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MEDICMETRIC: A VISUALIZATION TOOL TO SUPPORT THE MANAGEMENT OF TYPE 2 DIABETES MELLITUS

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ABSTRACT

Diabetes mellitus (DM) is a preventable, long-lasting, and rarely completely cured chronic disease of the pancreas. Many diabetes cases are preventable through lifestyle change. There are a lack of visualization tools for understanding and tracking causal factors and habits, however, which lead to diabetes and impede recovery from it. Without visualization tools that provide immediate feedback and an understanding of the relationship between insulin intake, blood sugar levels (BGLs), exercise, food intake, heart disease, and blood pressure (BP), individuals living with DM are less likely to make good health decisions. The aim of this paper is to discuss the development of a visualization tool called MedicMetric. Fitbit and Dexcom APIs were used to capture health data for the visualization tool. Three new visualization techniques were used in MedicMetric, namely the Annotated Line View, the Radial Progress View and the Change Rate View. 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 effort required to retrieve and interpret useful data. IV techniques were used to create and evaluate a new set of visualizations, which were used in the prototype. The results of a usability study showed that the participants would prefer using such an IV tool to better manage their T2DM and personal goals. These results support the theory that IV techniques can be used to support the self-management of T2DM. The MedicMetric prototype was compared to the MySygr and Diabetes:M applications. MedicMetric and MySugr obtained almost identical results for effectiveness and efficiency. However, participants indicated that MedicMetric provided the best support overall, with 100 percent of participants stating that they would prefer to use MedicMetric in future.

KEYWORDS

Diabetes Mellitus, Information Visualization, Prototype, Usability Evaluation

1. INTRODUCTION

Diabetes mellitus (DM) is a chronic disease that affects approximately 422 million people worldwide (World Health Organization, 2016). Many diabetes cases are preventable through lifestyle change (Health Information, 2017), but most of those who struggle with the condition lack the correct tools to understand and track 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 patients do not understand how their behavior affects their health. By not understanding the relationship between their insulin intake, blood sugar levels (BGLs), exercise, food intake, heart disease, and blood pressure (BP) (Delahanty & McCulloch, 2017), individuals with DM are less likely to make accurate decisions that can negatively affect their health.

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 BGLs (Schiffrin & Belmonte, 1982). Glucose meters 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).

Information Visualization (IV) is a method for representing data in a nontraditional, interactive, graphical form (Gelman & Unwin, 2012). IV is utilized in many fields, and can be customized for various applications (Shneiderman, 2013). Interactive IV and visual analytics methods could bring profound changes to personal health programs, healthcare delivery and self-management for DM patients through effective presentation of health information (Institute of Medicine, 2011).

This paper will investigate how IV techniques can be applied to create an effective tool, called MedicMetric, to aid in the self-management of DM. The aim of this research is to improve the presentation of variables associated with DM to support DM patients, and assist in the processing 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.

2. RELATED WORK

The current methods of self-management for diabetes do not include visualization tools that make use of IV. While IV has previously been used for visualization of medical data, systems that are currently in use are limited (Yordanov, 2016). For this reason, mobile IV systems that are used to visualize T2DM data, such as BGLs, were reviewed.

2.1 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 parts (Dexcom G5® Mobile App, 2015):

- A small sensor that measures glucose levels just underneath the skin.
- An element that is fastened on top of the sensor and sends data wirelessly to a compatible smart device or receiver.
- A compatible smart device with the Dexcom G5 Mobile app.

BGLs can then be viewed in different colors to identify when they are high, low or within range. With the Dexcom G5 Mobile CGM System, users are alerted on their compatible smart device (phone) 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 devices. The Dexcom G5 Mobile CGM System provides a platform to enter customizable events, giving users the ability to track how their daily activities influence their glucose trends. Customized reports can also be shared with physicians. Shortfalls of this system include a lack of automated input systems for diet or exercise plans, a lack of existing health pattern identification, and a lack of analysis within the mobile system.

