Using interactive 3D game play to make complex medical knowledge more accessible

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Abstract
This research outlines a new approach, that takes complex medical, nutritional & activity data and presents it to the diabetic patient in the form of a mobile app/game that uses interactive 3D computer graphics & game play to make this complex information more accessible. The pilot randomized control study results indicate that the Diabetes Visualizer’s use of interactive 3D game play increased the participants understanding of the condition, and its day-to-day management. More importantly the Diabetes Visualizer app stimulated participants interest in, and desire to engage in the task of diabetes management.

Keywords: Diabetes management, 3D Visualization, Mobile App, Health Informatics

1 Introduction
Diabetes is a chronic medical condition that negatively affects the lives of millions worldwide. This paper looks at the development of a new type of mobile software app that is designed to improve the way the diabetic patient, and those involved in their care, interact with the complex information related to the day-to-day management of the condition. Utilizing 3D interactive computer graphics and game play, this new interface to diabetes information focuses not on the information itself but on the way that the complex information is presented.

1.1 Why Diabetes Management Tools Matter
The World Health Organization [1] defines diabetes as a chronic medical condition that occurs when the body, and more specifically the pancreas, does not produce enough insulin or when the body cannot effectively use the insulin it produces. Insulin is the hormone that enables sugar in the blood to be absorbed and used by the cells of the body. With a shortage of insulin, yet the ongoing digestion of
sugars through food, sugar builds up in the blood (in the form of increased concentrations of glucose) leading to complications.

Diabetes itself has several forms (Type 1 and 2). Type 1 diabetes, widely known as insulin-dependent diabetes, is the less common form at approximately 10% of cases (34.7 million people worldwide) and is caused by a lack of insulin production (commonly caused by the auto-immune destruction of pancreatic beta cells that produce insulin and not related to lifestyle factors). Type 2 diabetes is the more common form at approximately 90% of cases (310+ million people worldwide), widely known as non-insulin dependent diabetes, and is caused by the bodies ineffective use of insulin. Type 2 diabetes often results from lifestyle factors including excess body weight and physical inactivity [1].

Increased levels of BS (Blood Sugar), maintained over long periods lead to serious complications for the diabetic patient. These complications are significant and have both short term negative symptoms as well as long term impacts on the patients health [2][3]. As a result diabetes is currently the worlds leading cause of blindness, amputation and kidney failure. The World Health Organization [1] predicts that by 2030 diabetes will be the 7th leading cause of death.

These figures indicate that the need to improve outcomes for diabetics, through improved management of the condition, is a worldwide priority. Poor diabetes management leads to serious health complications and costs for both the individual and society at large. Diabetes represents one of the worlds most significant health concerns.

‘Immediate action is needed to stem the tide of diabetes and to introduce cost effective strategies to reverse this trend’

(World Health Organization [1])

1.2 Managing Diabetes

Although these introductory statements sound relatively grim, there is significant potential to improve diabetic outcomes. Much of the worldwide problem relates to undiagnosed and untreated diabetes. More than 80% of diabetes related deaths occur in low-middle income countries. In cases where patients have access to diagnosis and management the rates of complications are lower. However even with the most modern management techniques, including the use of software based management tools, the diabetic patient has a significantly increased risk of complications. In order to reduce those risks the patient must commit to a complex diabetes management regime [1][4][5].

Diabetes is a self managed condition where the patient manages, on a day-to-day basis, the way that medications, foods and activity are utilized to best maintain “near normal” blood glucose levels and hence limit health complications. This management task is difficult and many diabetics, and those involved in their care, find it a challenging issue to maintain “near normal” levels [6][7]. This is evidenced by studies such as those by Quinn [8], which indicate that less than 7% of diabetic patients meet target levels.

Long term studies have shown that improved blood sugar control (that is keeping diabetic blood sugar levels as close as possible to the normal range) reduces medical complications caused by both type 1 and type 2 diabetes [2][3].

