and to determine its convenience. The experiment captured metrics for usability, convenience, cognitive load and satisfaction as well as metrics for each task completed. Questionnaires were used to determine how satisfied participants were with the prototype after using it for a period of time. Any usability problems identified during the use of the prototype are discussed in this section.

5.2.1 Research Design

The usability study required participants to complete a series of tasks, detailed in Appendix D and H, while using the prototype application to view the visualisations. In order to avoid participants learning the system, the study was done before they were asked to make use of the prototype for any prolonged period of time. The metrics used to determine the applications general usability and convenience included effectiveness (the ability to recognize patterns quickly while using the visualisations), efficiency (task completion as well as the time required to complete tasks), user satisfaction (how happy the user was to make use of the application and how likely they are to use it in future), cognitive load (how much effort was required to understand the information being presented to the user) and ease of use.

Three participants completed the evaluation using MedicMetric and were asked to make use of the entire system, including the Fitbit Charge 2 and Aria Scale for one week afterward in order to identify any problem factors with the system as a whole. Twelve other participants were asked to evaluate the system without prolonged in-home use. In total, fifteen participants evaluated the system.

5.2.1.1 Research Objectives

MedicMetric has seven core charts, which display information relevant to an individual with T2DM, including kilojoule expenditure, BGLs, medicine intake, water intake, weight and sleep patterns. There are three charts, which are capable of highlighting patterns or behaviors, which can have a direct impact on BGLs. The aim of the evaluation was to determine if the information is easily interpretable by the user, and to determine which of the three comparative charts (the Annotated Line View, Radial Progress View or Change Rate Line View) were preferred, and to determine if MedicMetric has any usability flaws which require fixing.

The Radial Progress View was initially not designed as an IV technique for recognizing health patterns, but its weekly overview shows a large amount of information about which goals participants met throughout the week, and whether or not their BGLs have remained stable for that time period. It is possible from looking at this view of the chart to infer a few health patterns, and thus it was evaluated with the two other charts intended for that purpose.

A brief evaluation of two alternative systems was also conducted in order to determine if MedicMetric could be as effective as existing systems at providing data to the participants.

5.2.1.2 Participants

A sample of fifteen participants (8 male and 7 female, with an average age of 34.8 years) were asked to participate in the usability evaluation. The participants either had T2DM, worked in a medical field or lived with close relatives affected by T2DM and could make use of a self-management tool to aid their relatives. 7 of the participants had T2DM. Participant’s age ranged from 26 to 64 years. Participants were not required to have any past experience with alternative T2DM self-management applications. Each evaluation took approximately 2 hours to complete. Although it was not required in order to participate in the evaluation, participants were asked if they had any prior experience with IV tools (Appendix C) and 86% of the participants indicated that they had used an IV tool previously. Eleven participants had a university degree.

The participants using the application for an additional week were required to have T2DM and make use of a Medtronic Blood Glucose Monitor (MBGM), or have an alternate device, which is capable of measuring BGLs throughout the day. The participants were required to have a smart phone. None of the participants had used a BGL tracking application previously, outside of the ones provided by their MBGM or an alternate device.

5.2.1.3 Evaluation Metrics

The following performance metrics for each task were measured:

Effectiveness: Whether the task was complete correctly or not, and
Efficiency: Time taken to complete the task.

User satisfaction, cognitive load and ease-of use were measured after the tasks were complete by way of questionnaires.

5.2.1.4 Questionnaires

Upon meeting, an oral/written information sheet was provided to each participant or read aloud to them (Appendix A). A consent form was provided to each participant before they were able to participate in the study (Appendix B). A questionnaire designed to collect demographic information for each participant was given to them (Appendix C).

Each of the three charts capable of displaying BGL patterns were shown to the participants and they were asked to identify any patterns that they could see out loud while they were timed.

Participants were then asked to complete a series of base tasks using the application (Appendix D). Thereafter, the participants were provided with a usability questionnaire in the form of the System Usability Scale (SUS) (Brooke, 1996), which makes use of a 5-point Likert scale (Appendix E). A cognitive load questionnaire in the form of the NASA-task load index (NASA TLI) was administered (Hart, 2006) (Appendix F) as well as an overall satisfaction questionnaire (Appendix H). Alternative cognitive load scales were also considered. The Paas scale is a single-item measure of invested mental effort, but the NASA-TLZ provides an overall workload score that is calculated as the sum of six 20-point subscales: mental demand, physical demand, temporal demand, performance, effort and frustration. As an overall cognitive measure, the NASA-TLZ was chosen, as physical demand could be used as measure for user input while using the systems (Naismith, Cheung, Ringsted and Cavalcanti, 2015). standard User Experience Questionnaire (UEQ) (Schrepp, 2015), which makes use of a 7-point semantic differential scale was administered (Appendix G).

Once these steps were completed, the participants were asked to evaluate three different visualisations within the application namely the Annotated Line View, the Radial Progress View and the Change Rate Line View. Again, participants were issued with a task list aimed at these three visualisations (Appendix H). The final section of the task lists were comprised of tasks to complete on two alternate applications, which are currently available, namely: Diabetes:M (Sirma Medical Systems, 2021) and MySugr (mySugr, 2012). After completing the tasks, they were asked to fill in a questionnaire addressing cognitive load, satisfaction and usability (Appendix I, J and K), and were asked to fill in a separate questionnaire to determine which chart they would prefer to use (Appendix L), and another to determine which system they preferred to use (Appendix M). Finally, they were asked to fill in an overall satisfaction questionnaire (Appendix N).

5.2.1.5 Experimental Setup

Two versions of the usability evaluations were developed to cater for Covid19 safety regulations and to minimize the risk for individuals with T2DM, as they are at a higher risk of obtaining serious symptoms. Participants could either do an evaluation at home or online.

In both at home and online environments, participants were seated at a desk with a laptop directly in front of them. The laptop was used to emulate the application.

In the at home environment the evaluator was positioned out of eye-line but within hearing range of the participant so that they could observe the participant and note the participants' answers to the questionnaires. The participant and evaluator communicated verbally during the evaluation. If the participant opted to do an online evaluation, the participant would communicate verbally through video chat to the evaluator. The VoIP used to conduct the experiment was Discord (https://discord.com/). Screen sharing was used when a participant evaluated the emulated application in order to minimise the amount of software that they would need to download or install.

Participant task times were manually recorded by the evaluator as well as the answers to questions in the task lists. Participants were given written and verbal instructions for each task and questionnaires were administered verbally.

5.2.1.6 Tasks

Two sets of different tasks were given to each participant (Appendix D and Appendix H). Appendix D contains general application tasks in order to evaluate the system as a whole, but Appendix H outlines tasks which are directly linked to the VISM and are thus directly supported by IV techniques. The tasks and the IV techniques supporting each task are described in Table 5-1. The Overview, Relate and History IV tasks were supported by all evaluation tasks. The Extract task was not supported by MedicMetric and thus not evaluated in this study.

Table 5-1 IV Technique Evaluation Tasks and the Visual Information Seeking Mantra Subcategories Supporting Them

Evaluation Task	IV Task Supported
Evaluation tasks for the Radial Progress View	
1. Identify the activity for which the participant has not met their goal by the largest degree using the Radial Progress View.	Details-on-demand Filter Relate Zoom
2. Identify the day for which the participant drank the most amount of water using the Radial Progress View.	Filter Zoom
3. Identify the day that the participant met the fewest of their goals using the Radial Progress View.	Details-on-demand Filter History Relate Zoom

4. Identify the day that the participant met most of their goals using the Radial Progress View.	Details-on-demand Relate
5. Identify the two goals that the participant met fully today using the Radial Progress View.	Details-on-demand Relate
Evaluation tasks for the Change Rate Line View	
6. Remove the weight and water consumption on the “Compare All” (Change Rate Line View) chart.	Filter Zoom
7. Identify whether or not water consumption increases, decreases or does not affect blood glucose levels at all using the “Compare All” (Change Rate Line View) chart.	Details-on-demand Relate
8. Identify whether or not kilojoule expenditure increases, decreases or does not affect blood glucose levels at all using the “Compare All” (Change Rate Line View) chart.	Details-on-demand Relate
Evaluation tasks for the Annotated Line View	
9. Identify the minimum acceptable blood glucose levels using the “Blood Glucose Level” (Annotated Line View) chart.	Details-on-demand History Zoom

10. Identify the maximum acceptable blood glucose levels using the "Blood Glucose Level" (Annotated Line View) chart.	Details-on-demand History Zoom
11. Identify the times for which the blood glucose levels are at their lowest and lowest for today using the "Blood Glucose Level" (Annotated Line View) chart.	Details-on-demand History Relate Zoom
12. Identify the times for which the blood glucose levels are at their highest and lowest for today using the "Blood Glucose Level" (Annotated Line View) chart.	Details-on-demand History Relate Zoom

In addition to these tasks, users were asked to identify what effects, if any, including weight, medication, water consumption, sleep and kilojoule expenditure (exercise), would have on BGLs while looking at the Radial Progress View, Change Rate Line View and Annotated Line View. The Radial Progress View was not initially designed as a tool for interpreting correlations between BGLs and affecting factors, but its weekly overview shows a large amount of information about all factors at once, and it has the potential to be a good source of correlative information. For these reasons, it was evaluated as an alternative to the Change Rate Line View and the Annotated Line View.

These tasks were designed as a direct comparator for all three charts in determining health patterns. All tasks were supported by Details-on-demand, History, Relate and Zoom from the VISM and are shown in Table 5-2 below.

Table 5-2 IV Technique Evaluation Tasks and the Visual Information Seeking Mantra Subcategories Supporting Them

Task	**IV Task Supported**

1. Determine if sleep increases, decreases or has no effect on BGLs	Details-on-demand History Relate Zoom
2. Determine if water consumption increases, decreases or has no effect on BGLs	Details-on-demand History Relate Zoom
3. Determine if kilojoule expenditure (exercise) increases, decreases or has no effect on BGLs	Details-on-demand History Relate Zoom
4. Determine if medication intake increases, decreases or has no effect on BGLs	Details-on-demand History Relate Zoom
5. Determine if weight change increases, decreases or has no effect on BGLs	Details-on-demand History Relate Zoom

Users were then asked to log in to two alternate systems MySugr (mySugr, 2012) and Diabetes:M (Sirma Medical Systems, 2021), after being given a brief tutorial in order to use each system, and to perform three tasks while looking at the charts within the alternative IV tools (Appendix H). Table 5-3 Illustrates the tasks that users were asked to perform.

Table 5-3 Alternative IV Tool IV Technique Evaluation and Supporting Visual Information Seeking Mantra Tasks

Task	IV Task Supported
1. Looking at the charts in this application, identify any noticeable trends in the daily activities with relation to BGLs.	Details-on-demand History Relate Zoom
2. Using the charts available within the application, which activities appear to negatively affect BGLs.	Details-on-demand History Relate Zoom
3. Determine when BGLs are at their lowest and highest using the charts available within the application.	Details-on-demand History Relate Zoom

5.2.1.7 Procedure

Each participant completed one evaluation and all evaluations were done one at a time. The procedure was briefly explained to all participants before the evaluation began. A generalized information sheet (Appendix A) about the purposes of the study was read aloud by the evaluator, and a written copy was given to the participant. The participant was then provided with a consent form (Appendix B).

Once the consent forms were signed and before the evaluation began, the participant was asked to complete a background questionnaire (Appendix C). The participant was asked to complete the initial set of tasks (Appendix D) and was administered a usability questionnaire (Appendix E), a cognitive load questionnaire (Appendix F) and a user experience questionnaire (Appendix G).

The participant was then asked to complete tasks for each of the main three charts and alternative IV tools (Appendix H). After completing the tasks for each chart and performing similar tasks on alternative applications, namely MySugr (mySugr, 2012) and Diabetes:M (Sirma Medical Systems, 2021), the participant was asked to identify which of the three systems best supported their tasks in terms of the VISM.

Hereafter, participants were asked to complete post-task questionnaires (Appendix I, J and K) and as part of the tasks, they were asked to evaluate which of the three systems they felt best met the VISM. Finally, they were asked to compare the three proposed charts (Appendix L) and IV tools (Appendix M), as well as an overall satisfaction questionnaire (Appendix N).

5.2.2 Research Results

Five metrics were used in the usability evaluation; effectiveness, efficiency, user-satisfaction, user-experience, and cognitive load. This section will describe the results of the evaluation.

5.2.2.1 Performance Results

This section will focus on the results in terms of effectiveness and efficiency for each of the three IV techniques that were evaluated and the three systems, which were briefly evaluated. The effectiveness and efficiency results support all three IV techniques as detailed below.

Effectiveness

For all tasks, which were supported by the VISM, participants were required to answer a question or identify a piece of information relating to the task. These tasks were identified in Section 5.2.1.6 above in Table 5-1, Table 5-2 and Table 5-3. Effectiveness was measured as the percentage of correct answers to the questions for each task.

Tasks detailed in Table 5-1, which were designed to evaluate the three main IV techniques developed as part of the prototype as a whole, received 100% success rate, except for three tasks. Two tasks in the Change Rate Line View and one task for the Annotated Line View did not receive 100% success rate. The two tasks for the Change Rate Line View received 86.67% (Task 7) and 80% (Task 8), and the task for the Annotated Line View received 80% (Task 12) success rate. In general, users found it more difficult to identify information accurately using the Change Rate Line View. All three of these tasks produced a high level of accuracy despite having the lowest success rates, and it can be concluded that all three visualisation techniques used, effectively supported the users' tasks.

Tasks detailed in Table 5-2, which were designed to directly compare the three main IV techniques developed as part of the prototype received varying success rates. Task 1 was completed with an 80% success rate, Task 2 with 82.22% success rate, Task 3 with 77.78% success rate, Task 4 with 86.67% success rate and Task 5 with 93.33% success rate. Task 3 and 5 asked participants to determine if exercise and weight, respectively, have any effect on BGLs according to the charts.

Breaking the above task success rate down by which chart was used to complete all five tasks, participants had a 71.11% success rate when using the Change Rate Line View, 80% success rate when using the Radial Progress View and a 96% success rate when using the Annotated Line View. Thus, it can be concluded that the most effective chart at supporting the users' interpretation of correlations between affecting factors and BGLs is the Annotated Line View, and the least effective at supporting the users' interpretation of correlations between affecting factors and BGLs is the Change Rate Line View.