2.2 MySugr

MySugr (mySugr GmbH, 2012) is a free cellular application available on both the iStore and Google PlayStore. MySugr (mySugr GmbH, 2012) has the aim 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 (Johnson, 2016).

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.

Two features of the application that deserve attention are reminders and tags. Tags are the notable events that occur and influence BGLs. Reminders can be set manually by the user so that an alarm sounds when medication is required (Johnson, 2016). The reminder is typically set between 15 minutes to 3 hours to remind users about a post meal medication intake. Shortfalls of this system include a lack of CGM, a lack of alerts for abnormally high/low blood glucose levels, a lack of an automated input system for BGLs, exercise or diet plan, and a lack of existing health pattern identification.

2.3 Diabetes:M

Diabetes:M (Sirma Medical Systems, 2021) is an award-winning diabetes logbook app for tracking and management of diabetes for individuals with all types of diabetes or pre-diabetes, 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: Logbook, Food Database, Bolus Calculator, Extended bolus calculator mode, Detailed Graph, Analytical Charts, various reports, and data import/export functionality (Yordanov, 2016).

The following features are included in Diabetes:M:

- **Detailed Graph:** Detailed timeline graph of blood sugar tests including boluses, basal insulin, and other useful data.
- **Analytical Charts:** A summary of all the users' collected data is shown in visual displays.
- **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 a lack of CGM, a lack of alerts for abnormally high/low blood glucose levels, a lack of an automated input system for BGLs, exercise or diet plan, and a lack of existing health pattern identifications.

3. DESIGN OF IV TOOL: MEDICMETRIC

This section includes the design of the prototype visualization system, called MedicMetric. The IV techniques that were used for the prototype are described. The prototype was developed to determine to what extent IV can be used to support the self-management of T2DM. Real-life DM data was used as a test set for implementation. The Dexcom sandbox diabetes data, and Fitbit test data sets were used as sample data for the prototype.

3.1 Data Collection

The metrics that must be self-managed by DM patients include BGLs, oral medication, exercise, diet and sleep (Deacon et al, 2005). These factors were identified during the research phase as prominent behavioral factors that can also affect BGLs, which a FitBit smart watch is capable of tracking. The analysis of DM data was based on the idea that 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 a variation in health data such as BMI, BGLs, BP and body-fat percentage. A dataset of BGLs, obtained from the DEXCOM and FitBit sandbox data, was used as the initial data for visual representation and testing.

3.2 Visualization Techniques

Temporal visualizations are visualizations that track time-series data, i.e., the performance of an indicator over a period. To represent DM data in a manner that supports effective self-management and cognition, the techniques used to visualize this information should adhere to certain requirements.

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 to discover if any other useful and beneficial features could be included in the system. For the application to be considered done, the following functions are required to be supported:

- Alerts must be sent to users during health critical times., including 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 must be designed to require minimum user input, as this is a deterrent and can cause users to feel discouraged by the amount of input required to obtain an accurate 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 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.

Only a few applications using IV to represent medical data have been found, 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 is the "Visual information-seeking mantra" (VISM), proposed by Shneiderman: “Overview first, zoom and filter, then details-on-demand” (Shneiderman et al, 2003). The taxonomy divides general VISM into seven data types and seven tasks: Overview, Zoom, Filter, Details-on-Demand, Relate, History, and Extract.

The VISM 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, a 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 easily zoom in on specific events, meals or points of interest of the DM data that are significant. 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 items that are not of interest to him, allowing him to concentrate on relevant factors. Users should be able to search for aspects of data based on their goal. A search facility should be provided to allow the user to navigate through the tool and find useful information, especially because of the large size of the data. If the user has a specific query in mind, he should be able to manipulate the data. 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 on demand or be able to find more information about the data represented when required. A user should be able to expand or contract segments of the data when needed.