Studies, including Connelly et al. [9], Garg et al. [4] and Balas et al. [10] have also demonstrated that the more engaged patients are in the management of their own condition, the better the health outcomes. To be effective in this self management, patients need to understand the relationships between medications (insulin), food (carbohydrates) & activity and their related impact on blood sugar levels. Unfortunately the information is complex and for an untrained professional this information is difficult to manage.
1.3 Managing Diabetes: Day to Day

With support of endocrinologists and diabetes educators, patients self manage the condition. Yet managing this condition is a complex task, there are many factors to understand and consider on a day by day, hour by hour basis. On a common day a patient will wake, undertake a blood sugar test, plan food to be eaten at breakfast, plan activities to be undertaken that morning then based on the combination of these factors decide how much insulin is needed to match the morning plan, finally the patient delivers the insulin (through either pumps, injection pens or in some Type 2 cases no insulin is required (diet alone)), eats breakfast and begins activities. This is repeated for every meal or change in the plan. The patients ability to judge these factors is what determines good or bad blood sugar levels for the morning. It is clear that the long term health implications of these judgments are high, yet in the short term these decisions are also critical. If the patient uses too much insulin, then they will have low blood sugar (hypoglycaemia) which is dangerous and can cause impaired ability and at extreme levels, unconsciousness and even death. But if they have too little insulin (hyperglycaemia – high blood sugar) this leads to short term symptoms and serious long term complications.

The big picture aim is to bring diabetic blood sugar levels to low levels (as close as possible to non diabetic). Health professionals provide assistance on a longer term basis (commonly meeting patients on a 3 monthly cycle), where they undertake analysis of blood sugar results and long term control levels such as HbA1c. From this retrospective analysis, areas of concern are identified and recommendations made (eg. lunch BS levels too high consistently, try more short acting insulin at breakfast). This approach follows the classic “problem solving” health professional method of diagnose problem and recommend treatment. This information is very useful to the patient and provides good tracking of how their control is progressing.

This approach works well but it has a relatively negative perspective (ie. diagnose the problem, find the faults in treatment and correct them). It is important to note that this approach is mirrored in most diabetes management software tools (ie. present results and find faults). For the health professional, this retrospective analysis of BS results is an effective means of reviewing progress and adjusting to make improvements. The information provided in the form of BS results, HbA1c and other blood levels are useful for the health professional in making their analysis and diagnosis of issues. Hence these tools are effective for the health professionals needs at the regular 3 monthly analysis meetings.

For the patient the issues are slightly different. Each day the patient does a blood test and must make decisions (based on activities, current BS levels, food to be eaten), although the retrospective analysis data is useful in broader terms, it doesn’t directly assist the patient in making the day to day decisions. Those decisions are directly related to the patients understanding of the effect of activity, insulin and food on their body and how to best generate the desired BS levels. This is complex and is a skill gained over many years of experience. It is this skill and knowledge base that the Diabetes Visualizer app targets.

1.4 Self Management Software Tools

Given the complexity of the information presented to the diabetic, it is easy to understand how many people associated with diabetes are confused and overwhelmed. To assist in managing this, there are many software and web based tools under the category “diabetes management”. These tools have been designed with the intent of assisting diabetics to manage their condition (and the complex information that comes with it) and these have come in a variety of forms. The great bulk of software tools relate to data transfer and statistical analysis of blood sugar results. More recent developments have seen these “diabetes management” tools move onto the mobile/handheld platform where apps now provide this functionality in the palm of the diabetics hand. Recent systematic reviews, such as Chomutare et al. [11], of diabetes management related mobile apps, have shown that statistical analysis of blood sugars, data transfer and food recording are the main functions of these tools. The
main finding from this systematic review is that a critical feature strongly recommended by clinical
guidelines -namely, personalized education- is not assimilated in current applications. Related
systematic reviews have also identified the fact that tools are very task specific (eg. food recorder, BS
recorder) and these reviews indicated a need to unify the tools.

