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Towards Early Diagnosis and Prevention of Type 2 Diabetes: the Role of Smartphones

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Abstract: ***Type 2 Diabetes Mellitus (T2DM) is a chronic condition characterized by high levels of blood glucose. In the United Kingdom (UK), about 7 million people are affected with Impaired Glucose Regulation (IGR) otherwise called prediabetes. T2DM is preventable in those at risk of developing the condition and early detection of T2DM can reduce diabetes related complications. Risk scores are a non-invasive way to detect those either at risk of developing diabetes or with current undiagnosed T2DM. In this work, we developed a Smartphone application (app) which incorporates a validated risk score for detecting undiagnosed T2DM and those at risk in a multi-ethnic UK population using XML and JAVA programming languages.***

Keywords: Type 2 Diabetes Mellitus, Android Based Mobile App, Diabetes Risk Apps, Impaired Fasting Glucose.

1. Introduction

Type 2 Diabetes Mellitus (T2DM) is a chronic condition characterized by high levels of blood glucose. T2DM is associated with increased weight and a lifestyle with irregular physical activity [1]. This condition is characterized by insufficient production of insulin or an improper functioning of the insulin producing cells in the body, leading to glucose build up in the blood.

Glucose is a continuum and there is a clinically important high risk state where glucose levels are elevated but not over the threshold for the diagnosis of T2DM. This high risk state is sometimes termed pre-diabetes or impaired glucose regulation [2]. IGR is an often reversible and under-diagnosed precursor condition that increases an individual's chance of developing T2DM by up to 15 times more than those without IGR [3] – [6]. Furthermore, IGR is associated with insulin resistance and impaired insulin secretion, features seen earlier and able to predict the development of T2DM [2]. Research has shown that T2DM can be prevented in people in this pre-diabetic state [6] – [8].

1.1 Incidence and Prevalence of T2DM

Of the world's population with diabetes, about 90% are affected with T2DM [9]. In the recent past, a growing number of young people within all ethnicities have been observed to be developing the condition [10]. The International Diabetes Federation (IDF) [11] estimated a prevalence growth of T2DM worldwide from 366 million people in 2011 to 522 million by 2030 and still, there is no adequate measure to stem its growth. From this estimate, 183 million people were estimated to have undiagnosed T2DM [11]. T2DM reduces life expectancy by as much as 15% with about 75% of deaths caused by macro vascular complications [12]. T2DM and IGR have been associated with increased risk of cardiovascular diseases [13], [14]. The problem with the incidence and prevalence of T2DM is that, the disease is not easily noticed as the symptoms develop slowly. Thus, it can take a long time before T2DM is fully diagnosed and treated.

IGR has been detected in about 7 million people in the UK [2]. Epidemiological research carried out in Asia, Europe and North America has shown that approximately 15% or 1 in every 7 adults has IGR following the WHO criteria for classification [15] - [18].

1.2 The need for risk prevention

The high prevalence of T2DM and its attendant lack of a cure, calls for early diagnosis of the disease and proper intervention focused on disease prevention. T2DM becoming the 7th leading cause of death by 2030 [18], necessitates the need for risk prevention. Risk scores provide an easy method of identifying those at high risk of developing the disease [19]. The Leicester Practice Score (LPRS) is a validated risk score for detecting undiagnosed T2DM and those at risk in a multi-ethnic UK population [20]. The score was developed by summing up the beta (β) coefficients generated from a custom logistic regression model for predicting IGR and T2DM using data which were routinely collected and stored in primary care [20]. Categorical variables considered in the development of the score included age, ethnicity, sex, family history of diabetes, antihypertensive therapy and Body Mass Index (BMI). There is less evidence that early treatment of T2DM contributes significantly to reducing associated complications [21], however, sufficient evidence does exist for delay in the rate of progression from IGR to T2DM with the adoption of lifestyle modification strategies [2], [22].

Using the Leicester Practice Risk Score, we focused on the detection of IGR and undiagnosed T2DM which allows for preventative measures that are cost effective and nearly as good as pharmacological interventions in delaying the progression to T2DM [22], reducing mortality and morbidity from CVD [2], as well as reducing the economic burden on the National Health Service, the UK, patients, as well as their families [2].