- **Relate**: Users should be easily able to connect the data and relate different aspects of the data to each other. The filter aspect should be used for relational advantage, so that the 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. Medical practitioners should be provided with an external view point, and not need log in as the user to view critical DM data.

3.3 Prototype Design

Several design iterations were conducted before the design was finalized. All the designs were evaluated by experts in the IV design domain, but user-centered design was difficult to implement during the design phase due to COVID-19 restrictions. Three visualizations, capable of providing users with the ability to view and correlate behaviors with BGLs, were implemented in MedicMetric using the HighCharts library (Usman, M., 2022). These charts were implemented for comparison purposes, and all three charts support the tasks listed in Section 3.2. 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, used to highlight aspects of the IV techniques more clearly.

The Radial Progress View was implemented using the HighCharts radial bar chart (Usman, M., 2022). The chart contains all tracked variables (Figure 1). The radial line meets the end of the track when participants have fully met their goals for the day. For instance, if a participant sets a reminder to take medication and indicates that the task is completed when the reminder is sent, then the goal for medicine intake has been met.

The Weekly Overview shows 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, to determine on which days they performed worse. For a participant to meet the goal for the BGL category, the 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 it was outside the acceptable range.

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

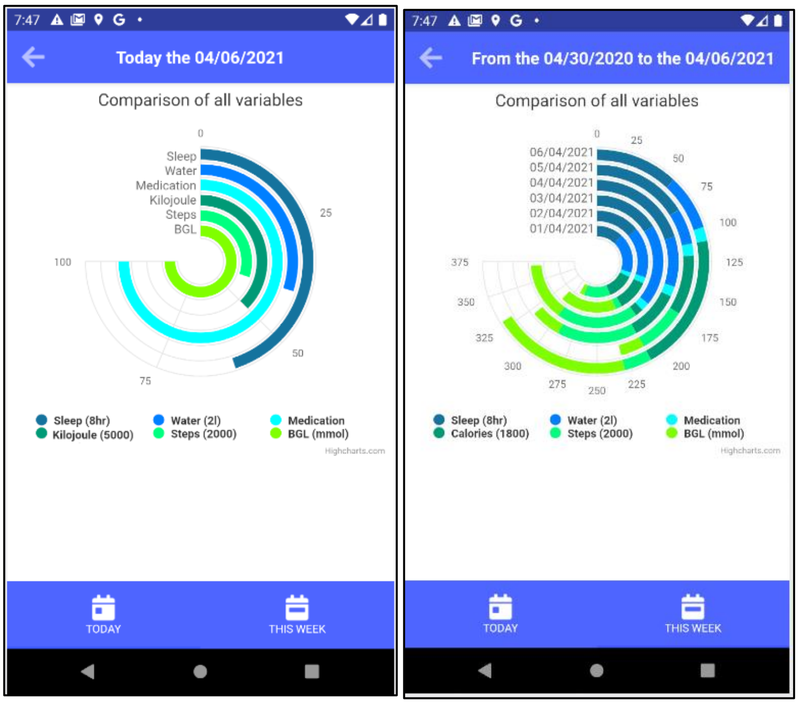

Figure 1. The Radial Progress Daily and Weekly Views

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 T2DM data can explore the data with ease and focus on their BGLs while doing so. All existing systems provide users with a line chart. This chart typically focuses only on BGLs and has markers to indicate when relevant events occur. For this reason, a line view was implemented to compare the existing techniques used for self-management of T2DM.

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

The Highcharts Annotated Line View was edited to display events as zones on the line chart (Usman, M., 2022). 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. 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 daily and weekly views of this chart can be seen in Figure 2.