Tasks detailed in Table 5-3, which were designed to compare two existing applications for self-management of T2DM to MedicMetric in terms of efficiency when interpreting data resulted in identical success rates between MySugr (mySugr GmbH, 2012) and MedicMetric. Participants answered the task questions while looking at MedicMetric and MySugr (mySugr GmbH, 2012) correctly 86.67% of the time, but only answered correctly while using Diabetes:M (Sirma Medical Systems, 2021) 42.22% of the time. This is possibly due to the navigation mechanisms used in Diabetes:M (Sirma Medical Systems, 2021), which multiple participants noted were confusing.

After completing the tasks for each chart and performing similar tasks on alternative applications, namely MySugr (mySugr, 2012) and Diabetes:M (Sirma Medical Systems, 2021), the participant was asked to identify which of the three systems best supported their tasks in terms of the VISM.

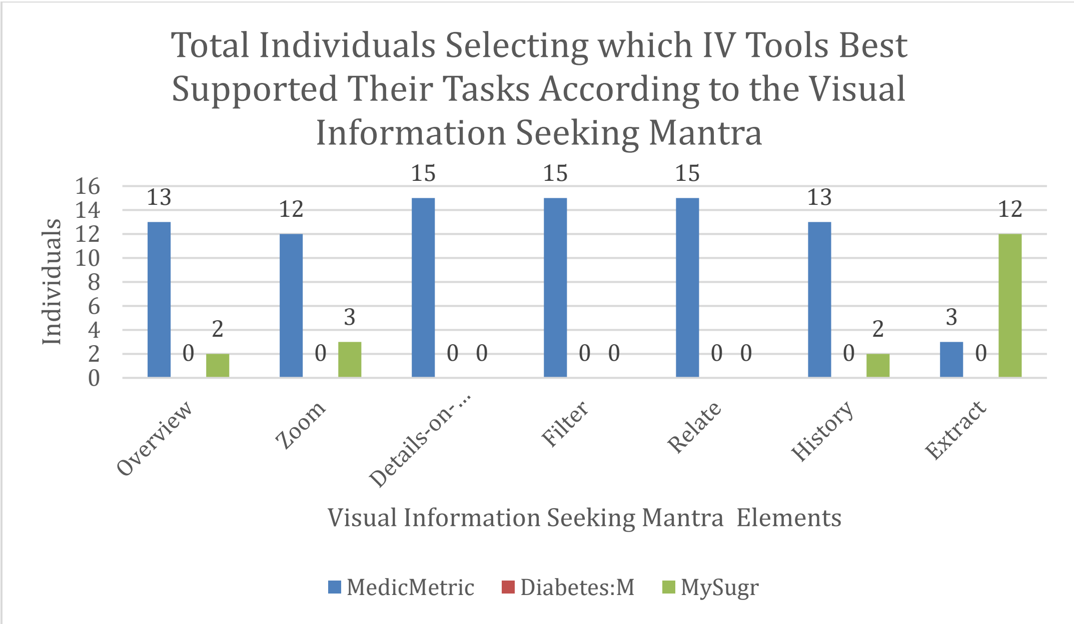


Figure 5-1 Total Individuals Selecting which IV Tool Best Supported Their Tasks According to the Visual Information Seeking Mantra

As shown by Figure 5-1, participants felt that the MedicMetric IV tool best supported their tasks according to the VISM. Since this data does not follow a normal distribution, a Wilcoxon (MacFarland & Yates, 2018) matched pairs non-parametric test was run between MySugr and MedicMetric and all results were statistically significant in favour of MedicMetric, apart from Extract, which was in favour of MySugr.

It is worth noting that the final question in Appendix N is 'If you were to choose one of the IV tools evaluated here today to use daily, which would it be?'. 100% of the participants stated that they would make use of MedicMetric.

In effectiveness and efficiency MedicMetric and MySugr obtained almost identical results. However, participants estimated that MedicMetric supported their tasks using the VISM the best overall, with 100% of participants stating that they would prefer to use the MedicMetric application.

Efficiency

After instructions were given to the participants for each task in the list shown in Section 5.2.1.6, a timer was started and reset once the participant verbally relayed their final answer to the investigator. The time for each task was taken as the time from completing the instruction, when MedicMetric opened the relevant screen after the instruction was finished, until the verbal answer was heard. If the participant changed their mind about the answer, the additional time from the first answer to the second or third was added to the initial amount. The answer could not be changed once the participant moved to the next task. Table 5-4 outlines the task times for each task in the initial task list in Table 5-1.

Table 5-4 Average Time Taken in Second to Complete Each Task

Task	Time (Average) in seconds	Standard Deviation in Seconds
Task 1: Identify the activity for which the participant has not met their goal by the largest degree using the Radial Progress View.	26.13	29.78
Task 2: Identify the day for which the participant drank the most amount of water using the Radial Progress View.	32.73	32.04
Task 3: Identify the day that the participant met the fewest of their goals using the Radial Progress View.	25.2	28.68
Task 4: Identify the day that the participant met most of their goals using the Radial Progress View.	11.4	8.83
Task 5: Identify the two goals that the participant met fully today using the Radial Progress View.	17.67	9.93
Task 6: Remove the weight and water consumption on the "Compare All" (Change Rate Line View) chart	Was Not Timed	

Task 7: Identify whether or not water consumption increases, decreases or does not affect blood glucose levels at all using the "Compare All" (Change Rate Line View) chart.	61.47	37.21
Task 8: Identify whether or not kilojoule expenditure increases, decreases or does not affect blood glucose levels at all using the "Compare All" (Change Rate Line View) chart.	46.47	21.13
Task 9: Identify the minimum acceptable blood glucose levels using the "Blood Glucose Level" (Annotated Line View) chart.	4.8	4.26
Task 10: Identify the maximum acceptable blood glucose levels using the "Blood Glucose Level" (Annotated Line View) chart.	2.8	2.83
Task 11: Identify the times for which the blood glucose levels are at their lowest and lowest for today using the "Blood Glucose Level" (Annotated Line View) chart.	4.94	1.16
Task 12: Identify the times for which the blood glucose levels are at their highest and lowest for today using the "Blood Glucose Level" (Annotated Line View) chart.	4.47	2.10

These tasks cannot be directly compared for each of the three IV techniques, since each represents different data and cannot be filtered similarly. Naturally, in tasks like Task 7 and 8, when participants were asked to study the charts to identify patterns, the tasks took a significant amount of time longer. However, when participants were asked to identify information within the chart like in Task 1,2,3,4,5,6,9,10 and 11, the times decreased significantly.

Participants were asked to identify whether or not sleep (Task 1), water consumption (Task 2), exercise (Task 3), medicine (Task 4) and weight (Task 5) had an effect on BGLs as shown in Table 5-2. They were asked all three questions while looking at the Radial Progress View, the Annotated Line View and the Change Rate Line View.

Participants correctly identified the effects that water consumption, kilojoule expenditure and medication and weight have on BGLs 100% of the time using the Annotated Line View but could correctly interpret the data concerning sleep 80% of the time. Participants could correctly identify health patterns in a similar way 71.11% of the time using the Change Rate Line View and 80% of the time using the Radial Progress View. The gauge chart is meant to be used to determine how close to a particular goal a participant is, but it proved effective (using its weekly view) in providing an alternative chart for interpreting relations between the factors affecting BGLs and BGLs. Table 5-5 below shows the average times for each task.

Table 5-5 Average Time Taken to Interpret Effects of Behaviors on BGLs For Each View Developed

Task	**Radial Progress View**	**Change Rate Line View**	**Annotated Line View**
Task 1: Determine if sleep increases, decreases or has no effect on BGLs	23.87 (σ = 8.85)	51.4 (σ = 20.27)	18.33 (σ = 4.54)
Task 2: Determine if water consumption increases, decreases or has no effect on BGLs	22.93 (σ = 6.39)	40.93 (σ = 21.74)	9.47 (σ = 5.38)
Task 3: Determine if kilojoule expenditure (exercise) increases, decreases or has no effect on BGLs	23.33 (σ = 7.89)	26.4 (σ = 11.92)	14.27 (σ = 3.45)

Task 4: Determine if medication intake increases, decreases or has no effect on BGLs	15.33 (σ = 5.6)	33(σ = 11.20)	12.53 (σ = 5.50)
Task 5: Determine if weight change increases, decreases or has no effect on BGLs	15.87 (σ = 7.06)	24.47 (σ = 9.64)	12.6 (σ = 6.37)

Task time has a strong tendency to be positively skewed. This is due to the fact that some individuals take longer to complete tasks. Some users may encounter problems with an interface or use software slower as they complete tasks. A few long task times can pull the mean task time up, making it longer than the typical task time. As an example, the task times of 100, 101, 102, 103 and 104 have a mean and median of 102. Adding an additional task time of 200 skews the distribution, making the mean 118.33 ad the median 102.5.

In order to determine if the task time data presented in Table 5-5 follows a normal distribution, a Shapiro-Wilk test was performed on all test times. The results are displayed in Table 5-6.

Table 5-6 Shapiro-Wilk Test Results for Task Time Per Chart Type

Task	Radial Progress View p-Value	Change Rate Line View p-Value	Annotated Line View p-Value
Task 1: Determine if sleep increases, decreases or has no effect on BGLs	0.00 (W = 0.80)	0.01 (W = 0.84)	0.04 (W = 0.88)
Task 2: Determine if water consumption increases, decreases or has no effect on BGLs	0.00 (W = 0.82)	0.04 (W = 0.87)	0.03 (W = 0.87)
Task 3: Determine if kilojoule expenditure (exercise) increases,	0.02 (W = 0.85)	0.02 (W = 0.86)	0.01 (W = 0.84)

decreases or has no effect on BGLs			
Task 4: Determine if medication intake increases, decreases or has no effect on BGLs	0.00 (W = 0.78)	0.03 (W = 0.86)	0.04 (W = 0.88)
Task 5: Determine if weight change increases, decreases or has no effect on BGLs	0.03 (W = 0.86)	0.04 (W = 0.88)	0.04 (W = 0.88)

Since n <= 50, the Shapiro-Wilk tables were used to calculate the p-values. Since p-value < α (where α = 0.05), H_0 is rejected and since H_0 assumes that the data follows a normal distribution, the concluding hypothesis is that the difference between the data sample and the normal distribution is big enough to be statistically significant. All p-values were lower than α, meaning that the chance of type 1 error, rejecting a correct H_0, is low (less than 5%).

Since the data is not normally distributed, a One-Way Repeated Measures ANOVA significance test is inappropriate (Zimmerma and Zumbo, 1993). As an alternative for data which does not follow a normal distribution, a Friedman significance test can be performed. The Friedman test is used for one-way repeated measures analysis of variance in ranks and the median and sum of ranks is displayed in Table 5-7.

Table 5-7 Descriptive Statistics from Calculating Friedman Significance Test

	N	**Median**	**Sum of Ranks**
Radial Progress View	5	22.93	10
Change Rate Line View	5	33	15
Annotated Line View	5	12.6	5

Overall	15	22.93	

The calculation summary is:

$X^2r = (12/(nk(k+1)) * (\sum R^2) - 3n(k+1)$
$X^2r = 0.2 * 350 - 60$
$X^2r = 10$

The X^2 statistic is 10 (2, N = 5). The p-value is 0.01. The result is significant at $p<0.05$. Because the p-value for the task times of the different chart types is less than the significance level of 0.05, the null hypothesis, which assumes that at least none of the three types of charts has a different effect, is rejected. As shown in Table 5-7, the median responses for the Radial Progress View and Annotated Line View are closer to the overall median, but the median task times for the Change Rate Line View is substantially higher. These results indicate that the Annotated Line View and Radial Progress View might be more effective than the Change Rate Line View. The Change Rate Line View has the highest mean and the highest time average of all the IV techniques.

Removing the poorest performing chart, the Change Rate Line View, a Wilcoxon (MacFarland & Yates, 2018) matched pairs non-parametric test can be performed on the other two charts with a 95% confidence interval. Table 5-8 show the results of this test.

Table 5-8 Wilcoxon (MacFarland & Yates, 2018) Matched Paired Non-Parametric Test Results

Task	**Annotated Line View**	**Radial Progress View**	**Z**	**p-value**
Task 1: Determine if sleep increases, decreases or has no effect on BGLs	**18.33 (σ = 4.54)**	23.87 (σ = 8.85)	**-2.7**	**0.00**
Task 2: Determine if water consumption increases, decreases or has no effect on BGLs	**9.47 (σ = 5.38)**	22.93 (σ = 6.39)	**-3.4**	**0.00**

Task 3: Determine if kilojoule expenditure (exercise) increases, decreases or has no effect on BGLs	**14.27 (σ = 3.45)**	23.33 (σ = 7.89)	**-3.3**	**0.00**
Task 4: Determine if medication intake increases, decreases or has no effect on BGLs	**12.53 (σ = 5.50)**	15.33 (σ = 5.6)	**-2.6**	**0.00**
Task 5: Determine if weight change increases, decreases or has no effect on BGLs	**12.6 (σ = 6.37)**	15.87 (σ = 7.06)	**-2.0**	**0.02**

All five differences in task times were statistically significant, shown in bold in Table 5-8. All tasks were in favour of the Annotated Line View. The result shows that individuals were able to interpret and relay health patterns faster using the Annotated Line View, as all five tasks involved determining how BGLs are affected by a behavioral pattern. This is understandable, given that the Radial Progress View was not specifically meant to relay correlative information about the factors affecting BGLs, but unexpectedly performed better than the Change Rate Line View, which was supposed to act as an alternative to the Annotated Line View.

The IV tool efficiency was also contrasted against two other systems, MySugr (mySugr GmbH, 2012) and Diabetes:M (Sirma Medical Systems, 2021) using the tasks outlined in Table 5-3. Task times were nearly identical between MySugr and MedicMetric. On average, the tasks took participants 14.33 seconds to complete using MedicMetric, and 14.86 seconds to complete using MySugr (mySugr GmbH, 2012). It took participants an average of 42.22 seconds to complete a task using the Diabetes:M (Sirma Medical Systems, 2021) application.

In order to determine if a Wilxocon matched pairs non-parametric test could be performed on the task times, it was necessary to determine if the data follows a normal distribution. A Shapiro-Wilk test was performed on the task times and is shown in Table 5-9.

Table 5-9 Shapiro-Wilk Test for Normal Distribution in Task Times for Multiple Systems

Task	MedicMetric	MySugr
1	0.77 (W = 0.96)	0.19 (W = 0.92)
2	**0.00 (W = 0.64)**	0.36 (W = 0.94)
3	0.41 (W = 0.94)	0.88 (W = 0.97)

Since n <= 50, the Shapiro-Wilk tables were used to calculate the p-values. Since p-value > α (where α = 0.05), H_0 is accepted and since H_0 assumes that the data follows a normal distribution, the concluding hypothesis is that the difference between the data sample and the normal distribution is small enough to be statistically insignificant. All p-values (except those indicated in bold in Table 5-9) were higher than α, meaning that the chance of type 1 error, accepting a correct H_0, is low (less than 5%).