2. Related Work

Interventions using Smartphones have come a long way in aiding efficient self-care measures particularly in the management of T2DM [23]. According to Liang [23], Smartphones can help to establish a firm communication channel between health care professionals and the patient. Of special interest for the use of Smartphones in the management of T2DM, is the fact that it has a tendency to be used within the low-income earners and those with poor health status [24], [25]. The use of Smartphones in T2DM management is further enhanced by the fact that people who do not have the chance to attend a screening, have a portable and cheap device they can use to check their risk level.

Apps for Apple iOS and Android platforms exist for predicting an individual's risk of developing T2DM or having an undiagnosed form of T2DM and they can be downloaded from their different app stores. However, in this review, only Android based apps were considered. Reason being that most cheap and relatively affordable Smartphones run on Android platform.

Healthier Me (Diabetes Risk Calculator): This app is based on the validated FINDRISC score [26]. It had no clear information on lifestyle modification. The app required the individual to have knowledge of their Body Mass Index (BMI) prior to taking the test. It further required users to respond to 10 different questions around their diet, health and current lifestyle in order to determine their risk level.

Irahhoten (Diabetes Risk): The app though not based on any validated risk score [27], recommended adequate lifestyle changes relative to the user's risk level. It also offered the opportunity for users to identify their daily food requirement based on age. With the app, individuals could tell their risk of developing or having developed the disease condition.

TonicMinds (Diabetes Risk Calculator): This app is also based on the validated risk score (FINDRISC) [28]. It provided adequate lifestyle change information and stored the last outcome of the individual's assessment. It displayed the individual's BMI with an explanation of its implications

Lloydspharmacy (Diabetes Check-up): This app looked at basic risk factors as well as other factors like smoking and alcohol intake levels [29]. The app had the feature to email assessment results to users upon submission of email addresses, provided hyperlinks to more information on T2DM. In addition, Google Map feature was used to locate the nearest Lloydspharmacy based on user Post code. Refer to Table 1 for further details on the analysis of existing Smartphone apps on the prediction of an individual's risk of developing T2DM.

3. The Proposed System

In this work, we designed a Smartphone app which incorporated the validated Leicester Practice Score in a multi-ethnic UK population. The uniqueness of this design was in the incorporation of a reminder service via text messaging and email to the user at a predefined time (usually every 3 months), in addition to other features like access to lifestyle modification tips, interpretation and implication of calculated BMI using graphs and colour coding schemes, and the implication of predicted risk scores to daily living. Refer to Fig. 1 for a description of the application flow of the proposed system.

4. Programming the Proposed System

The design and development of the app made use of various development tools. These tools are described and how they were used briefly;

4.1 Android Software Development Kit (SDK)

The Android SDK is a collection of development tools that are used for building apps for the Android platform [30].These tools include the required libraries, an emulator, a debugger, Application Programming Interface (API) documentation, sample source codes, and tutorials for the Android Operating System. With the SDK, Software for Android devices can be written in Java [31]. This gives room for a high level of platform independence (such that apps can be developed to run on various devices without any major adjustments). Although Android programs can be written from the command line using the SDK, it is recommended that an integrated development environment (IDE) like Eclipse with the Android Development Tools (ADT) plug-in, be used.

4.2 JAVA

Java is most well known for having the feature called platform independence. This feature enables all java programs, which are compiled into byte codes to run on any machine that has a Java Virtual Machine (JVM) installed, regardless of the internal structure of that computer. Other notable features of Java are; it is Object oriented, portable, secured, can run multiple threads, and works on a distributed environment.

4.3 Eclipse

Eclipse is an IDE that provides a high level of support for JAVA code editing, validation, successive code compilation, code cross-referencing, and an Extensible Markup Language (XML) editor. Being open source, it is also considered extensible [32]. Developed in 2001 by IBM, Eclipse carries special features such as code refactoring, code unit testing, automatic code updates, a task list, and linking with the Jakarta Ant build tool [31]. According to Scott [32], Eclipse offered a unique feature that made it platform and language independent. It further supports other languages such as Python, PHP, Ruby, and C#. This way, with a single IDE, development can be done using multiple programming languages.