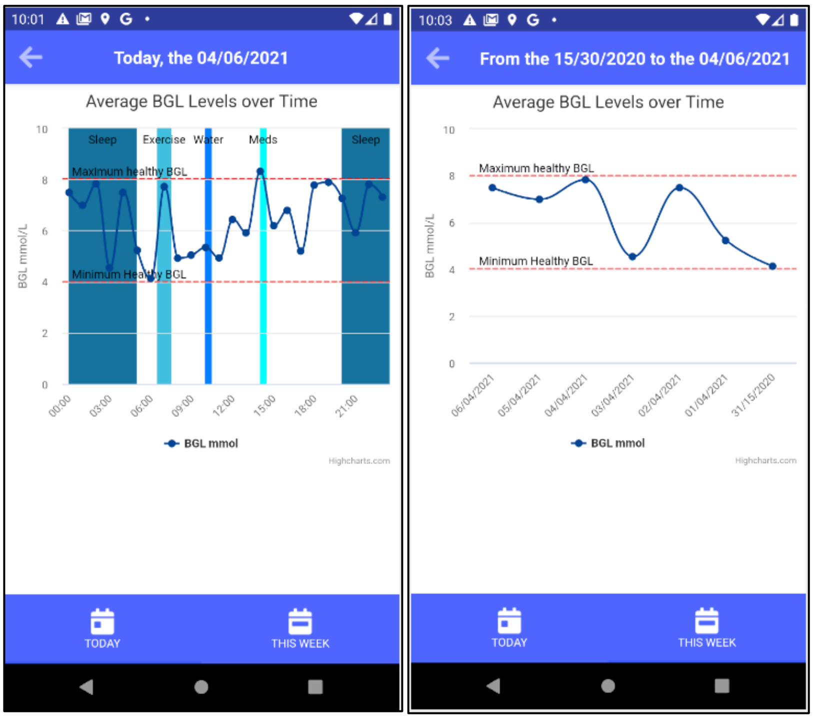

Figure 2. Annotated Line Daily and Weekly Views

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 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 such as 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 relationship 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.

To highlight trends in the data, a ROC line for different variables was calculated. The calculation for ROC was 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 generate a percentage. This results in the chart in Figure 3. This chart would be useful in determining if one factor has an effect on another, but it would be difficult to tell if that effect was negative or positive, as ROC does not relay that kind of information.

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 with the name of the chart that the user would like to view (Figure 3).

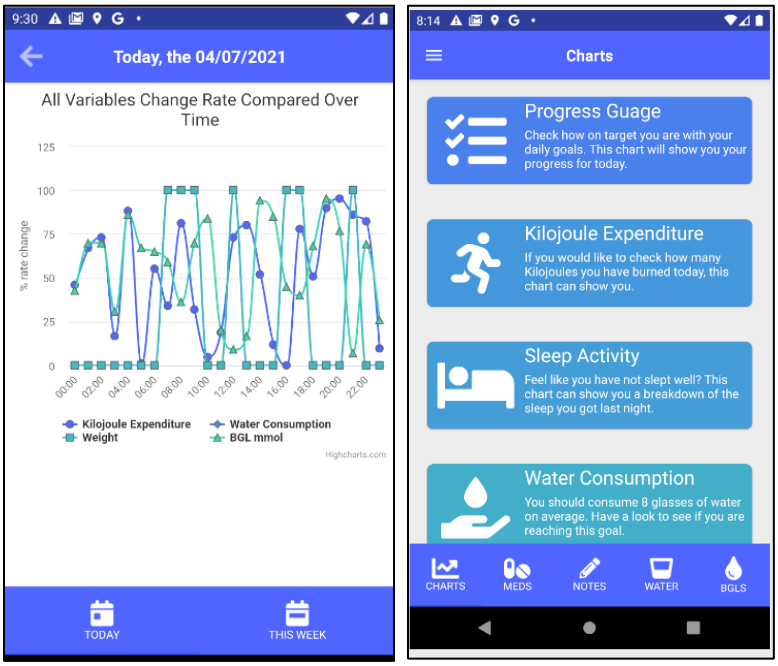

Figure 3. Change Rate Filtered View and Navigation Screen

4. EVALUATION: USER STUDY

The usability study required participants to complete a series of tasks while using the prototype application to view the visualizations. To avoid participants learning the system, the study was done before they were asked to make use of the prototype for a prolonged period. 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 afterwards to identify any problems 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.