Because the data is normally distributed, a Wilcoxon matched pairs non-parametric test is inappropriate and a T-test will be performed (Kim, 2015). A T-test compares the means of two groups. The T-test compares one variable between two groups. The T-test results when performed for MedicMetric and MySugr are shown in Table 5-10.

Table 5-10 T-test results for Diabetes:M and MedicMetric Task Times

Task	MedicMetric	MySugr	t	p-value
Task 1: Looking at the charts in this application, identify any noticeable trends in the daily activities with relation to BGLs.	12.53 (σ = 4.6)	12.33 (σ = 4.95)	0.11	0.90
Task 2: Using the charts available within the application, which activities appear to negatively affect BGLs.	21.33 (σ = 15.60)	19.53 (σ = 4.37)	0.43	0.26

Task 3: Determine when BGLs are at their lowest and highest using the charts available within the application.	**9.13 (**σ =1.85)	12.73 (σ = 3.53)	**3.49**	**0.00**

By conventional criteria, the p-value for tasks 1 and 2 is < 0.05, and thus statistically insignificant. Task 3 involved identifying when BGLs were at their lowest and highest. This task was significantly faster to perform using MedicMetric charts as opposed to MySugr (mySugr GmbH, 2012) or Diabetes:M (Sirma Medical Systems, 2021).

Table 5-11 below shows the T-test results when performed on MedicMetric and Diabetes:M.

Table 5-11 T-test results for Diabetes:M and MedicMetric Task Times

Task	**MedicMetric**	**Diabetes:M**	**t**	**p-value**
Task 1: Looking at the charts in this application, identify any noticeable trends in the daily activities with relation to BGLs.	**12.53 (σ = 4.6)**	18.67 (σ = 7.25)	**-2.76**	**0.00**
Task 2: Using the charts available within the application, which activities appear to negatively affect BGLs.	21.33 (σ = 15.60)	20.86 (σ = 10.64)	0.09	0.46
Task 3: Determine when BGLs are at their lowest and highest using the charts available within the application.	**9.13 (σ =1.85)**	30.46 (σ =11.40)	**-7.15**	**0.00**

Table 5-11 indicates that there was a significant decrease in time taken to make cognitive correlations between data when using the MedicMetric application as opposed to using Diabetes:M (Sirma Medical Systems, 2021).

5.2.2.2 Satisfaction Results

Satisfaction results were obtained using questionnaires (Appendix I, J, K and M). The questionnaires captured satisfaction in terms of cognitive load and usability. A general section was also included in the questionnaire to allow the participant to note positive and negative aspects for each of the three main visualisation techniques. Participants were also asked to fill in a SUS (Appendix E) and UEQ (Appendix G) questionnaire which is discussed in Section 5.2.2.3 (Usability Results). Additional satisfaction results were captured as well as a preference questionnaire in order to determine which of the IV techniques and tools the participants preferred. This section discusses these satisfaction results.

Satisfaction results were captured on these questionnaires using a seven-point semantic differential scale, and a 5-point Likert scale. The satisfaction in the post-task questionnaire was broken down into three sections, namely cognitive load, overall satisfaction and usability.

Workload Results

The cognitive load ratings can be seen in Figure 5-2. On average the Annotated Line View was evaluated to create the least cognitive load with the lowest average mental demand of 1.06. It was also estimated by the participants to increase their performance, with the highest average performance rating of 6.4.

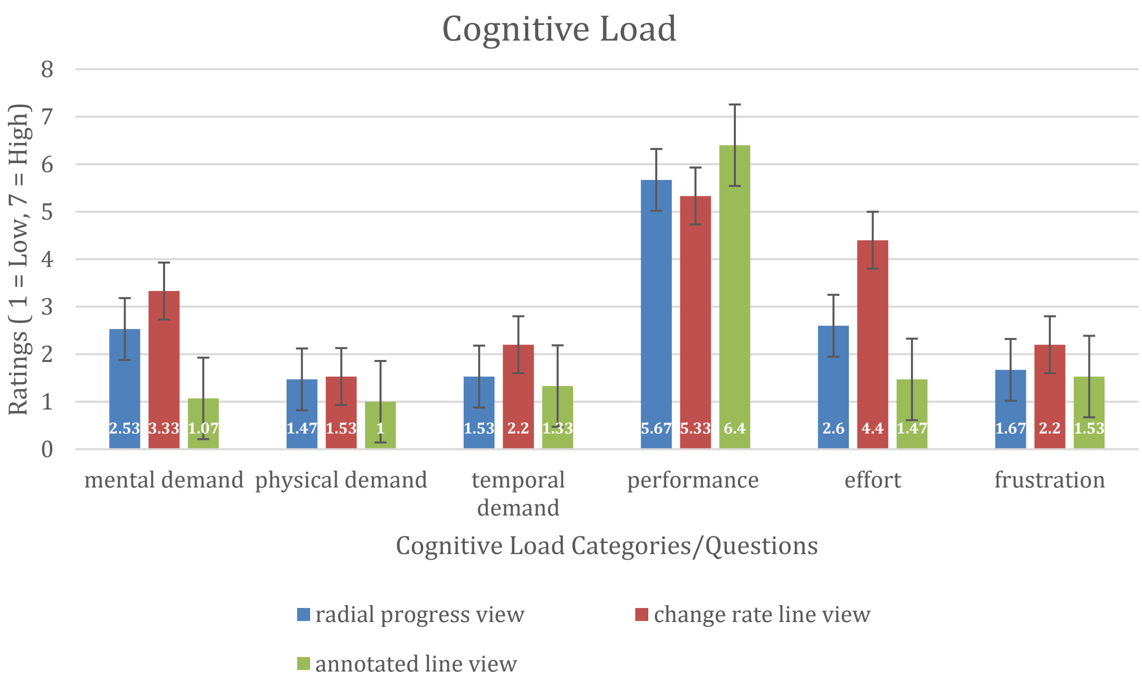


Figure 5-2 Cognitive Load Using a Seven-Point Semantic Differential Scale (n=15) with Standard Error Indicators

The Change Rate Line View performed the worst yielding the lowest performance, and the highest level of mental demand, temporal demand, effort and frustration.

Overall Satisfaction Results

The Annotated Line View received higher ratings in all four satisfaction questions. Overall, the participants found the Annotated Line View simpler, easier to use and easier to learn. Participants were significantly more satisfied with the Annotated Line View than with the alternative two charts. Figure 5-3 shows the mean values for overall satisfaction.

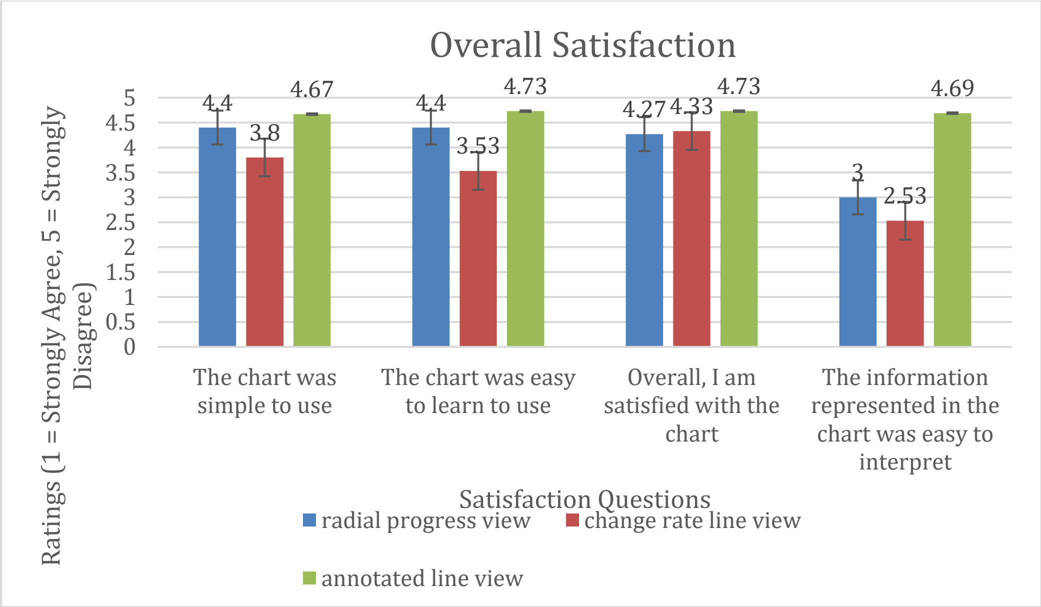


Figure 5-3 Overall Satisfaction Using a Five-Point Likert Scale (n=15) with Standard Error Indicators

Usability Results

The SUS questionnaire was used to evaluate the usability of MedicMetric (Appendix E). This questionnaire can be used to yield a single value which represents a composite measure of overall usability (Brooke, 1996). The SUS questionnaire is made up of 10 standard questions. In order to calculate the total SUS score, all odd questions are added up and 5 is subtracted from the total to calculate X. The even numbered questions are then added and the total is subtracted from 25 to calculate Y. X and Y are then added and multiplied by 2.5 to yield an overall SUS score.

The Radial Progress View yielded a SUS score of 83.33. The Abbitated Line View yielded a SUS score of 92.65, but the Change Rate Line View yielded a SUS score of 66.55. In order for an application to have acceptable usability, the final score should be greater than 68. The usability ratings were in favour of the Annotated Line View.

Figure 5-4 illustrates the mean values for the usability ratings for the fifteen questions. Participants perceived that they could effectively and efficiently identify factors affecting their BGLs using the Annotated Line View best. Despite the fact that the overall effectiveness of all three IV techniques was good, the perception that the participants could effectively and efficiently find the information that they were looking for using this IV technique, supports the efficiency results that identifying health patterns using the Annotated Line View was significantly faster than using the other two views.

Generally, participants preferred the Annotated Line View when trying to interpret their data. This supports the related work in which the type of data structure to be visualized determined the IV technique to be used for viewing correlative information like BGLs and the factors affecting them (Shneiderman 1996).

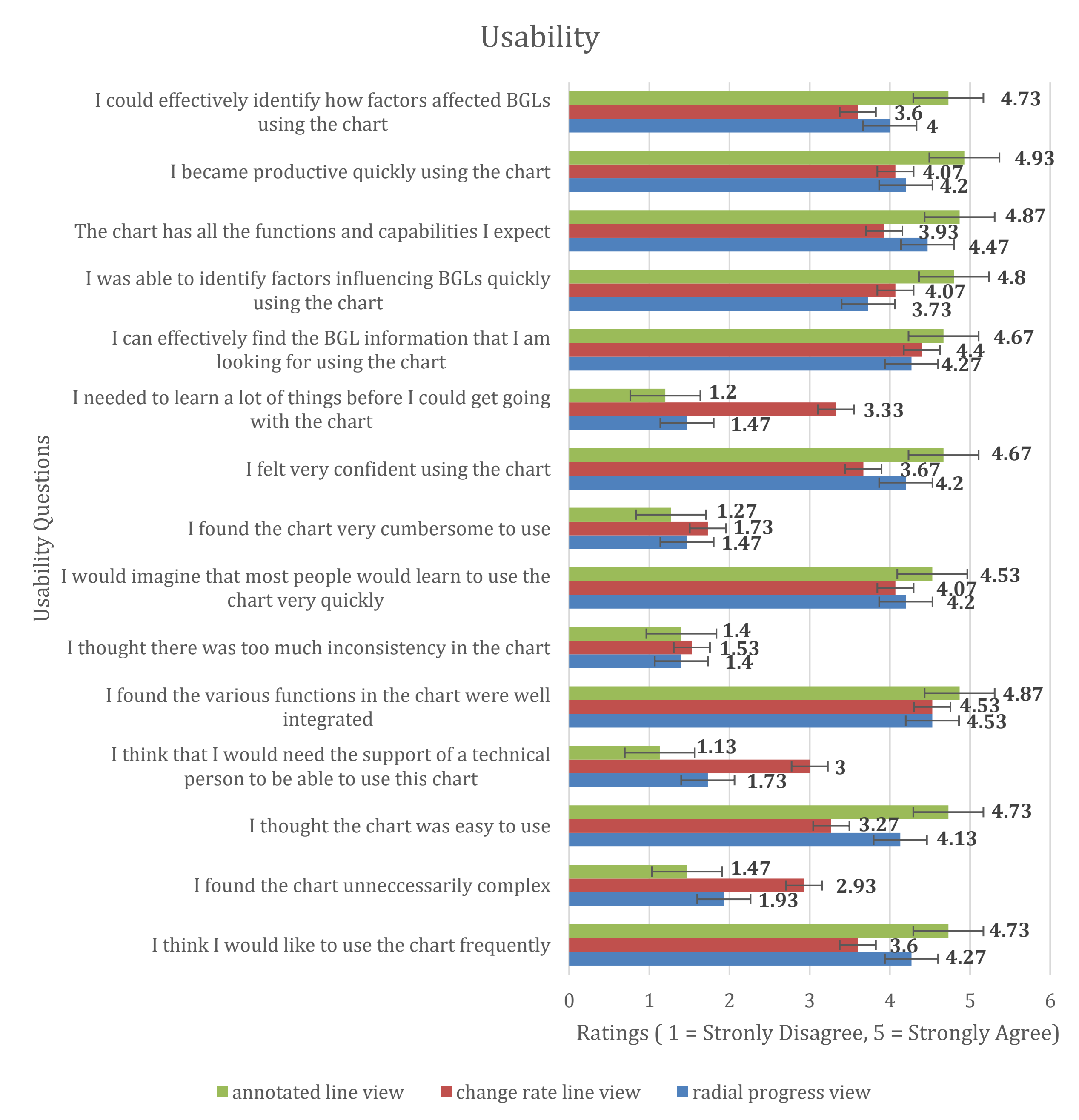


Figure 5-4 Usability using a 5-point Likert Scale (n=15) with Standard Error Indicators

Participants were also generally very positive when providing feedback about the visualisations. Participants were asked to make a note of the most positive and most negative aspects of each of the three visualisation techniques. The positive comments regarding the Annotated Line View are shown in Table 5-12, where n (n>1) represents the number of participants who made similar statements. Four participants noted that this IV technique was the easiest to interpret and the most useable, while two noted that it was nice to not have to filter the chart before using it to interpret data. Other participants noted that the chart was clear and concise about the BGL data and that the chart was not cluttered. One participant also noted that the BGL limit lines on the graph were useful for knowing when their BGLs would be elevated beyond the normal range.