4.4 Extensible Mark-up Language

Derived from Standard Generalized Markup Language (SGML), XML is a very simple and flexible text formatted language designed for handling the display of large-scale electronic data [23]. Today, XML is used for transferring data between all sorts of applications. Like Java, XML is a platform independent tool that receives and displays data sent to it from other applications [33].

4.5 App Logic and Coding

The app's interface was designed using XML. XML tags were used to define the controls and their properties as well as the layout and the kind of data to receive and display. The checking for valid data input, calculation of BMI and risk scores, as well as communicating results to user was implemented via JAVA.

A brief introduction to T2DM and how it can be developed is given. Further explanations on risk scores and their development, how T2DM can be diagnosed and properly managed, what the symptoms are, and the importance of taking a self-assessment test are displayed on Fig. 1. The user is able to view the related research article on the development of "the Leicester Practice Score" (See Fig. 2).

With the BMI calculated using the data for the user's weight and height, a graphical display of the users BMI range is shown (See Fig. 3).

Only after calculating their BMI can the user then proceed to calculate risk score. The values retrieved for each categorical variable, plus using the validated statistical coefficients assigned to each categorical variable was used in deriving the risk score (See Eq. 1 below).

Risk score = (age x 0.0408359) + gender + (BMI x 0.0820698) + ethnicity + family history + blood pressure …………………………… Eq. 1

Where;
Gender = 0.1839942 if male, or 0.0 if female.
Ethnicity= 0.7565977 if other ethnic group, or 0.0 if white European.
Family history = 0.4770517 if there is a family history of diabetes, or 0.0 if none.
Blood pressure = 0.5498978 if on blood pressure medication or 0.0 if not on medication.

The risk score and its corresponding risk level are displayed to the user (See Fig. 4). The checkbox option on Fig. 5 enables the user to set up a reminder service via a Short Messaging Service (SMS) as to when next to take the test. A comprehensive summary of the test information and results gets forwarded to the user's email as well.

5. Implementation and Performance Evaluation

The application upon successful installation can be launched by double clicking the app icon from its installed location on the device. The user then continues by reading through the instructions and executing the corresponding actions. See Fig. 7;

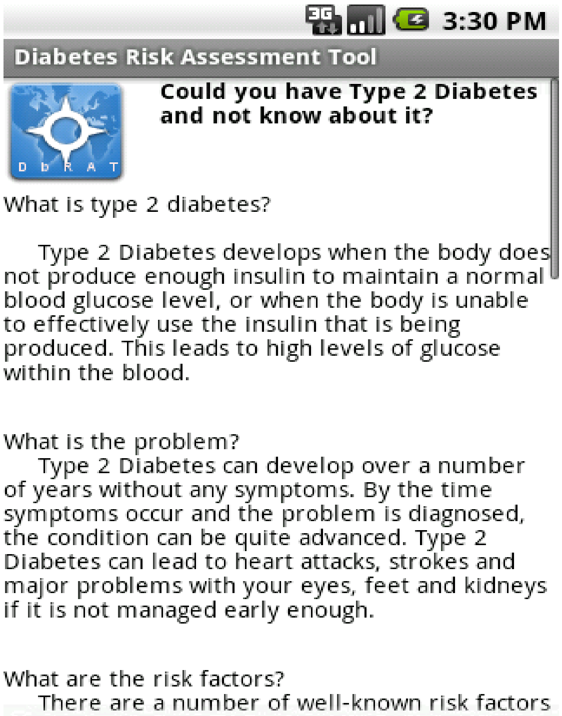

Figure 1: Introduction to Type 2 Diabetes, Risk scores and how it can be managed.