4.1 Research Objectives

MedicMetric has seven core charts, including kilojoule expenditure, BGLs, medicine intake, water intake, weight and sleep patterns. There are three charts 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 was easily understood by the user, and to determine which of the three charts was preferred.

The Radial Progress View (Figure 1) 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 during the week. 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.

4.2 Participants

A sample of fifteen participants (eight male and seven females, 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 use a self-management tool to aid their relatives. Participants' ages ranged from 26 to 64 years. Participants were asked if they had any prior experience with IV tools, and 86 percent of the participants indicated that they had used an IV tool previously. Participants were asked to provide consent that they were willing to participate in the study on the premise that their DM data would be secure and that their participation could be withdrawn at any time. Participants were not evaluated on their ability to interpret graphics, and the small participant pool means that this could influence the results.

4.3 Evaluation Metrics

The following performance metrics were measured for each task:

- **Effectiveness:** Whether the task was completed 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 completed using standard usability questionnaires.

4.4 Experimental Setup

Two versions of the usability evaluations were developed to cater for COVID-19 safety regulations and to minimize the risk for individuals with T2DM. Participants could either do an evaluation at home, or online. In the at-home environment, the evaluator was positioned out of eye-line, but within the hearing range of the participant. The participant and the evaluator communicated verbally during the evaluation. If the participant opted to do an online evaluation, the participant would communicate verbally through a video chat with the evaluator. Screen sharing was used when a participant evaluated the emulated application to minimize the amount of software they would need to download or install.

The participants completed the evaluation of the three main charts, while being asked to identify health patterns in the chart data. Participant task times were manually recorded by the evaluator, as well as the answers to the questions in the task lists. Participants were given written and verbal instructions for each task, and standard usability questionnaires were administered verbally.

4.5 Procedure

Each participant completed one evaluation and all evaluations were done one at a time. The participants were asked to complete the initial set of tasks and usability, cognitive load, and user experience questionnaires were administered. The participants were then asked to complete tasks for each of the main three charts and alternative IV tools. Participants were not informed that the MedicMetric application was the proposed alternative IV tool. After completing the tasks for each chart and performing similar tasks on alternative applications, namely MySugr (mySugr GmbH, 2012) and Diabetes:M (Sirma Medical Systems, 2021), the participants were asked to identify which of the three systems best supported their tasks.

4.6 Results

Tasks designed to directly compare the three main IV techniques received varying success rates. Participants had a 71.11 percent success rate when using the Change Rate Line View (Figure 3), an 80 percent success rate when using the Radial Progress View (Figure 1), and a 96 percent success rate when using the Annotated Line View (Figure 2). Thus, it can be concluded that the most effective chart was the Annotated Line View, and the least effective was the Change Rate Line View.

4.6.1 Performance Results

Tasks were designed to compare MedicMetric in terms of efficiency with MySugr and Diabetes:M. Identical success rates were recorded for MySugr and MedicMetric. Participants correctly answered the tasks using MySugr 86.67 percent of the time, but only answered correctly using Diabetes:M 42.22 percent of the time. This is possibly due to the navigation mechanisms used in Diabetes:M, that many participants noted were confusing.

Participants felt that the MedicMetric tool best supported their tasks according to the VISM (Figure 4). A Shapiro-Wilk test was run between MySugr and MedicMetric, and results were statistically significant in favor of MedicMetric, apart from Extract, where the results were in favor of MySugr. It is worth noting that the final question asked was, '*If you were to choose one of the IV tools evaluated here to use daily, which would it be?*' One hundred percent of the participants stated that they would make use of MedicMetric in future.