Table 5-12 Annotated Line View: Most Positive Aspects

Annotated Line View: Most Positive Aspects		
#	**Description**	**N**
1	This chart was the easiest to use as it was the most user-friendly.	4
2	The events on the chart made it very easy to relate data to the BGLs	2
3	No filters need to be applied in order to view BGLs throughout the day, so it’s the easiest to use for that purpose.	2
4	This chart is concise, clear and more focused on the effects that factors have directly on BGLs.	1
5	It’s useful to see the limits that the BGLs must stay between. It’s a great indicator for when you aren’t doing something healthy.	1
6	The chart was not cluttered and made good use of the small screen space used.	1
7	This is a great chart for looking at what happened over a full day	1

The most notable negative aspect of the Annotated Line View was its colouring, with three participants noting that the events indicated on the chart would obscure out the colour of the line indicating the BGLs. This can be seen in Table 5-13. One participant noted that the chart was difficult to read because the times were too small, however, this participant opted to do the evaluation online, and the screen size may have been smaller than a normal laptop screen.

Table 5-13 Annotated Line View: Most Negative Aspects

Annotated Line View: Most Negative Aspects		
#	**Description**	**N**
1	The blue background markers used to indicate when events like sleep, water intake or exercise occurred, obscure out the line which displays BGLs.	3
2	The x-axis of the chart displaying time was quite small and difficult to read.	1
3	A legend for what the background markers mean would be nice to be able to see, even though the event is written directly on the chart.	1

The positive comments related to the Change Rate Line View are shown in Table 5-14. Participants noted that the chart was easier to interpret once it was explained to them how it worked. They enjoyed looking at the trend information and figuring out what caused problems with their BGLs.

Table 5-14 Change Rate Line View: Most Positive Aspects

Change Rate Line View: Most Positive Aspects		
#	**Description**	**N**
1	This chart was great for working out what the cause of a BGL problem could be	2
2	The trends were interesting and showed a direct correlation between the data represented	2
3	It was easy to use and understand once it was explained to me	2
4	Using the trend information, the data is quick to interpret and everything I would need to see is there	1

The most negative aspects of the Change Rate Line View are shown in Table 5-15. Participants generally felt that the chart was cluttered and that it was very difficult to tell the lines on the chart apart, despite the fact that the lines had both colour and shape differences to indicate the individual data groups. Three participants also noted that the chart had the highest learning curve of the three charts that they were asked to use. One participant pointed out that the kilojoule expenditure was cumulative and suggested that as an alternative the difference could be calculated hourly so that the normalized data would be able to show the trend better.

Table 5-15 Change Rate Line View: Most Negative Aspects

Change Rate Line View: Most Negative Aspects		
#	**Description**	**N**
1	The colours of the different lines are too similar, even though they have shapes to help differentiate them	4
2	This chart has the highest learning curve out of the charts that were used	3
3	This chart is cluttered when you first navigate to it, but once filtered it looks nice.	3
4	This chart displays less variables than the other two. I'd like to be able to see the effects of sleep in this chart too	1

The most positive aspects of the Radial Progress View are shown in Table 5-16. The most positive aspects of the Radial Progress View were that it was the easiest to intuitively learn how to use. Five participants noted that this chart could help them reach their goals easier.

Table 5-16 Radial Progress View: Most Positive Aspects

Radial Progress View: Most Positive Aspects		
#	**Description**	**N**
1	This chart showed a lot of information but was the quickest and easiest to interpret	6
2	This chart would help me to reach my goals the best as it highlights correct behavior and sets the goal for you.	5

3	I could find the information I needed quickest using this chart	1
4	The tooltip was very useful	1
5	It is very aesthetically pleasing	1

The most negative aspects of the Radial Progress View are shown in Table 5-17. The most notable negative aspects of the Radial Progress View were its lack of configurability (participants wanted to be able to set their own goals), its curvature causing difficulty reading headings, and how crowded it looked when participants initially navigated to it in the weekly view.

Table 5-17 Radial Progress View: Most Negative Aspects

Radial Progress View: Most Negative Aspects		
#	**Description**	**N**
1	It wasn’t easy to be able to tell what the goals were set as. I’d like to be able to set them myself	2
2	It looked too crowded in the weekly view	2
3	Because the chart is curved, it’s harder to follow the bar backward to see it’s label	2
4	The slant of the graph made it difficult to tell if variables had the same value but just at an angle, or if the outer one was greater than the inner one	1
5	The time wasn’t formatted correctly on this chart	1
6	The goals cannot be changed so it might be difficult for older individuals to meet a goal like burning a certain number of kilojoules throughout the day	1
7	This chart guilts you into doing the right thing	1
8	The colours are very similar	1

Post-Test Satisfaction Results

The post-test satisfaction results are shown in Figure 5-5. The post-test satisfaction questionnaire captured results by asking participants which of the three charts they preferred in different scenarios.

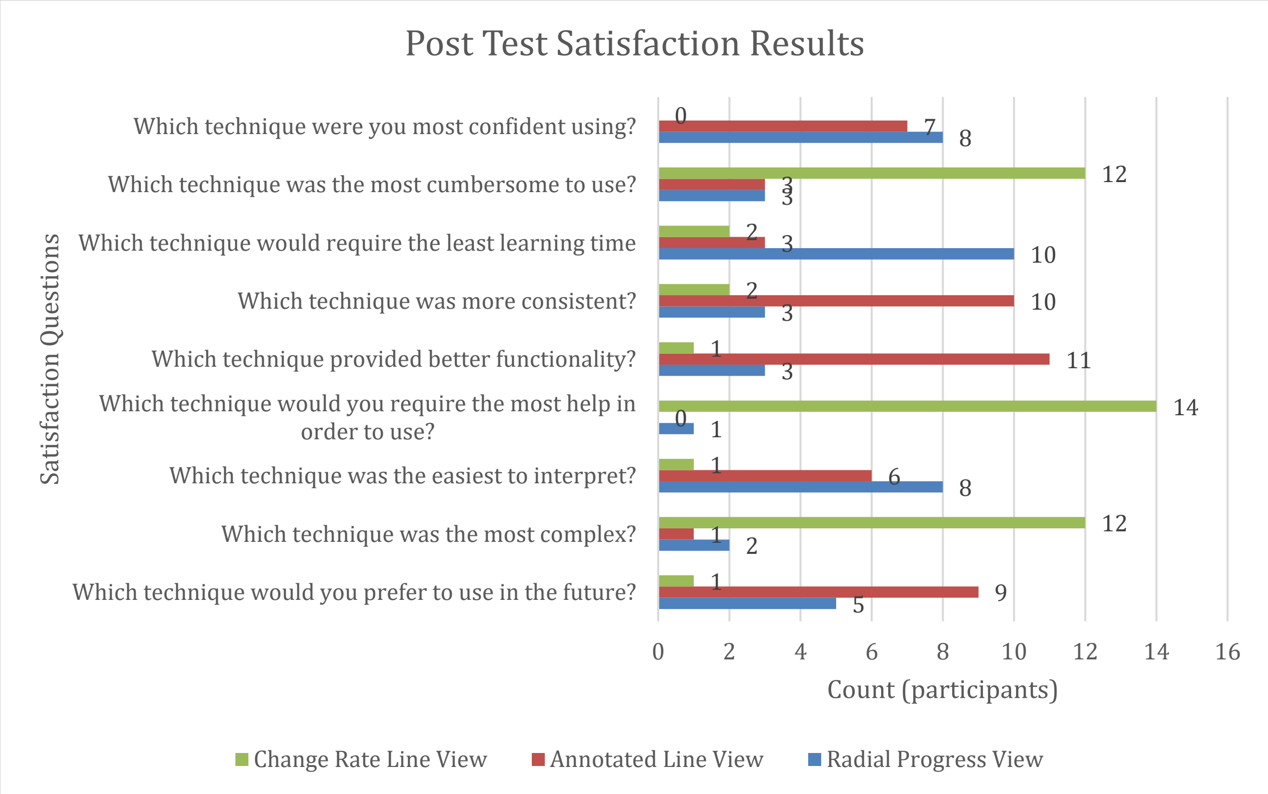


Figure 5-5 Post-Test Satisfaction Results (n-=15)

Nine out of fifteen participants indicated that they would prefer to use the Annotated Line View in future. Eleven out of fifteen indicated that they felt the advanced timeline chart provided the best functionality, and ten of the fifteen participants indicated that the advanced timeline chart was the most consistent.

It can also be noted from Figure 5-6 that the Change Rate Line View was indicated to be the most complex by twelve of the fifteen participants, and fourteen of the fifteen participants stated that they would require the most help in order to make use of this IV technique. Twelve noted that it was the most cumbersome to use.

The Radial Progress View scored highest in ease of use with ten participants indicating that it required the least learning time, and eight indicating that it was the easiest to interpret.

5.2.3 Discussion

From the results it can be concluded that the advanced timeline chart was the preferred method used to visualize the effect that variables like water consumption and exercise may have on BGLs. The effectiveness results supported all three IV techniques. Even though the times taken to complete tasks using the Change Rate Line View were the worst over all, the effectiveness scores were still very high. The satisfaction scores were also relatively high for all three charts, but the Change Rate Line View had the worst satisfaction review overall.

In effectiveness and efficiency MedicMetric and MySugr obtained almost identical results. However, participants estimated that MedicMetric supported their tasks using the VISM the best overall, with 100% of participants stating that they would prefer to use the MedicMetric application.

In addition to using the questionnaires to determine the efficiency and effectiveness of the application, they were also used to determine if there were any identifiable usability issues, which needed to be addressed. The following usability problems were identified and addressed shortly after the study:

- Chart colouring is not conducive to clear data interpretation as it can distract from more important information.
- Formatting issues discovered in the x-axis time line.
- Crowded charts are difficult to read and filters should be applied initially to reduce the amount of data shown.

Suggestions for improvements for the charts in future include the following:

- Allow users to dynamically set their own goals using the application so that the Radial Progress View will not penalize a participant incapable of meeting one or more goals.
- The chart view should be editable so that when participants are navigating through the IV tool, they are able to move the most important charts to the top and access them more quickly.
- Heart-rate could be included as a parameter, which is mapped in the IV tool, as stress is also a factor which can affect BGLs.

This study was significantly hindered by Covid19 restrictions and safety regulations around high-risk individuals like those who have T2DM. As a result, not all participants who evaluated the system have T2DM, but are working professionals in the health field or are close to someone who could benefit from using a system like MedicMetric.

Additional limitations were that due to new POPI regulations, participants who make use of MCGMs were not contactable for use in the study. For this reason individuals who made use of the system for one week, either exported their data directly to the investigator so that it could be uploaded at the end of each day, or used an alternative CGM and inputted their BGLs into the IV tool so that the data could be visualized. This means that the IV tool did not act as a real time data analysis tool as intended, even though it was designed as such.

5.2.4 Modifications

Modifications were implemented for MedicMetric following the results of the evaluation. The usability problems were addressed as follows:

- **Chart colouring is not conducive to clear data interpretation as it can distract from more important information**

  Multiple participants indicated that the Annotated Line View had event indicators which were similar blue colours to the BGL line plotted across the axes. It was also noted that the Change Rate Line View had multiple very similar coloured lines, making it confusing to tell variables apart. As a result of this, the lines were re-coloured using orange for the Annotated Line View, and orange, blue and purple for the Change Rate Line View. Colours like green and red were avoided to rule out problems that could arise for individuals with red-green colour blindness. For these reasons, all charts were re-coloured to more appropriate colouring in order to make the information more visible and to reduce cognition required to interpret the colours. Figure 5-6 and Figure 5-7 show the re-coloured charts.

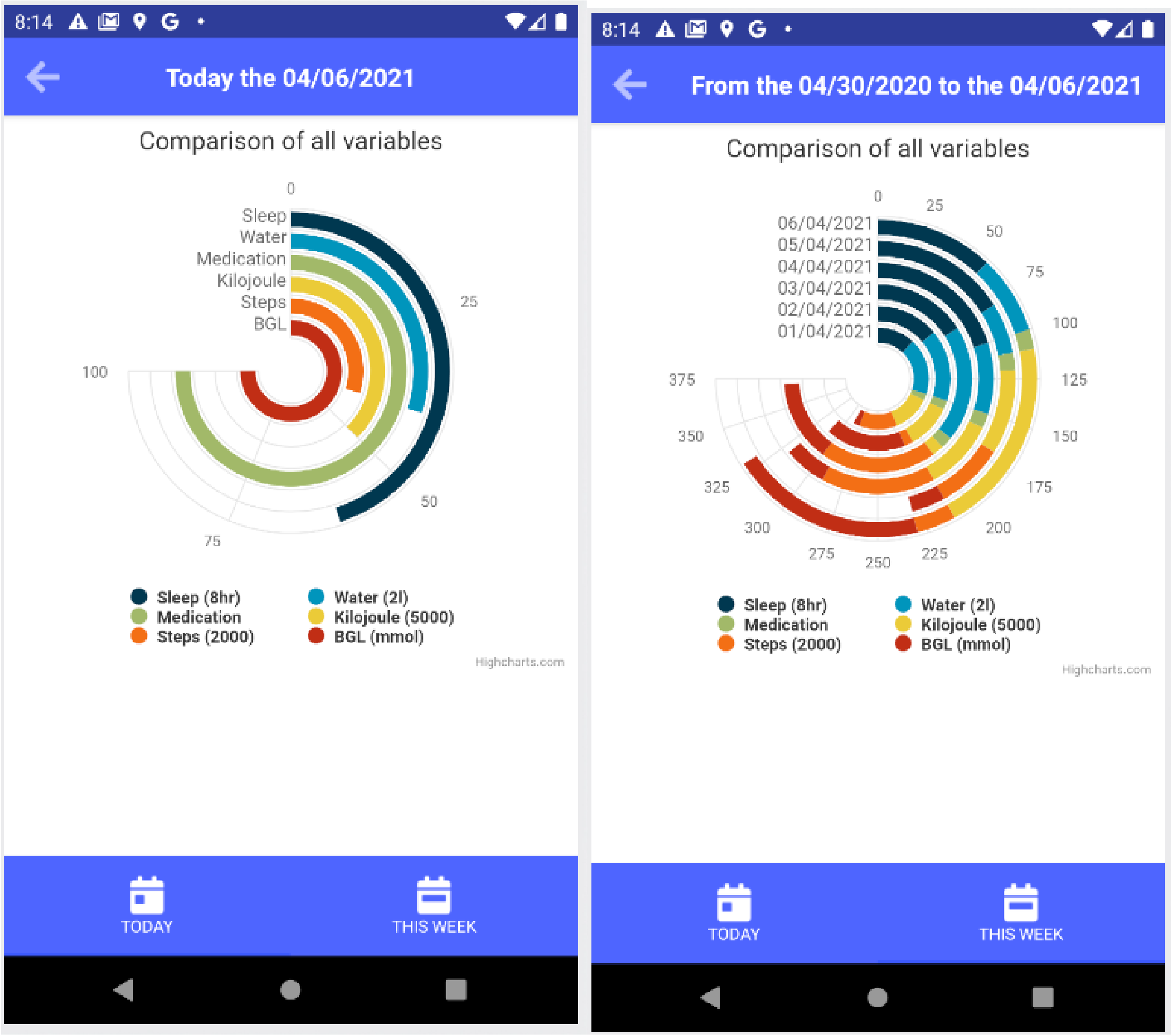


Figure 5-6 Re-coloured Radial Progress View

Figure 5-7 Old vs New Colouring for the Annotated Line View

- **Formatting issues discovered in the x-axis time line**
  One user identified that the times along the x-axis were written incorrectly. Instead of 06:00 to indicate 6AM, 00:06 was written on the axis. This was fixed by formatting the date correctly before rendering the chart.
- **Crowded charts are difficult to read and filters should be applied initially to reduce the amount of data shown.**
  The Change Rate Line View (Figure 5-8) was over crowded once opened as it contained four similar coloured lines over-top of each other. Each point on the chart also had a shape in order to help differentiate the lines. The shapes were removed and the chart was recoloured in order to reduce the amount of clutter present on the screen.