“Applications that support healthy eating habits should be integrated with applications for
managing blood glucose data and physical activity data, and potentially medication data as
well”  Arsand et al. [12]

At their core, all of the diabetes management software tools aim to assist the management of
diabetes. Significant studies have shown that the use of management software can improve health
outcomes by measurably improving BS levels. Studies of individual tools such as the Bant mobile app
found improvements in the engagement of participants with the management task – a 50% increase in
amount of BS testing undertaken [13][14]. This improved engagement supports the BS outcomes
found in other trials, including trials of the WellDoc app that show statistically significant
improvements of 2.03% in HbA1c level [15][8] and GlucoseBuddy which showed a 1.28% HbA1c
improvement [16][17].

These individual tool outcomes match the findings from 3 systematic reviews, by El-Gayar et al.
[18], Holtz & Lackner [19] and Boren et al. [20], on the health impact of mobile diabetes management
software tools. These reviews found that, due to the new nature of the mobile platform, further long
term testing was needed to confirm findings, but that initial results indicate the significant positive
impact that diabetes management apps had on diabetic BS control [18][19][20].

These finding match earlier studies on diabetes management that found that a patients engagement
in their own condition directly relates to improved BS control. We also know through related large
scale studies that better BS control is linked to higher quality of life for diabetics [21][22].

These examples demonstrate that diabetics can improve BS control through the use of digital
software tools, yet the number of diabetics who regularly use these tools is small. One of the key
challenges is to make the software tools more engaging, so that the patients find them easier to use,
and the knowledge easier to obtain. It is this human-computer interface between the user/patient and
the complex diabetes information/knowledge that this project focused on.

Figure 1: Example App Interfaces [13], [23] & [24]

Figure 2: More example App Interfaces [16]
As the images in figures 1 and 2 show the existing interfaces of the mobile tools are largely based on data entry/recording and 2D statistical/chart analysis of retrospective BS data (note that SIDiary uses a 3D pie chart but not interactive 3D graphics, otherwise none of the existing tools use interactive 3D computer graphics). Unfortunately most diabetic patients are not statisticians and find this analytical work challenging and difficult to engage with. The study by Tse et al. [25] demonstrated the fact that many diabetics had limited skills with statistics and charting and found they needed specialized induction into the use of tools of this type. Fortunately patients learnt quickly, but had difficulty engaging initially and staying enthusiastic about the tool use. This demonstrated a need for a more engaging way of presenting this complex diabetes management information.

The elements of the apps that are listed as “most engaging”, by users in studies, relate to items outside the analytical tasks, for example in the study by Cafazzo et al. [14] it was demonstrated that the “bant app” has strong social media links and this feature is a unique and effective part of the system.

2 Diabetes Visualizer 3D Game

The Diabetes Visualizer app designed in this project aims to more effectively engage with users. To do this the app is designed to utilize several key areas, these include interactive game play (experimentation with options and learning in process) and 3D animated & interactive first person visuals (3D first person has dominated the computer game industry for more than 20 years yet this successful form of engagement has not been previously applied in diabetes management tools).

The Diabetes Visualizer uses a simple, yet graphically rich interactive system to present the same information (see Figures 3 & 4). The key differences are in the use of interaction, 3D graphics and animation. The animation allows the viewer to see the changing status of “blood sugar” over time as an animated visualization in contrast to the more static points on a chart as shown in Figures 1 & 2.

![Figure 3: The 3D Diabetes Visualizer.](image)

The Diabetes Visualizer tool presents a very uncluttered 3D interface featuring a large 3D tube (shown in red in Figure 3) with the viewer being positioned inside the tube (much like being inside a blood vessel/tube/ring system that is flowing past). This tube is a visual representation of the blood vessel and within that tube there are several small 3D objects. These objects can be of several different types, representing differing foods, blood sugar or insulin. A variety of object types were trialed for this purpose with the simple sugar cube being chosen as most effective for blood sugar and the simple blue droplet being chosen for insulin. Note that food types are represented as shapes of that type eg. a banana shaped 3D object). These objects represent unit measures (where one insulin “ball” is a match
to one “cube” of blood sugar). Thus a snapshot in time of the basic display shows the amount of blood sugar at that point in time. Time changes and the display is animated to show this, with the tube flowing past the viewer and showing the changing amount of blood sugar over a time period.