Participants correctly identified the effects that water consumption, kilojoule expenditure, medication and weight have on BGLs 100 percent of the time using the Annotated Line View, but could only correctly interpret the data concerning sleep 80 percent of the time. Participants could correctly identify health patterns 71.11 percent of the time using the Change Rate View, and 80 percent of the time using the Radial Progress View.

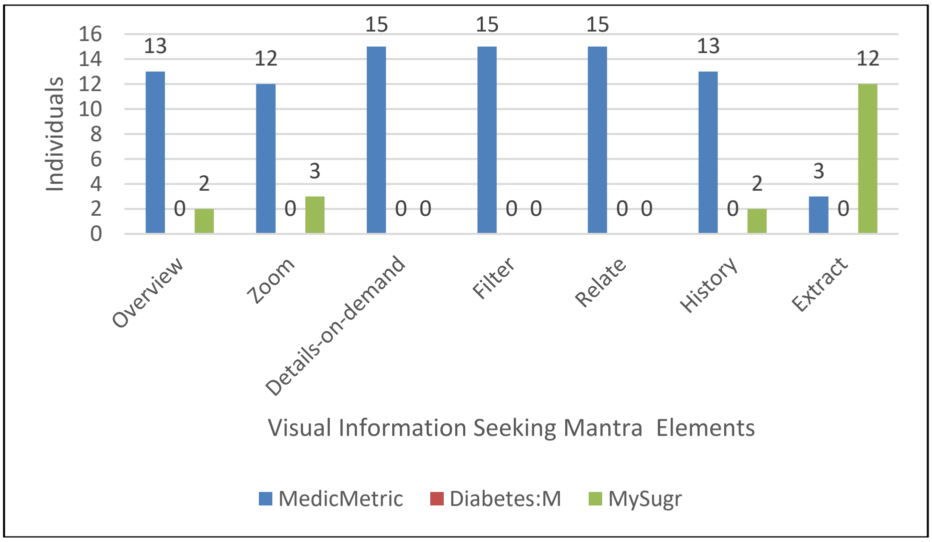

Figure 4. Total number of individuals who selected which IV tool best supported their tasks according to the Visual Information Seeking Mantra (n=15)

4.6.2 Satisfaction Results

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

On average, the Annotated Line View (Figure 2) was evaluated to create the least cognitive load with the lowest average mental demand of 1.06, as shown in Figure 6. It was also estimated by the participants to increase their performance, with the highest average performance rating of 6.4.

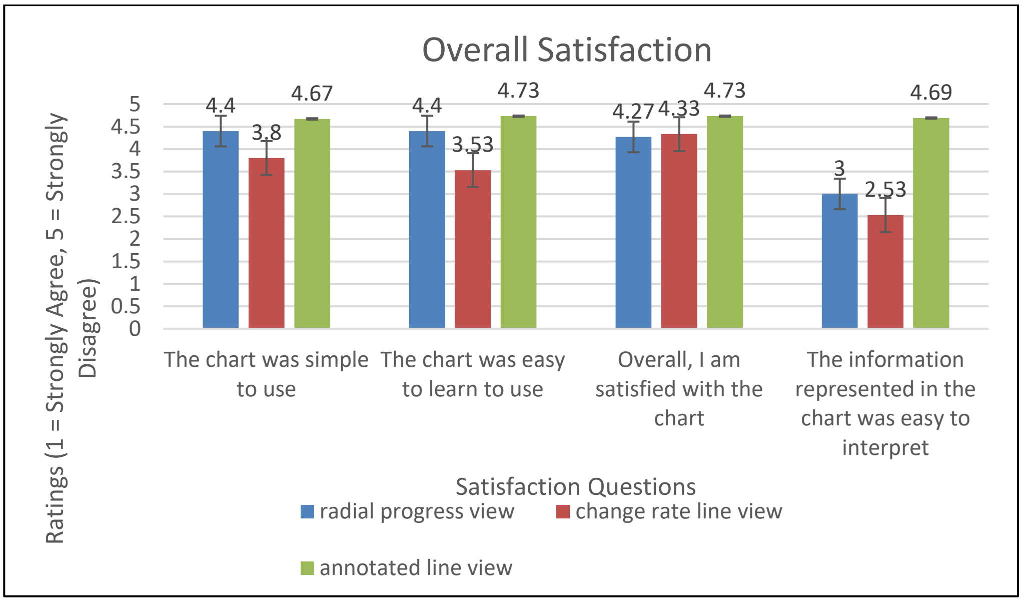

Figure 5. Overall Satisfaction Using a Five-Point Likert Scale with Standard Error Indicators (n=15)