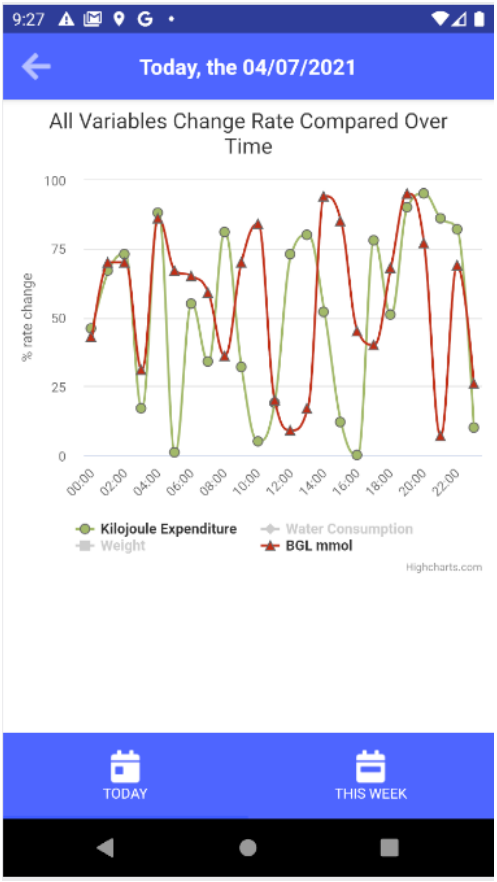


Figure 5-8 Default Filter Configuration and Altered Colours for the Change Rate Line View

5.3 Conclusion

A usability evaluation was conducted with fifteen participants to compare three core IV techniques, and three IV tools, which can support interpretation of the effects that different variables can have on BGLs. Participants were required to complete a series of tasks using each IV technique and each IV tool. The main result of the evaluation was that participants preferred the advanced timeline chart IV technique. The Change Rate Line View provided no advantages over either of the other two techniques used, and despite the fact that the Radial Progress View isn't effective at representing time series data, it performed better in effectiveness, efficiency, usability, satisfaction and cognitive load than the Change Rate Line View, with the advanced timeline chart performing the best overall.

Certain usability problems were identified. The similar colouring used in the charts and data formatting problems were addressed in a newer version of the IV tool. This chapter also answered the fifth research question identified in Chapter 1: *How effective are the identified IV techniques in supporting self-management of T2DM?*

Chapter 6 will address the conclusions of this study, as well as a review of the research objectives and research achievements.

6 Conclusions

6.1 Introduction

The aim of this research was to investigate the effectiveness of IV techniques to support the self-management of T2DM. Problems with existing T2DM self-management tools were identified and a proposal of a new design was created in order to overcome the shortfalls of existing systems. Appropriate IV techniques were identified and applied to a new IV tool for self-management of T2DM. A usability study was conducted in order to determine the effectiveness of the developed tools and to gauge whether it's IV techniques were adequate for the interpretation of the intended data.

This chapter concludes the research and provides a summary of the findings. An outline of the contributions of the work and the limits of the research are described in detail. The chapter ends with problems that were encountered and suggestions for future work and continued research.

6.2 Achievements of Research Objectives

This section will revisit the research objectives defined in Chapter 1 and discuss the achievements of the research in terms of those objectives.

6.2.1 Review of Research Objectives

The problem statement for this research, identified in Chapter 1, is as follows:

There is a lack of effective information visualisation tools that can be used to support the self-management of DM.

The main research objective for this research, which was identified in Chapter 1, is as follows:

To develop a tool using IV techniques to support effective self-management of DM.

The sub-objectives of this research, which were used to address the main research objective, were as follows:

- RO1: Identify existing problems with self-management of DM.
- RO2: Identify health patterns for patients with DM.

- RO3: Identify possible IV techniques that can be used to support self-management of DM
- RO4: Design an IV tool to aid in self-management of DM.
- RO5: Evaluate the effectiveness of the developed tool.

The extent to which these research objectives were met is discussed in the next section.

6.2.2 Research Achievements

This research has shown that IV can be used successfully to support the self-management of T2DM through positive change affecting data interpretation. This outcome was determined by addressing the above-mentioned research objectives.

The first research question was addressed in Chapter 2. DM was discussed at length and the factors which contribute to exacerbating it. This was done in order to gain insight into the problem domain. Extant systems were investigated and shortfalls for each were discovered. The result of this yielded multiple problems due to lengthy user inputs and lack of graphically intuitive displays. The use of these extant IV tools did not direct focus on the presentation of T2DM data and did not contribute to connections between relevant T2DM data. It was discovered that the responsibility of care for the disease was placed mostly on the patient and can lead to many problems. Patients may not follow sufficient diet plans, remember to take medications or understand the link between sleep, diet, exercise and medication consumption to their fluctuating BGLs and potentially worsening DM. The first research question, '*What are the existing problems with self-management in DM patients?*', was answered by conducting a thorough analysis of existing systems and their short falls.

The second research question was also addressed in Chapter 2. Gordons Functional Health Patterns were discussed in Section 2.5.1. These health patterns provide a useful framework for assessing the factors which influence drug response and impact compliance, as well as successful outcomes of drug therapy. DM health patterns were discussed and outlined in Section 2.5.2. While Gordons Functional Health Patterns are not specific to DM, they can offer a quick diagnosis of problems resulting from DM. In a similar manner, patterns were observed for DM. Patient health can be affected by tailoring behaviours according to those patterns. This section thus achieved research objective, namely: '*Identify health patterns for patients with DM.'*

The use of health patterns in medicine is not a new concept and has been utilized previously in the form of GFHP's for diagnostic purposes. Health patterns in DM were identified and can be useful in developing a cognitive awareness of the connections existing between BGLs and variables like sleep patterns, blood pressure, medication intake, food intake and exercise plans. This discovery thus answers the second research question: '*How can existing health patterns be used to improve self-management of DM?'*

Chapter 3 aimed to address the third research question, namely '*What possible IV techniques could be used to support the self-management of DM?'*

Suitable IV techniques were identified by determining the type of data that required visualisation. The applications analyzed in Chapter 2 as existing systems typically made use of tables, pie and bar charts. But it was identified that DM data, in large part, is a form of time series data that can be visualized in numerous ways, as identified in Section 3.7.4.

Requirements of the IV for DM data was proposed according to the functionality identified in Section 2.7 and 3.10, and the tasks defined by the VISM. The user tasks that should require support by the system included overview, zoom, details-on-demand, filter, relate, history and extract tasks.

Chapter 4 aimed to answer the fourth research question identified in Chapter 1, namely '*How can IV techniques be applied to support self-management of DM?'*

In the design process, a method for acquiring test data was discovered through the use of the Fitbit and Dexcom APIs. The visualisations, which were designed, made use of relevant IV techniques. It was discovered that IV techniques can be applied to support the self-management of DM by helping to refine new IV designs, which reduce the cognition required to retrieve and interpret useful data from a visualisation. The most useful IV techniques were used to create and evaluate, through three design iterations, a new set of visualisations, which could be used in the implemented application.
In the implementation section, Highcharts (Usman, 2022) was selected as the library to be used to create the visualisations as it easily rendered aesthetically pleasing charts, which are most similar to the designed ones. The implemented screens were reviewed and explained for elaboration purposes.

Chapter 5 aimed to answer the fifth research question identified in Chapter 1, namely '*How effective are the identified IV techniques in supporting self-management of T2DM?'*

A usability evaluation was conducted with fifteen participants to compare three core IV techniques, and three IV tools, which can support interpretation of the effects that different variables can have on BGLs. Participants were required to complete a series of tasks using each IV technique and each IV tool. The main result of the evaluation was that participants preferred the advanced timeline chart IV technique. The Change Rate Line View provided no advantages over either of the other two techniques used, and despite the fact that the Radial Progress View isn't effective at representing time series data, it performed better in effectiveness, efficiency, usability, satisfaction and cognitive load than the Change Rate Line View, with the advanced timeline chart performing the best overall.

For all tasks, which were supported by the visual information-seeking mantra, participants were required to answer a question or identify a piece of information relating to the task. These tasks were identified in Section 5.2.1.6 in Table 5-1, Table 5-2 and Table 5-3. Effectiveness was measured as the percentage of correct answers to the questions for each task.

Tasks detailed in Table 5-1, which were designed to evaluate the three main IV techniques (the advanced timeline chart, the Change Rate Line View and the Radial Progress View) developed as part of the prototype as a whole, received 100% success rate, except for three tasks. Two tasks in the Change Rate Line View and one task for the advanced timeline chart did not receive 100% success rate. The two tasks for the Change Rate Line View received 86.67% (Task 7) and 80% (Task 8), and the task for the advanced timeline chart received 80% (Task 12) success rate. In general, users found it more difficult to identify information accurately using the Change Rate Line View. All three of these tasks produced a high level of accuracy despite having the lowest success rates, and it can be concluded that all three visualisation techniques effectively supported the users' tasks.

Tasks detailed in Table 5-2, which were designed to directly compare the three main IV techniques developed as part of the prototype, received varying success rates. Task 1 was completed with an 80% success rate, Task 2 with 82.22% success rate, Task 3 with 77.78% success rate, Task 4 with 86.67% success rate and Task 5 with 93.33% success rate. Task 3 and 5 asked participants to determine if exercise and weight, respectively, have any effect on BGLs according to the charts. Breaking the above task success rate down by which chart was used to complete all five tasks, participants had a 71.11% success rate when using the Change Rate Line View, an 80% success rate when using the Radial Progress View, and a 96% success rate when using the advanced timeline chart. Thus, it can be concluded that the most effective chart at supporting the user's interpretation of correlations between affecting factors and BGLs is the advanced timeline chart, and the least effective at supporting the user's interpretation of correlations between affecting factors and BGLs is the Change Rate Line View.

Tasks detailed in Table 5-3, which were designed to compare two existing applications for self-management of T2DM to MedicMetric in terms of efficiency when interpreting data, resulted in identical success rates between MySugr (mySugr GmbH, 2012) and MedicMetric. Participants answered the task questions while looking at MedicMetric and MySugr correctly 86.67% of the time, but only answered correctly while using Diabetes:M (Sirma Medical Systems, 2021) 42.22% of the time. This is possibly due to the navigation mechanisms used in Diabetes:M (Sirma Medical Systems, 2021), which multiple participants noted were confusing.

In effectiveness and efficiency MedicMetric and MySugr obtained almost identical results. However, participants estimated that MedicMetric supported their tasks using the VISM the best overall, with 100% of participants stating that they would prefer to use the MedicMetric application.

Participants were asked to identify whether or not sleep (Task 1), water consumption (Task 2), exercise (Task 3), medicine (Task 4) and weight (Task 5) had an effect on BGLs as shown in Table 5-2. They were asked all three questions while looking at the Radial Progress View, the advanced timeline chart and the Change Rate Line View.

Participants correctly identified the effects that water consumption, kilojoule expenditure and medication and weight have on BGLs 100% of the time using the advanced timeline chart but could only correctly interpret the data concerning sleep 80% of the time. Participants could correctly identify health patterns in a similar way 71.11% of the time using the Change Rate Line View, and 80% of the time using the Radial Progress View. The gauge chart is meant to be used to determine how close to a particular goal a participant is, but it proved effective (using its weekly view) in providing an alternative chart for interpreting relations between the factors affecting BGLs, and BGLs.

Removing the poorest performing chart, the Change Rate Line View, a Wilcoxon (MacFarland & Yates, 2018) matched pairs non-parametric test was performed on the other two charts, with a 95% confidence interval.

Four of the five differences in task times were statistically significant, as shown in bold in Table 5-8. All four tasks were in favour of the advanced timeline chart and the remaining task was not statistically significant. The result shows that individuals were able to interpret and relay health patterns faster using the advanced timeline chart than the two alternatives developed, as all five tasks involved determining how BGL is affected by a behavioral pattern.

This result is understandable, given that the radial gauge chart was not specifically meant to relay correlative information about the factors affecting BGLs, but unexpectedly performed better than the Change Rate Line View, which was supposed to act as an alternative to the Annotated Line View.

Certain usability problems were identified. The similar colouring used in the charts and data formatting problems were addressed in a newer version of the IV tool. This chapter also answered the fifth research question identified in Chapter 1: *How effective are the identified IV techniques in supporting self-management of T2DM?*

6.2.3 Summary

This research supported the research objectives defined in Chapter 1. The participants of the usability study showed that the developed IV tool is effective at reducing the cognition required to interpret their BGL data, and showed that they would prefer using such an IV tool if it were available to them in order to better manage their T2DM and personal goals. This result supports the problem statement that IV techniques can be used to support the self-management of T2DM.