The ring cycles constantly, rotating around towards the viewers position representing changing time (also indicated via the clock in the upper right hand corner). This time scale is significantly accelerated relative to “real” time, thus allowing the user to visualize the effect of food/insulin over several hours in a very quick accelerated cycle of less than 30 seconds.

The visualization involves the tool calculating the blood sugar level (either by using blood sugar data from patients blood tests or using a predictive model based on insulin injections, activity and food to be eaten), these calculations are then used to display the correct amount of “sugar cubes” to match the food eaten and the correct amount of insulin “balls” to represent the insulin injected. Using calculations based on the absorption rates of the food and insulin the visualization then shows the patient the effect of the food/insulin over a period of time. The objective here is for the patient to see the impact of food and insulin decisions (the main aim being to have a match in insulin to food). When there is correct match of food and insulin there will be no sugar cubes left in the blood vessel.

The patient needs to “play” with the values to attempt to get this outcome. Although this sounds simple, the delayed impact of foods and insulin (as each takes time to be absorbed) and the differing amounts in food types and absorption rates can be very confusing. This is the difficult challenge that patients have in managing blood sugars in their normal daily lives. In this game play process, the patient comes to understand how to match food eaten to insulin injected, understanding the delays and impacts of decisions in a visual interactive way. Thus improving their skills in managing food and insulin and in the longer term their overall long term BS control.

Figure 4: The Mobile Diabetes Visualizer

As shown in Figure 3 & 4 the games display includes the red vessel, sugar cubes (representing blood sugars) and blue balls (representing insulin). When a blue ball and sugar cube are both in the vessel the ball moves to the cube and drags it away (as can be seen in Figure 3 where the ball is linked to cube just prior to removal), out through the blood vessel wall (this is the tools way of showing the sugar being used by the body when the insulin is present to allow absorption). Thus the insulin and sugar are taken out of the system and the user moves towards a balanced (i.e. no extra cubes) and desired level.

On the left of the game screen are the absorption rings, these show the amount of sugar and insulin currently being brought into the body (through eating for food or injection for insulin) and give the user an indication of what is coming in the near future. For example the blue ball in the ring in Figure 4 is almost full size indicating it is almost fully absorbed and will soon be able to move into blood
vessel and remove one of those extra sugar cubes thus lowering the blood sugar level). As there is a delay between when food is eaten and when it appears as sugar in the blood, these absorption rings allow the user to see the level of incoming food or insulin (and as such they can visualize the rate of availability and also the times when there is insufficient supply of either sugar (hypoglycaemia) or insulin (hyperglycaemia).

![Food absorption (from banana to sugar with spinning absorption ring).](image)

The rings around the “food” objects spin at different speeds depending on how quickly that food type is absorbed (based on GI for food and published absorption rates for insulin) and this also helps the user to learn about different foods and how they are absorbed. This is particularly relevant for Type 2 diabetics who use diet alone to manage their condition.

The calculations of how insulin and food is absorbed are based either on a rule based system (the default involving known absorption rates for insulin types & foods, and the amounts of carbohydrate content in a serving) or calculated from the users blood sugar and food data as provided by the patient. If the system is provided with information on food and insulin intake by the user and also blood sugar impact, the tool then calculates the rates of the absorption and bases its timing on those. Note that this is not a definitive system. To be highly accurate in predicting blood sugars there is a need for any tool to include far more factors and personal adjustments (eg. exercise, activity, stress can all alter the absorption rates on an individual basis). As such the tool is a simple predictive model that provides an indication of expected impact rather than a highly accurate personal blood sugar predictive tool. As its primary role is in engaging the user and helping in learning, this is not critical at this point, but it does offer potential for future research to refine the predictive elements that may be relevant on a patient specific basis.