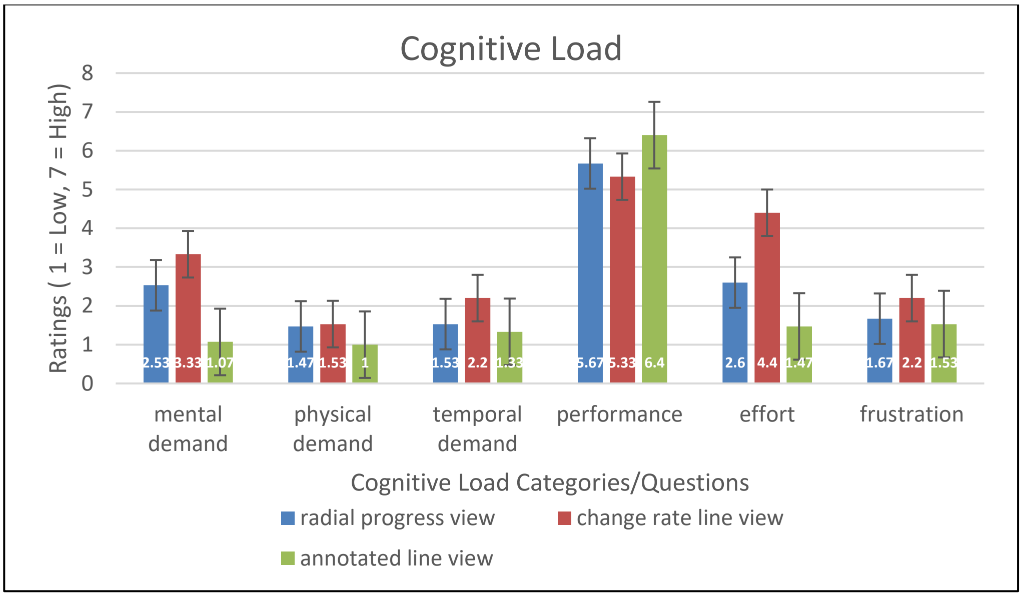

Figure 6. Cognitive Load Using a Seven-Point Semantic Differential Scale with Standard Error Indicators (n=15)

The usability ratings were also all in favour of the Annotated Line View, as shown in Figure 7. For this reason, the Wilcoxon Matched Pairs Test for Usability was performed comparing the results for the Annotated Line View against the other two IV techniques (MacFarland & Yates, 2018). The difference between the question rankings for the Annotated Line View and the Radial Progress View were statistically significant for 7 of the 15 questions.

Figure 7. Usability Ratings using a 5-point Likert Scale with standard error indicators (n=15)

4.7 Discussion

From the results, it can be concluded that the Annotated Line View (Figure 2) was the preferred method used to visualize the effect that variables, such as water consumption and exercise, have on BGLs. The satisfaction scores were also relatively high for all three charts, but the Change Rate View (Figure 3) had the worst satisfaction rating overall.

For effectiveness and efficiency, MedicMetric and MySugr obtained almost identical results. However, participants considered that MedicMetric supported their VISM tasks the best overall, allowing them to zoom and filter, search and acquire details-on-demand and generally get a better overview. One hundred percent of participants stated that they would prefer to use the MedicMetric application in the future, especially considering the MySugr results.