The research achievements include the following:

- Identification of several problems with existing T2DM management systems.
- Outlining the criteria for a new IV tool which can address the problems with extant systems.
- Defining IV requirements for self-management of T2DM.
- Selection of the most appropriate IV technique for visualizing T2DM data.
- Development of a prototype tool for interactive visualisation of T2DM data.
- Determining the usefulness of using IV techniques to support the self-management of T2DM.
- Identification of multiple potential IV techniques to support the self-management of T2DM.

- Future design recommendations when using IV techniques to support the self-management of T2DM.

6.3 Summary of Contributions

The contributions of this research are discussed in terms of the theoretical and practical contributions which were made. The theoretical contributions relate to the general use of IV to support the self-management of T2DM. The practical contributions relate to the implementation of the IV techniques identified.

6.3.1 Theoretical Contribution

Several theoretical contributions were made by this research. The problem statement was supported because it was shown that IV techniques can be used to effectively support the self-management of T2DM. Criteria were identified in Chapter 3 that can be used to compare the different methods of self-management of T2DM in order to determine which IV techniques provide the most support for effective self-management. Requirements for the self-management of T2DM were determined by using the VISM. This can assist in future work involving IV techniques for self-management of T2DM.

Finally, general future design recommendations for using the IV techniques researched here were proposed. One of the greater suggestions made, was those goals for individuals using the IV techniques should be editable. The charts should provide some level of user configuration and filter should be auto applied to minimize initial information shown to the users.

6.3.2 Practical Contribution

The practical contribution of this research includes the IV techniques, which were designed and implemented in MedicMetric. Three IV techniques were implemented in MedicMetric supporting the IV requirements for self-management of T2DM identified in Chapter 3. Most of the participants in the usability evaluation preferred using the advanced timeline chart in all categories in which it was evaluated.

Results of the usability evaluations provide a practical contribution as other researchers can use these results for comparison purposes. MedicMetric was developed as a tool for self-managing T2DM using interactive visualisations. MedicMetric can be used to incorporate more IV techniques for future work.

6.4 Limitations and Problems Encountered

Limitations include the fact that only sandbox data could be used during online and in person interviews as the evaluations were done during a peak wave of Covid19. This meant that interactions with individuals with T2DM could prove to be a major health risk for the participants. As a result of this, not all participants in the evaluations had T2DM, or were capable of measuring their BGLs to constantly input them into the IV tool.

Due to POPI restrictions, BGL data generated by the Medtronic CGMs was unobtainable, and sandbox data also needed to be used in order to develop the application. An alternative API, the Dexcom API, which was identified in Chapter 3, was also only available within the US; for this reason, it could not be used within the application but is recommended for future research.

6.5 Future Research

In addition to the design recommendations made in Chapter 5, future work is possible with MedicMetric. Due to the ubiquitous nature of computing today, it may be possible that an alternative to the Dexcom API or Medtronic CGM may soon become available, and it would be possible to integrate them into MedicMetric. This would generate a real-time application, capable of constantly displaying BGL data to the user. It could be possible to conduct a further study in collaboration with industry in order to evaluate this system in such an environment.

MedicMetric could be extended to enhance the features that it currently supports. With new advancements in machine learning predictions, it could be possible to incorporate prediction trend analysis so that individuals are capable of understanding how their BGLs may continue to rise or fall based on their current behavior patterns. MedicMetric could also be repurposed and used to represent more than BGL information.

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Appendices

Appendix A: Information Sheet Provided to Participants (Oral/ Written)

The following information sheet was read to participants before they agreed to participate in order to supply them with the relevant information about the study and core details.

Information Sheet

Introduction

I am Meggan Naude, conducting my research through the tertiary study institution, Nelson Mandela University. I am doing research on Information Visualisation (IV) and its usefulness for aiding the process of self-managing diabetes mellitus (DM), which is very common in this country. I am going to give you, the potential participant, information and invite you to be part of this research.

Purpose of Research

Diabetes Mellitus (DM) is the leading cause of death in South Africa. Type 2 DM is also widely-held to be a self-managed disease. A lot of the factors influencing recovery or decline in health with DM are self-managed, like the intake of medications, exercise, diet, stress and sleep. Information Visualisation (IV) is the representation of complex data in non-traditional, graphical formats. Few tools have been discovered regarding the application of IV to the self-management of DM. This research will investigate how IV can be applied to create an effective tool to support the process of self-management of DM. The aim of the research is to improve the presentation of variables strongly associated with of DM to support DM patients. This could in turn lead to a cause-and-effect awareness for DM patients and allow them to self-manage their DM more effectively.

Type of Research Intervention

This research will involve the use of a continuous glucose monitor, the Medtronic CGM, which the participants are already equipped with, or an alternative BGL testing device, which the participant already makes use of. Participants will also be requested to make use of Fitbit devices (the Fitbit Charge 2 and Fitbit Aria) and install a mobile application (the IV tool) on their smartphone. The application must remain on their smartphone for the full duration of the study. The Fitbit Charge 2 must be worn throughout the duration of the study. I will request that participants make use of the mobile application daily by performing tasks. Participants will also be asked to make use of the Fitbit Aria twice daily. After the duration of the study, which will be 3 weeks, I will request that participants fill in a questionnaire.

Alternatively, participants with Type 2 DM can opt to do a one-day participation study in which they evaluate the system in a similar manner, and provide honest feedback about whether they believe the application could prove useful to them or not. This will be used solely to evaluate the effectiveness of the visualisations and not the system as a whole tool.

Participant Selection

I am inviting all adults with DM, a Medtronic CGM (and a medical practitioner familiar with their case) or an alternative BGL measuring device, and smartphone to participate in the research on the use of IV to support the self-management of DM.

Voluntary Participation

Participation in this research is entirely voluntary. It is the participants' choice whether to participate or not. Whether participants choose to participate or not, all the services they receive at the institute they were selected from will continue and nothing will change. If they choose not to participate in this research project, they will be offered the treatment that is routinely offered in the institute that they were selected from. Participants may change their mind later and stop participating even if they agreed earlier.

Procedures and Protocol

All participants will be provided with the same IV tool to utilize and a secondary mobile application for tracking DM data. Participants will be asked at the completion of the study a series of questions, pertaining to the usefulness of the application and its ease of use, and a comparison will be done between the IV tool provided in the form of an application and two alternative management tools, which already exist. This is the best way that the PI has for testing without being influenced by what she thinks, or hopes, might happen.

Device Loans

All devices given to participants for use, including any Fitbit device, is property of Nelson Mandela University. By agreeing to be part of the study, participants are also agreeing to take full responsibility of the Fitbit devices with which they are provided and its protection. Upon the completion of the study, the Fitbits must be returned to the PI in the same condition that they were loaned to the participant.

Risks

There will be no added risk introduced using the Fitbit devices or mobile application with which the participants are provided. The application information DOES NOT serve as medical advice; the visualisations are to be used for interpretation reasons only, and any opinions formed should not be used as a form of further treatment.

Benefits

There may not be any personal benefit for participants, but participation is likely to help the PI find the answer to her main research question. There may not be any benefit to the society at this stage of the research, but future generations are likely to benefit.

Re-imbursements

Participation is free. No monetary or other imbursements will be given for participation.

Confidentiality

The identity of those participating in the research will not be shared. The information that the PI collects from this research project will be kept confidential. Information about participants that will be collected during the research will be stored and no-one, but the researchers will be able to see it. Any information about participants will have a number on it instead of names. Only the PI will know what the participant numbers are. This will not be shared with or given to anyone.

Sharing the Results

The knowledge that is obtained by doing this research will be shared with participants upon completion of the study. Confidential information will not be shared. After the study has been completed, the results will be published for other interested people to learn from the research.

Again, no personal information or information that could plausibly lead to participant identification will be shared in the published document.

Refuse or Withdrawal

Participants do not have to take part in this research if they do not wish to do so. They may also stop participating in the research at any time they choose.

Alternatives to Participating

If participants do not wish to take part in the research, they will be provided with the established standard treatment available at the center/institute/hospital from which they were selected.

Contact Information

If participants have any questions, they may ask them at any point before or during the research study has taken place of the following individuals:

Miss Meggan Naude e-mail: s213203510@mandela.ac.za

This proposal has been reviewed and approved by the Nelson Mandela University Research Ethics Committee (with reference number H 18 SCI CSS 007) - Human (REC-H), which is a committee whose task it is to make sure that research participants are protected from harm. If participants wish to find about more about the REC-H, they can freely view the information publicly available at:

http://rcd.mandela.ac.za/Research-Ethics/Research-Ethics-Committee-Human-(REC-H)

Appendix B: Consent Form

NELSON MANDELA METROPOLITAN UNIVERSITY

INFORMATION AND INFORMED CONSENT FORM

RESEARCHER'S DETAILS	
Title of the research project	Using Information Visualisation to Support the Self-Management of Type 2 Diabetes Mellitus
Reference number	H 18 SCI CSS 007
Principal investigator	Meggan Kate Naude
Address	31 Melan, Montmedy Road, Gqeberha
Postal Code	6070
Contact telephone number	(+27) 76 284 2535

DECLARATION BY OR ON BEHALF OF PARTICIPANT		Initial
I, the participant and the undersigned		
ID number		
OR		
I, in my capacity as		
of the participant		
ID number		
Address (of participant)		

HEREBY CONFIRM AS FOLLOWS:		**Initial**
I, the participant, was invited to participate in the above-mentioned research project		
that is being undertaken by	**Meggan Kate Naude**	
from	**Computing Science Department, Nelson Mandela University**	
of the Nelson Mandela Metropolitan University.		

THE FOLLOWING ASPECTS HAVE BEEN EXPLAINED TO ME, THE PARTICIPANT:			**Initial**
2.1	**Aim:**	The investigators are studying how Information Visualisation Techniques can be used to improve the self-management of Type 2 Diabetes Mellitus. The information will be used to/for research purposes.	
2.2	**Procedures:**	I understand that it is necessary for me to use a mobile application, Fitbit Charge 2 and Fitbit Aria scale to evaluate the visualisations that were created, while eye-tracking and voice recording is conducted on me in order to gain insight into the usability and effectiveness of the visualisations.	
2.3	**Risks:**	I understand that there are no risks involved in this process.	
2.4	**Possible benefits:**	As a result of my participation in this study a contribution will be made to the field of self-management of Type 2 Diabetes Mellitus	
2.5	**Confidentiality:**	My identity will not be revealed in any discussion, description or scientific publications by the investigators.	

		I understand that other researchers will have access to this data only if they agree to preserve the confidentiality of the data, and if they agree to the terms I have specified in this form.			
2.6	**Access to findings:**	Any new information or benefit that develops during the course of the study will be shared with participants upon request. They will be provided with a copy of the dissertation.			
2.6	**Voluntary participation / refusal / discontinuation:**	My participation is voluntary	**YES**	**NO**	
		My decision whether or not to participate will in no way affect my present or future care / employment / lifestyle	**TRUE**	**FALSE**	

<u>THE INFORMATION ABOVE WAS EXPLAINED TO ME/THE PARTICIPANT BY:</u>									**<u>Initial</u>**
Meggan Kate Naude									
in	**Afrikaans**		**English**		**Xhosa**		**Other**		
and I am in command of this language, **or** it was satisfactorily translated to me by									
I was given the opportunity to ask questions and all these questions were answered satisfactorily.									

4.	No pressure was exerted on me to consent to participation and I understand that I may withdraw at any stage without penalization.	

5.	Participation in this study will not result in any additional cost to myself.	

I HEREBY VOLUNTARILY CONSENT TO PARTICIPATE IN THE ABOVE-MENTIONED PROJECT:	
Signed/confirmed at on 20	
Signature or right thumb print of participant	Signature of witness:
	Full name of witness:

STATEMENT BY OR ON BEHALF OF INVESTIGATOR(S)									
I,		declare that:							
1.	I have explained the information given in this document to								
	and / or his / her representative								
2.	He / she was encouraged and given ample time to ask me any questions;								
3.	This conversation was conducted in	**Afrikaans**		**English**	X	**Xhosa**		**Other**	
	And no translator was used OR this conversation was translated into								
	(language)	by							

4.	I have detached Section D and handed it to the participant	YES	NO
Signed/confirmed at	on		20

Signature of interviewer	Signature of witness:
	Full name of witness:

DECLARATION BY TRANSLATOR (WHEN APPLICABLE)			
I,			
ID number			
Qualifications and/or			
Current employment			
confirm that I:			
1.	Translated the contents of this document from English into		
2.	Also translated questions posed by		as well as the answers given by the investigator/representative;
3.	Conveyed a factually correct version of what was related to me.		
Signed/confirmed at	on		20
I hereby declare that all information acquired by me for the purposes of this study will be kept confidential.			

Signature of translator	Signature of witness:
	Full name of witness:

IMPORTANT MESSAGE TO PATIENT/REPRESENTATIVE OF PARTICIPANT	
Dear participant/representative of the participant Thank you for your/the participant's participation in this study. Should, at any time during the study: - an emergency arise as a result of the research, or - you require any further information with regard to the study	
Kindly contact	Meggan Kate Naude
at telephone number	(+27)76 284 2535
or via e-mail	s213203510@mandela.ac.za

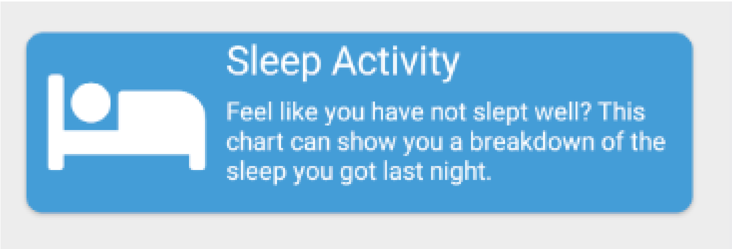
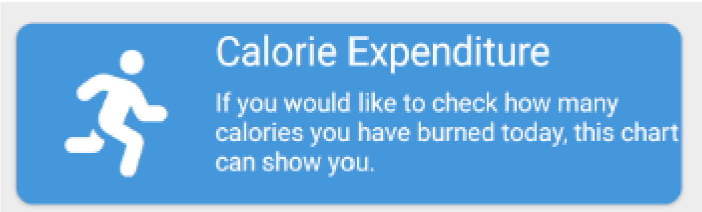
Appendix C: Background Questionnaire

DEMOGRAPHIC INFORMATION								
Gender	Male				Female			
Education Level	Under Graduate Degree		Honours Degree		Masters Degree		PhD Degree	
Age								
Occupation								

TECHNICAL EXPERIENCE	
Have you used any information visualisation tools before? (If YES please specify)	
Have you used any apps to track your Type 2 Diabetes Mellitus? (If YES please specify)	

Appendix D: Evaluation Task List of Entire App

GENERAL APPLICATION BEHAVIOUR		
Task 01	Create a new profile and sign in to the application	
Task 02	Log out of the application	
Task 01	Log in to the MedicMetric mobile application using the following credentials:	
	Username:	Password:
Task 01	Log how many glasses of water that you have had today.	
Task 02	Log the medication that you have taken today	
Task 03	Set a reminder to take your medication tomorrow.	
Task 04	Change the user profile information from the default.	
Task 05	View kilojoule expenditure for this week.	