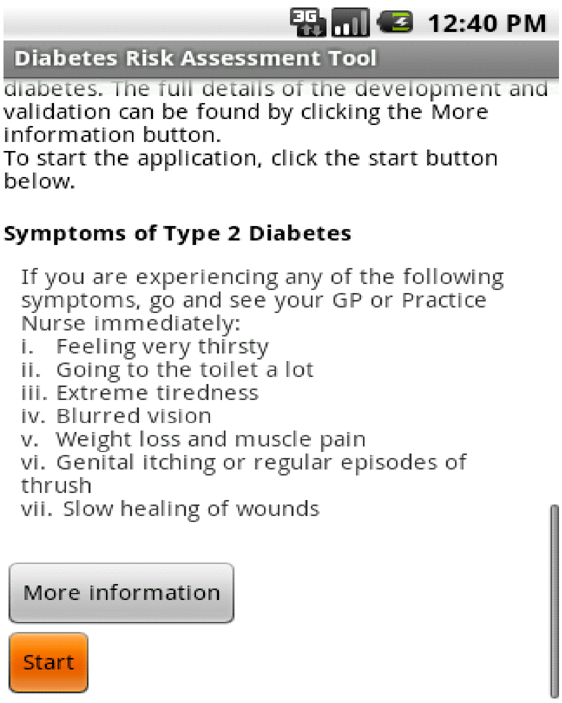

Figure 2: Symptoms of Type 2 Diabetes and link to related research article on the Leicester Practice Score.

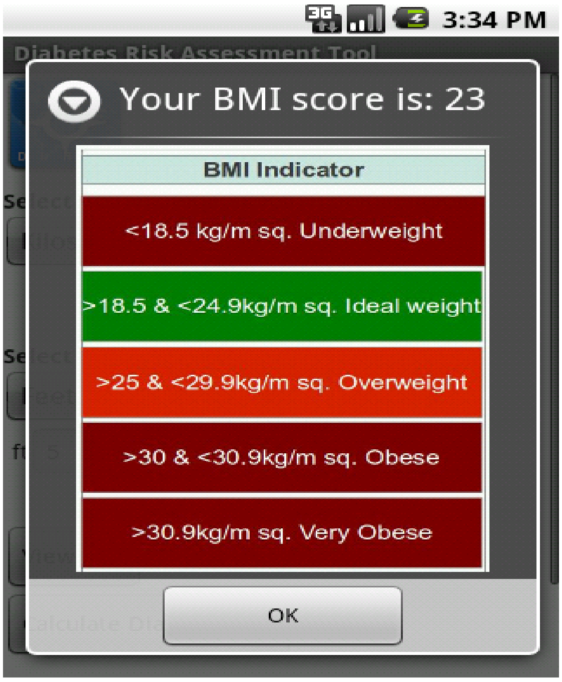

Figure 3: BMI indicator using colours to indicate the significance of the BMI score.

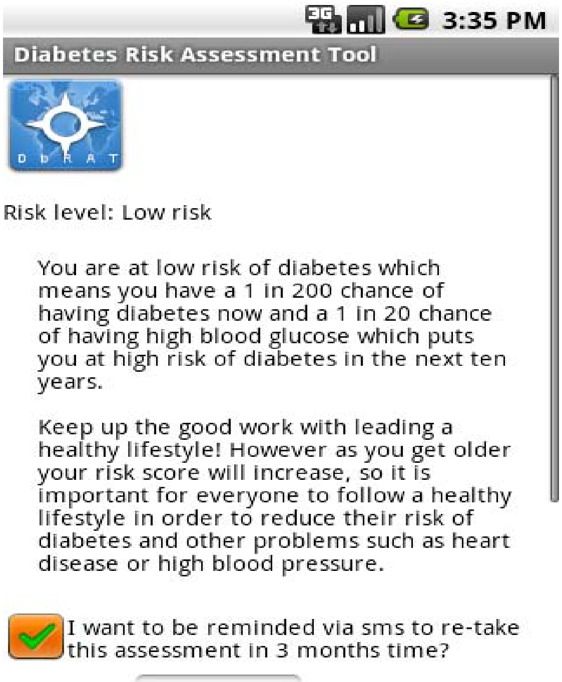

Figure 4: Notification of user risk level and option to get reminded in 3 months to retake the test.

Figure 5: Validating user input.