This visualization/game attempts to make the understanding of blood sugars easier by using a combination of rich 3D graphics in conjunction with animated 3D flow and interaction. This is much more active and graphically rich than the commonly used 2D charts and it is this rich game play and interaction which is the core innovation of this tool. In playing this game, and attempting to balance the insulin and sugar intakes, the player learns important skills in judging food content and matching that, both in amounts and timings, to the insulin needed to maintain good blood sugar levels.

The predictive model allows the player to propose scenarios, involving differing food intakes and then attempt to match those. This allows the patient to think through possible options and ways of handling common real-world situations and virtually play out a “prediction” of that scenario.

The “play” oriented nature of the tool allows patients to experiment with different food and insulin levels and visualize the outcomes without needing to experiment with “real” food and insulin. The game challenge of eliminating the extra cubes gives players a sense of satisfaction and in the process helps to teach the player how insulin and food interact and how to manage them more effectively.

In reality this tool is definitely slower to display the data than the equivalent 2D chart (as it will take time to “flow” through the time and changes), but it offers new levels of engagement and a much richer visual experience for the patient.

The aim of the tool is to provide the user with skills (and knowledge) of how blood sugars are affected by food, insulin and activity. The main audience for the tool is diabetics, in particular those...
who are new to the condition and learning how to manage it successfully. The tool is also relevant to non-diabetics who are involved in activities with the diabetic, such as family, friends and carers.

3 Results from Experimental Process

This project’s focus is on the usability and ability of the human-computer interface to engage the user in diabetes management. It also looks to identify whether 3D interactive game play can make complex medical data more accessible to a mainstream audience.

From a health perspective it is clear that avoiding long term complications is the key objective for diabetics. A separate long term study is currently underway reviewing the specific diabetes related health outcomes from this tool. Previous research has shown that software tools, when used, are effective in helping improve BS control. This study looked at developing new forms of interface between the diabetes software tools and the human user with the aim of encouraging and assisting the user to engage with the task diabetes management and it is this interaction and engagement that was experimentally surveyed in this paper.

This randomized control study involved twenty two trial users, all over the age of 18 years and all volunteers. It included a representative group of potential users, including participants who had no knowledge of diabetes (representative of those new to the condition & family) as well as participants who had existing knowledge of the condition (both type 1 and type 2). The participants were randomly allocated into one of two groups, the control group – who used a 2D charting app to engage with diabetes data, and the 3D Visualizer group – who used the 3D Diabetes Visualizer app to engage with diabetes data. The engagement task included both viewing and interacting with recorded data (viewing results from blood tests and food data) as well as experimenting with possible outcomes from “real” scenarios. The trials involved no special training or experience with the diabetes or 3D systems prior to testing.

The experiments were designed to isolate one feature of an interface (e.g. take the same task with the same items only presented in a different manner). To achieve this all other factors are kept consistent across the trials, including the hardware, device set-up, software systems used and data presented. By maintaining this consistent system, and having the trial interface as the only varying feature, conclusions can be reached regarding the relative performances of the systems and the effectiveness of the various forms of presenting data to the user.

As the charts in Figure 6 show, the 3D Diabetes Visualizer (average 8.67 out of 10) received ratings of engagement at significantly higher levels than the 2D Chart control (average of 2.9 out of 10). The 3D tool also received higher average ratings in terms of knowledge gained, and was used for longer periods of time in the trial, but these were not statistically significant.
4 Conclusions

The Diabetes Visualizer, visually presents a simple animated 3D display of complex medical information. The results from the pilot randomized controlled trial indicate that this simple 3D form of information representation (with change over time) is more effective than the widely used 2D charting information tools. The visual richness and game like interaction of the 3D tool evidently attracted the participants, and this ability to inspire interest alone makes the technique worthwhile. The fact that it was also useful in helping them to learn about insulin, food and blood sugar management was the major positive practical outcome from this research.

Overall, the use of interactive 3D animated presentation of diabetes data was effective in engaging participants. The preference for interactive 3D game play over 2D statistical analysis tools was significant and the systems described here could be applied in other health management topics and clearly have benefit in presenting diabetes related information to a broad audience.

References