HORIZONTAL TIME SERIES BAR CHART	
Task 01	Navigate to the sleep chart by clicking on this tab: 
Task 02	Identify the day that the participant slept the worst.
	Day:
Task 03	How many hours of sleep did the participant get the night before?
	Hours:
HORIZONTAL TIME SERIES BAR CHART	
Task 01	Navigate to the kilojoule chart by clicking on this tab: 
Task 02	Identify the day in which the participant did the most exercise
	Day:
Task 03	Which hour of today did the participant expend the most kilojoules?
	Hour:

Appendix E: Post-Evaluation Usability Questionnaire for Entire App

USABILITY QUESTIONNAIRE: SYSTEM USABILITY SCALE						
The questionnaire consists of pairs of contrasting attributes that may apply to the product. The circles between the attributes represent gradations between the opposites. You can express your agreement with the attributes by ticking the circle that most closely reflects your impression. Please decide spontaneously. Don’t think too long about your decision to make sure that you convey your original impression. Sometimes you may not be completely sure about your agreement with a particular attribute or you may find that the attribute does not apply completely to the particular product. Nevertheless, please tick a circle in every line. It is your personal opinion that counts. Please remember: there is no wrong or right answer!						
I think that I would like to use this system frequently.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I found the system unnecessarily complex.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I thought the system was easy to use.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I think that I would need the support of a technical person to be able to use this system.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I found the various functions in this system were well integrated.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I thought there was too much inconsistency in this system.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I would imagine that most people would learn to use this system very quickly.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I found the system very cumbersome to use.						

Strongly Disagree	○	○	○	○	○	Strongly Agree
I felt very confident using the system.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I needed to learn a lot of things before I could get going with this system						
Strongly Disagree	○	○	○	○	○	Strongly Agree

Appendix F: Post-Evaluation Cognitive Load Questionnaire for Entire App

SELF EVALUATION OF COGNITIVE LOAD/ EMOTIONAL STATE WHEN PERFORMING TASKS								
The questionnaire consists of pairs of contrasting attributes that may apply to the product. The circles between the attributes represent gradations between the opposites. You can express your agreement with the attributes by ticking the circle that most closely reflects your impression. While completing the tasks which did you feel reflected your frame of mind more?								
tense	○	○	○	○	○	○	○	calm
nervous	○	○	○	○	○	○	○	relaxed
stressed	○	○	○	○	○	○	○	serene
upset	○	○	○	○	○	○	○	contented
sad	○	○	○	○	○	○	○	happy
depressed	○	○	○	○	○	○	○	elated
lethargic	○	○	○	○	○	○	○	excited
bored	○	○	○	○	○	○	○	alert
In daily life, while contemplating the patterns in your blood glucose levels and considering all factors involved when self-managing type 2 Diabetes Mellitus, which do you feel reflected your frame of mind more?								
tense	○	○	○	○	○	○	○	calm
nervous	○	○	○	○	○	○	○	relaxed
stressed	○	○	○	○	○	○	○	serene
upset	○	○	○	○	○	○	○	contented
sad	○	○	○	○	○	○	○	happy
depressed	○	○	○	○	○	○	○	elated
lethargic	○	○	○	○	○	○	○	excited
bored	○	○	○	○	○	○	○	alert

SELF EVALUATION OF COGNITIVE LOAD								
Please place an X in the box that best describes your experience								
Did you feel that the task descriptions were clear and concise?							YES	NO
Did you feel stressed for any external reasons before starting the evaluation?							YES	NO
The scale below ranges from 1 (Very low) to 7 (Very high). Please make an X in the box which you feel best describes your opinion. The questionnaire consists of pairs of contrasting attributes from 1 (Very low) to 7 (Very high) that apply to statement made about the product. The circles between the attributes represent gradations between the opposites. You can express your agreement with the attributes by ticking the circle that most closely reflects your impression. Please decide spontaneously. Don't think too long about your decision to make sure that you convey your original impression. Sometimes you may not be completely sure about your agreement with a particular attribute or you may find that the attribute does not apply completely to the particular product. Nevertheless, please tick a circle in every line. It is your personal opinion that counts. Please remember: there is no wrong or right answer!								
How Mentally Demanding were the tasks?								
very low	○	○	○	○	○	○	○	very high
How physically demanding were the tasks?								
very low	○	○	○	○	○	○	○	very high
How rushed did you feel while performing the tasks?								
very low	○	○	○	○	○	○	○	very high
How successful were you in performing the tasks?								
very low	○	○	○	○	○	○	○	very high
How hard did you have to work (mentally and physically) to accomplish your level of performance?								
very low	○	○	○	○	○	○	○	very high

How irritated, stressed, and annoyed versus content, relaxed, and complacent did you feel during the task?		
very low	○ ○ ○ ○ ○ ○ ○	very high

Appendix G: Post-Evaluation User Experience Questionnaire for Entire App

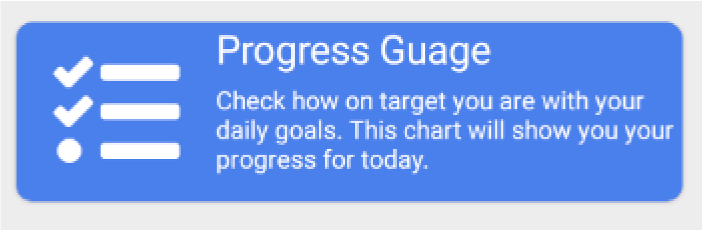
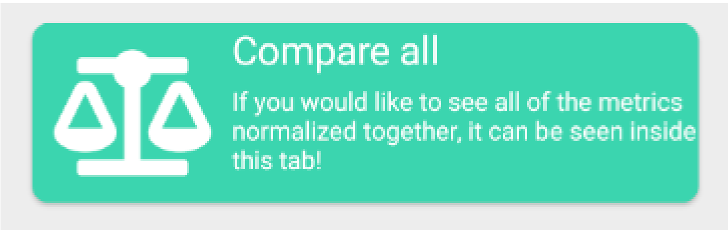
USER EXPERIENCE QUESTIONNAIRE: STANDARD UEQ

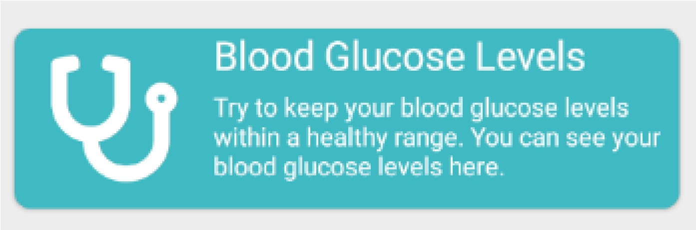
The questionnaire consists of pairs of contrasting attributes that may apply to the product. The circles between the attributes represent gradations between the opposites. You can express your agreement with the attributes by ticking the circle that most closely reflects your impression.
Please decide spontaneously. Don’t think too long about your decision to make sure that you convey your original impression.
Sometimes you may not be completely sure about your agreement with a particular attribute or you may find that the attribute does not apply completely to the particular product. Nevertheless, please tick a circle in every line.
It is your personal opinion that counts. Please remember: there is no wrong or right answer!

annoying	○	○	○	○	○	○	○	enjoyable
not understandable	○	○	○	○	○	○	○	understandable
creative	○	○	○	○	○	○	○	dull
easy to learn	○	○	○	○	○	○	○	difficult to learn
valuable	○	○	○	○	○	○	○	inferior
boring	○	○	○	○	○	○	○	exciting
not interesting	○	○	○	○	○	○	○	interesting
unpredictable	○	○	○	○	○	○	○	predictable
fast	○	○	○	○	○	○	○	slow
inventive	○	○	○	○	○	○	○	conventional
obstructive	○	○	○	○	○	○	○	supportive
good	○	○	○	○	○	○	○	bad
complicated	○	○	○	○	○	○	○	easy
unlikable	○	○	○	○	○	○	○	pleasing
usual	○	○	○	○	○	○	○	cutting edge
unpleasant	○	○	○	○	○	○	○	pleasant
secure	○	○	○	○	○	○	○	not secure
motivating	○	○	○	○	○	○	○	demotivating
meets expectations	○	○	○	○	○	○	○	does not meet expectations
inefficient	○	○	○	○	○	○	○	efficient

clear	○	○	○	○	○	○	○	confusing
impractical	○	○	○	○	○	○	○	practical
organized	○	○	○	○	○	○	○	cluttered
attractive	○	○	○	○	○	○	○	unattractive
friendly	○	○	○	○	○	○	○	unfriendly
conservative	○	○	○	○	○	○	○	innovative

Appendix H: Evaluation Task List for Charts

Radial Progress Bar (Progress Gauge)	
Task 01	Navigate to the Progress Gauge by clicking on the following tab: 
Task 02	Identify the activity for which the participant has not met their goal by the largest degree.
	Activity:
Task 03	Which day did the participant drink the most water?
	Day:
Task 04	Identify the day in which the participant performed the worst.
	Day:
Task 05	Identify the day in which the participant performed their best
	Day:
Task 06	Which two goals did the participant meet fully?
NORMALIZED COMPARATIVE AREA CHART	
Task 01	Navigate to the “Compare All” chart by clicking on this tab: 
Task 02	Filter the chart by removing the weight and water consumption from the chart.
Task 03	Does kilojoule expenditure increase or decrease blood glucose levels according to this chart?
Task 04	Does water consumption increase or decrease blood glucose levels according to this chart?

<table>
<tr><th colspan="3"><u>ADVANCED TIMELINE LINE CHART</u></th></tr>
<tr><td>Task 01</td><td colspan="2">Navigate to the Blood Glucose Levels chart by clicking on the following tab:

</td></tr>
<tr><td rowspan="3">Task 02</td><td colspan="2">What is the minimum and maximum acceptable blood glucose levels according to these charts?</td></tr>
<tr><td colspan="2">Minimum:</td></tr>
<tr><td colspan="2">Maximum:</td></tr>
<tr><td rowspan="3">Task 04</td><td colspan="2">What time of day were the blood glucose levels at their lowest and at their highest respectively?</td></tr>
<tr><td colspan="2">Lowest:</td></tr>
<tr><td colspan="2">Highest:</td></tr>
<tr><td colspan="3">Please follow this link https://app.gazerecorder.com/Study/Test?StudyID=study_91dc3165-f7d4-4845-ac3c-6827a7692656&lang=en&RespondentID=null and complete the assessment inside the eye tracking application.</td></tr>
<tr><th colspan="3"><u>ALTERNATE SYSTEM: MySugr</u></th></tr>
<tr><td rowspan="2">Task 01</td><td colspan="2">Log in to the MySugr app using the following credentials:</td></tr>
<tr><td>Username:</td><td>Password:</td></tr>
<tr><td rowspan="3">Task 02</td><td colspan="2">When looking at this chart are there any noticeable trends in daily activity with relation to blood glucose levels which you can see? If yes, please write them below</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="2"></td></tr>
<tr><td rowspan="3">Task 03</td><td colspan="2">Using the chart, can you determine which activities would negatively affect blood glucose levels? If yes, please write them below.</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="2"></td></tr>
<tr><td>Task 04</td><td colspan="2">What time of day were the blood glucose levels at their lowest and at their highest respectively?</td></tr>
</table>

	Lowest:	
	Highest	
ALTERNATE SYSTEM: Diabetes:M		
Task 01	Log in to the MySugr app using the following credentials:	
	Username:	Password:
Task 02	When looking at this chart are there any noticeable trends in daily activity with relation to blood glucose levels which you can see? If yes, please write them below	
Task 03	Using the chart, can you determine which activities would negatively affect blood glucose levels? If yes, please write them below.	
Task 04	What time of day were the blood glucose levels at their lowest and at their highest respectively?	
	Lowest:	
	Highest	

VISUAL INFORMATION SEEKING MANTRA COMPLIANCE

Below are the main elements of the visual information seeking mantra, for each app which was evaluated, please place an X over each statement which you agree with.

Overview – I can see historical data
Zoom – I have the ability to zoom in on data and obtain more information
Details on Demand – I can select sections of the graphics and obtain details or find more information about the represented data
Filter – I can remove items that are not of interest
Relate – I can connect the data and relate different aspects of the data to each other easily
History – Navigation is dynamic and I can move forward and back
Extract – I can share the data with others using the app

MedicMetric	Overview	Zoom	Details on Demand	Filter	Relate	History	Extract
Diabetes M	Overview	Zoom	Details on Demand	Filter	Relate	History	Extract
MySugr	Overview	Zoom	Details on Demand	Filter	Relate	History	Extract

Appendix I: First Evaluation Post-Evaluation Questionnaire: Progress Gauge View

<table>
<tr><td colspan="9">This questionnaire relates specifically to the Radial Progress View. Please keep this chart in mind while answering the questions and be as honest as possible. Remember, there are no right or wrong answers.</td></tr>
<tr><td colspan="9"><u>SELF EVALUATION OF COGNITIVE LOAD</u>
please place an X in the box that best describes your experience</td></tr>
<tr><td colspan="7">Did you feel that the task descriptions were clear and concise?</td><td>YES</td><td>NO</td></tr>
<tr><td colspan="7">Did you feel stressed for any external reasons before starting the evaluation?</td><td>YES</td><td>NO</td></tr>
<tr><td colspan="9">The scale below ranges from 1 (Very low) to 7 (Very high). Please make an X in the box which you feel best describes your opinion.

The questionnaire consists of pairs of contrasting attributes from 1 (Very low) to 7 (Very high) that apply to statement made about the product. The circles between the attributes represent gradations between the opposites. You can express your agreement with the attributes by ticking the circle that most closely reflects your impression.