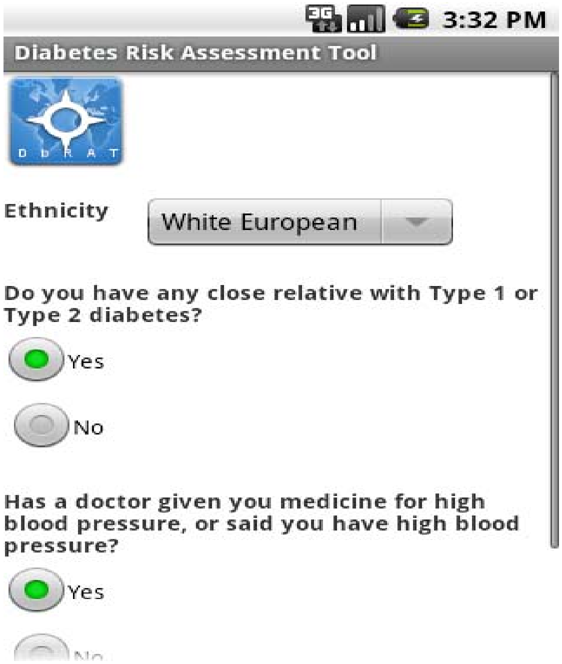

Figure 6: Responding to one of the categorical variables.

The performance of this app was evaluated using real life data. The time it took to generate risk scores was significantly improved and the scores generated measured approximately with scores obtained from practical surveys. Refer to Fig. 8 below for details on this comparison.