The following usability problems were identified by the participants, and addressed shortly after the study:

- Chart coloring is not conducive to clear data interpretation as it can distract from more important information. The new color scheme is illustrated in Figure 8.
- Formatting issues were discovered in the x-axis timeline.
- Crowded charts are difficult to read and filters should be applied initially to reduce the amount of data shown. The crowded charts were auto filtered, as shown in Figure 9.

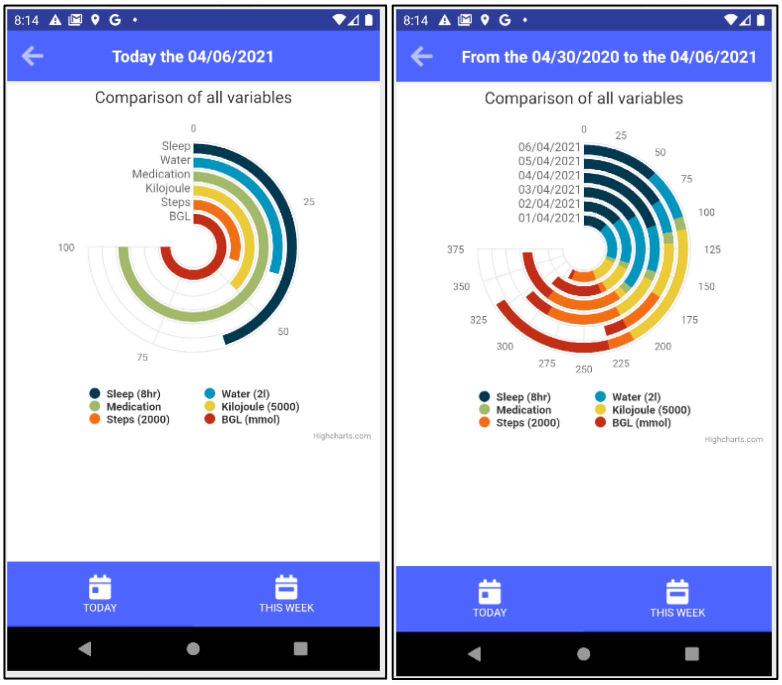

Figure 8. Re-colored Radial Progress View

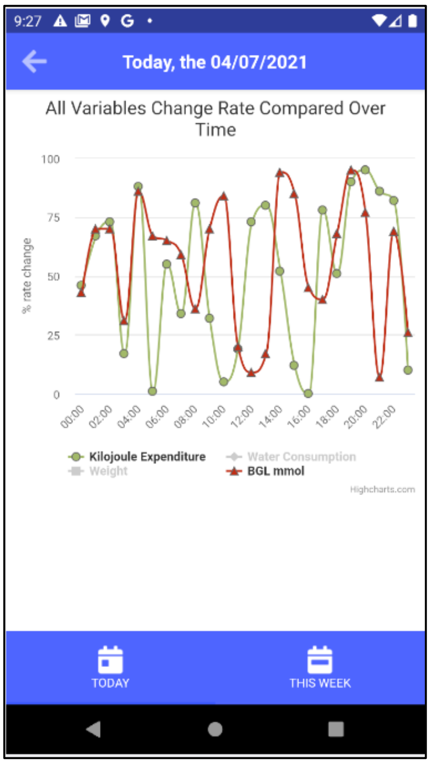

Figure 9. Default Filter Configuration and Altered Colours for the Change Rate Line View

5. CONCLUSIONS

This research has shown that IV can be used successfully to support the self-management of T2DM. The participants of the usability study showed that MedicMetric is effective in reducing the effort required to interpret their BGL data, and showed that they would prefer using such an IV tool to better manage their T2DM and personal goals.

The practical contribution of this research includes the three IV techniques, which were designed and implemented in MedicMetric. Most of the participants in the usability evaluation preferred the Annotated Line View in all categories in which it was evaluated.

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 also be possible to conduct a further study in collaboration with the health industry 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.

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