Please decide spontaneously. Don’t think too long about your decision to make sure that you convey your original impression.
Sometimes you may not be completely sure about your agreement with a particular attribute or you may find that the attribute does not apply completely to the particular product. Nevertheless, please tick a circle in every line.
It is your personal opinion that counts. Please remember: there is no wrong or right answer!</td></tr>
<tr><td colspan="9">How Mentally Demanding were the tasks?</td></tr>
<tr><td>very low</td><td>○</td><td>○</td><td>○</td><td>○</td><td>○</td><td>○</td><td>○</td><td>very high</td></tr>
<tr><td colspan="9">How physically demanding were the tasks?</td></tr>
<tr><td>very low</td><td>○</td><td>○</td><td>○</td><td>○</td><td>○</td><td>○</td><td>○</td><td>very high</td></tr>
<tr><td colspan="9">How rushed did you feel while performing the tasks?</td></tr>
</table>

very low	○	○	○	○	○	○	○	very high
How successful were you in performing the tasks?								
very low	○	○	○	○	○	○	○	very high
How hard did you have to work (mentally and physically) to accomplish your level of performance?								
very low	○	○	○	○	○	○	○	very high
How irritated, stressed, and annoyed versus content, relaxed, and complacent did you feel during the task?								
very low	○	○	○	○	○	○	○	very high

SELF EVALUATION OVERALL SATISFACTION						
The **Radial Progress View** was simple to use						
Strongly Disagree	○	○	○	○	○	Strongly Agree
The **Radial Progress View** was easy to **learn** to use						
Strongly Disagree	○	○	○	○	○	Strongly Agree
Overall, I'm satisfied with the **Radial Progress View**						
Strongly Disagree	○	○	○	○	○	Strongly Agree
The information represented in the **Radial Progress View** was easy to interpret						
Strongly Disagree	○	○	○	○	○	Strongly Agree
SELF EVALUATION OF CHART USABILITY						
I think that I would like to use **Radial Progress View** frequently.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I found the **Radial Progress View** unnecessarily complex.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I thought the **Radial Progress View** was easy to use.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I think that I would need the support of a technical person to be able to use this **Radial Progress View**						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I found the various functions in the **Radial Progress View** were well integrated.						
Strongly Disagree	○	○	○	○	○	Strongly Agree

I thought there was too much inconsistency in the **Radial Progress View**						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I would imagine that most people would learn to use the **Radial Progress View** very quickly.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I found the **Radial Progress View** very cumbersome to use.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I felt very confident using the **Radial Progress View**.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I needed to learn a lot of things before I could get going with the **Radial Progress View**						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I can effectively find the Blood Glucose Level information that I am looking for using the **Radial Progress View**						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I was able to identify factors influencing Blood Glucose Levels quickly using the **Radial Progress View**						
Strongly Disagree	○	○	○	○	○	Strongly Agree
The **Radial Progress View** has all the functions and capabilities I expect from a chart which could assist me in finding factors affecting Blood Glucose Levels.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I became productive quickly using the **Radial Progress View**						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I could effectively identify how factors affected Blood Glucose Levels using the **Radial Progress View**						
Strongly Disagree	○	○	○	○	○	Strongly Agree
SELF EVALUATION GENERAL COMMENTS						
What was the most positive aspect of this visualisation technique?						
What was the most negative aspect of this visualisation technique?						

Please add any general comments/ improvements that you are important.

Appendix J: First Evaluation Post-Evaluation Questionnaire: Change Rate Line View

This questionnaire relates specifically to the **Change Rate Line View**. Please keep this chart in mind while answering the questions and be as honest as possible. Remember, there are no right or wrong answers.								
SELF EVALUATION OF COGNITIVE LOAD please place an X in the box that best describes your experience								
Did you feel that the task descriptions were clear and concise?							YES	NO
Did you feel stressed for any external reasons before starting the evaluation?							YES	NO
The scale below ranges from 1 (Very low) to 7 (Very high). Please make an X in the box which you feel best describes your opinion. The questionnaire consists of pairs of contrasting attributes from 1 (Very low) to 7 (Very high) that apply to statement made about the product. The circles between the attributes represent gradations between the opposites. You can express your agreement with the attributes by ticking the circle that most closely reflects your impression. Please decide spontaneously. Don't think too long about your decision to make sure that you convey your original impression. Sometimes you may not be completely sure about your agreement with a particular attribute or you may find that the attribute does not apply completely to the particular product. Nevertheless, please tick a circle in every line. It is your personal opinion that counts. Please remember: there is no wrong or right answer!								
How Mentally Demanding were the tasks?								
very low	○	○	○	○	○	○	○	very high
How physically demanding were the tasks?								
very low	○	○	○	○	○	○	○	very high
How rushed did you feel while performing the tasks?								

very low	○	○	○	○	○	○	○	very high
How successful were you in performing the tasks?								
very low	○	○	○	○	○	○	○	very high
How hard did you have to work (mentally and physically) to accomplish your level of performance?								
very low	○	○	○	○	○	○	○	very high
How irritated, stressed, and annoyed versus content, relaxed, and complacent did you feel during the task?								
very low	○	○	○	○	○	○	○	very high
SELF EVALUATION OVERALL SATISFACTION								
The **Change Rate Line View** was simple to use								
Strongly Disagree	○	○	○	○	○			Strongly Agree
The **Change Rate Line View** was easy to learn to use								
Strongly Disagree	○	○	○	○	○			Strongly Agree
Overall, I’m satisfied with the **Change Rate Line View**								
Strongly Disagree	○	○	○	○	○			Strongly Agree
The information represented in the **Change Rate Line View** was easy to interpret								
Strongly Disagree	○	○	○	○	○			Strongly Agree
SELF EVALUATION OF CHART USABILITY								
I think that I would like to use **Change Rate Line View** frequently.								
Strongly Disagree	○	○	○	○	○			Strongly Agree
I found the **Change Rate Line View** unnecessarily complex.								
Strongly Disagree	○	○	○	○	○			Strongly Agree
I thought the **Change Rate Line View** was easy to use.								
Strongly Disagree	○	○	○	○	○			Strongly Agree
I think that I would need the support of a technical person to be able to use this **Change Rate Line View**.								
Strongly Disagree	○	○	○	○	○			Strongly Agree
I found the various functions in the **Change Rate Line View** were well integrated.								
Strongly Disagree	○	○	○	○	○			Strongly Agree

I thought there was too much inconsistency in the **Change Rate Line View**.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I would imagine that most people would learn to use the **Change Rate Line View** very quickly.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I found the **Change Rate Line View** very cumbersome to use.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I felt very confident using the **Change Rate Line View**.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I needed to learn a lot of things before I could get going with the **Change Rate Line View**						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I can effectively find the Blood Glucose Level information that I am looking for using the **Change Rate Line View**						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I was able to identify factors influencing Blood Glucose Levels quickly using the **Change Rate Line View**						
Strongly Disagree	○	○	○	○	○	Strongly Agree
The **Change Rate Line View** has all the functions and capabilities I expect from a chart which could assist me in finding factors affecting Blood Glucose Levels.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I became productive quickly using the **Change Rate Line View**						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I could effectively identify how factors affected Blood Glucose Levels using the **Change Rate Line View**						
Strongly Disagree	○	○	○	○	○	Strongly Agree
SELF EVALUATION GENERAL COMMENTS						
What was the most positive aspect of this visualisation technique?						
What was the most negative aspect of this visualisation technique?						

Please add any general comments/ improvements that you are important.

Appendix K: First Evaluation Post-Evaluation Questionnaire: Annotated Line View

<table>
<tr><td colspan="10">This questionnaire relates specifically to the Annotated Line View. Please keep this chart in mind while answering the questions and be as honest as possible. Remember, there are no right or wrong answers.</td></tr>
<tr><td colspan="10"><u>SELF EVALUATION OF COGNITIVE LOAD</u>
please place an X in the box that best describes your experience</td></tr>
<tr><td colspan="8">Did you feel that the task descriptions were clear and concise?</td><td>YES</td><td>NO</td></tr>
<tr><td colspan="8">Did you feel stressed for any external reasons before starting the evaluation?</td><td>YES</td><td>NO</td></tr>
<tr><td colspan="10">The scale below ranges from 1 (Very low) to 7 (Very high). Please make an X in the box which you feel best describes your opinion.

The questionnaire consists of pairs of contrasting attributes from 1 (Very low) to 7 (Very high) that apply to statement made about the product. The circles between the attributes represent gradations between the opposites. You can express your agreement with the attributes by ticking the circle that most closely reflects your impression.
Please decide spontaneously. Don’t think too long about your decision to make sure that you convey your original impression.
Sometimes you may not be completely sure about your agreement with a particular attribute or you may find that the attribute does not apply completely to the particular product. Nevertheless, please tick a circle in every line.
It is your personal opinion that counts. Please remember: there is no wrong or right answer!</td></tr>
<tr><td colspan="10">How Mentally Demanding were the tasks?</td></tr>
<tr><td>very low</td><td>○</td><td>○</td><td>○</td><td>○</td><td>○</td><td>○</td><td>○</td><td colspan="2">very high</td></tr>
<tr><td colspan="10">How physically demanding were the tasks?</td></tr>
<tr><td>very low</td><td>○</td><td>○</td><td>○</td><td>○</td><td>○</td><td>○</td><td>○</td><td colspan="2">very high</td></tr>
<tr><td colspan="10">How rushed did you feel while performing the tasks?</td></tr>
<tr><td>very low</td><td>○</td><td>○</td><td>○</td><td>○</td><td>○</td><td>○</td><td>○</td><td colspan="2">very high</td></tr>
</table>

How successful were you in performing the tasks?								
very low	○	○	○	○	○	○	○	very high
How hard did you have to work (mentally and physically) to accomplish your level of performance?								
very low	○	○	○	○	○	○	○	very high
How irritated, stressed, and annoyed versus content, relaxed, and complacent did you feel during the task?								
very low	○	○	○	○	○	○	○	very high

SELF EVALUATION OVERALL SATISFACTION						
The **Annotated Line View** was simple to use						
Strongly Disagree	○	○	○	○	○	Strongly Agree
The **Annotated Line View** was easy to **learn** to use						
Strongly Disagree	○	○	○	○	○	Strongly Agree
Overall, I'm satisfied with the **Annotated Line View**						
Strongly Disagree	○	○	○	○	○	Strongly Agree
The information represented in the **Annotated Line View** was easy to interpret						
Strongly Disagree	○	○	○	○	○	Strongly Agree
SELF EVALUATION OF CHART USABILITY						
I think that I would like to use the **Annotated Line View** frequently.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I found the **Annotated Line View** unnecessarily complex.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I thought the **Annotated Line View** was easy to use.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I think that I would need the support of a technical person to be able to use the **Annotated Line View**.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I found the various functions in the **Annotated Line View** were well integrated.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I thought there was too much inconsistency in the **Annotated Line View**.						

Strongly Disagree	○	○	○	○	○	Strongly Agree
I would imagine that most people would learn to use the **Annotated Line View** very quickly.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I found the **Annotated Line View** very cumbersome to use.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I felt very confident using the **Annotated Line View**.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I needed to learn a lot of things before I could get going with the **Annotated Line View**						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I can effectively find the Blood Glucose Level information that I am looking for using the **Annotated Line View**						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I was able to identify factors influencing Blood Glucose Levels quickly using the **Annotated Line View**						
Strongly Disagree	○	○	○	○	○	Strongly Agree
The **Annotated Line View** has all the functions and capabilities I expect from a chart which could assist me in finding factors affecting Blood Glucose Levels.						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I became productive quickly using the **Annotated Line View**						
Strongly Disagree	○	○	○	○	○	Strongly Agree
I could effectively identify how factors affected Blood Glucose Levels using the **Annotated Line View**						
Strongly Disagree	○	○	○	○	○	Strongly Agree
SELF EVALUATION GENERAL COMMENTS						
What was the most positive aspect of this visualisation technique?						
What was the most negative aspect of this visualisation technique?						

Please add any general comments/ improvements that you are important.

Appendix L: Post-Evaluation Chart Questionnaire

PREFERRED TECHNIQUE POST-EVALUATION QUESTIONNAIRE Please select from the three options provided below each question which option you feel better provides for your needs.		
Which chart/technique would you prefer to use in the future?		
Annotated Line View	Change Rate Line View	Radial Progress View
Which chart/technique was the most complex?		
Advanced Timeline iChart	Change Rate Line View	Radial Progress View
Which technique was the easiest to interpret?		
Annotated Line View	Change Rate Line View	Radial Progress View
Which technique would require the most help in order to use?		
Annotated Line View	Change Rate Line View	Radial Progress View
Which chart/technique provided better functionality?		
Annotated Line View	Change Rate Line View	Radial Progress View
Which chart/technique was more consistent?		
Annotated Line View	Change Rate Line View	Radial Progress View
Which chart/technique would require the least learning time?		
Annotated Line View	Change Rate Line View	Radial Progress View
Which chart/technique was more cumbersome to use?		
Annotated Line View	Change Rate Line View	Radial Progress View
Which chart/technique were you most confident using?		
Annotated Line View	Change Rate Line View	Radial Progress View

Appendix M: Post-Evaluation IV Tool Questionnaire

PREFERRED IV TOOL POST-EVALUATION QUESTIONNAIRE Please select from the three options provided below each question which option you feel best provides for your needs.		
Which IV tool would you prefer to use in the future?		
MedicMetric	MySugr	Diabetes:M
Which IV tool was the most complex?		
MedicMetric	MySugr	Diabetes:M
Which IV tool was the easiest to interpret?		
MedicMetric	MySugr	Diabetes:M
Which IV tool would require the most help in order to use?		
MedicMetric	MySugr	Diabetes:M
Which IV tool provided better functionality?		
MedicMetric	MySugr	Diabetes:M
Which IV tool was more consistent?		
MedicMetric	MySugr	Diabetes:M
Which IV tool would require the least learning time?		
MedicMetric	MySugr	Diabetes:M
Which IV tool was more cumbersome to use?		
MedicMetric	MySugr	Diabetes:M
Which IV tool were you most confident using?		
MedicMetric	MySugr	Diabetes:M

Appendix N: Post-Evaluation Overall Satisfaction Questionnaire

GENERAL SATISFACTION QUESTIONS
Have you made use of an application to help self-manage your Type 2 Diabetes Mellitus before?
An application is currently provided with the continuous glucose monitor that you make use of, which application (the IV tool or standard application) did you prefer and why?
Did you find that the visualisations were useful for interpreting why your blood glucose levels were elevated at times during the day, why or why not?
Which visualisation would you consider the most useful and why?
Which visualisation would you consider least useful and why?
Did the visualisations highlight any information or patterns that you had not noticed about your habits before the use of the application? If so, which patterns were noticed?
Would you consider using an application like this one and why or why not?

What did you feel was missing from the application?
What did you feel was the most useful part of the application?
How can features be reworked to support your needs better?
For what reasons, if any, would you not use the application?
If you were to choose one of the IV tools evaluated here today to use daily, which would it be?