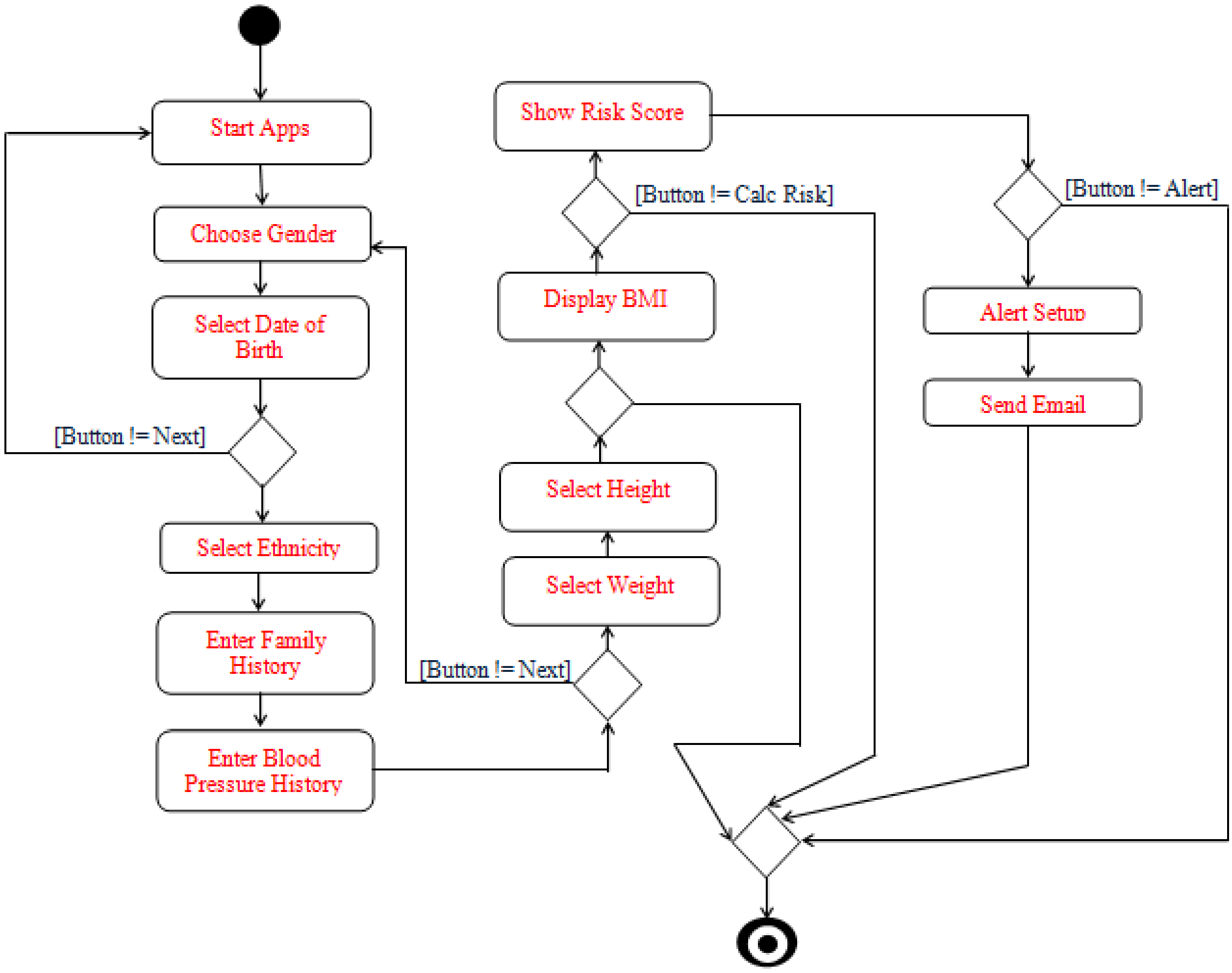

Figure 7: Activity diagram of the proposed solution

sex	age	height	weight	bmi	antihyp	familyhx_crf	eth2	myscore	Prog. Scores
Female	64	1.59	79.3	31.36743	Yes	Yes	White Eur	6.214766	6.2147305166
Male	54	1.67	86.4	30.97996	No	Yes	SA/other	6.165301	6.165304604
Male	44	1.71	51	17.44126	No	No	SA/other	4.168773	4.1687508818
Female	44	1.54	64.2	27.07033	No	No	SA/other	4.775034	4.775006786
Male	42	1.8	129.2	39.87654	No	No	SA/other	5.92836	5.9283971146
Male	49	1.77	73	23.3011	No	No	SA/other	4.853867	4.8538594098
Female	59	1.49	62	27.92667	Yes	No	SA/other	6.00775	6.0077769046
Female	44	1.58	55.2	22.11184	No	Yes	SA/other	4.845143	4.8451564176
Male	46	1.7	84.7	29.30796	No	No	SA/other	5.224341	5.2243449984
Male	65	1.64	62.2	23.12612	Yes	Yes	SA/other	6.519831	6.5198210948
Male	32	1.65	64	23.50781	No	Yes	SA/other	4.653673	4.6536892584
Female	41	1.56	84.3	34.64004	No	Yes	SA/other	5.750823	5.750819172
Male	41	1.67	74.3	26.64133	No	No	SA/other	4.801312	4.8012853418
Male	41	1.57	50.3	20.40651	No	Yes	SA/other	4.766674	4.7667139086
Male	53	1.65	67.4	24.75666	No	Yes	SA/other	5.61372	5.6137483386
Male	32	1.74	111	36.6627	No	Yes	SA/other	5.733293	5.7333174774
Male	28	1.65	61.2	22.47934	No	No	SA/other	3.928872	3.9288441342
Male	45	1.65	84	30.854	No	Yes	SA/other	5.78744	5.7874407092
Male	40	1.74	73.04	24.12472	No	Yes	SA/other	5.030991	5.031013525
Male	44	1.68	73.3	25.97081	No	Yes	SA/other	5.345842	5.3458579758
Male	47	1.61	58	22.37568	No	No	SA/other	4.696247	4.6962730448
Male	58	1.66	72.8	26.41893	Yes	Yes	SA/other	6.50422	6.5042256462
Male	59	1.68	92.8	32.87982	No	No	SA/other	6.04835	6.048365024
Male	52	1.72	102.3	34.5795	Yes	Yes	SA/other	6.928941	6.928981884
Male	72	1.74	68.2	22.52609	Yes	Yes	SA/other	6.756438	6.7564305148
Male	49	1.67	78.8	28.25487	No	Yes	SA/other	5.737474	5.737484899

Figure 8: Established data used for verifying program: the data under column “myscore” refer to established risk scores while data under column “Prog Scores” in yellow refer to risk scores generated from the app.

Table 1: Analysis of Android Based Smartphone Apps for Type 2 Diabetes Risk Calculation

App Name	*Risk Score Used*	*Questions Asked*	*Recommendations*	*Other Features*	*Design Style*
Diabetes Risk (A. Irahhoten)	N/A	Gender, Date of Birth, Weight, Height, Waist size, Daily 30mins exercise, High blood Pressure, High blood sugar level, Record of family history	Provided	Detailed explanation of risk outcomes recommended lifestyle, identification of specific risk factors for the individual, list risk boundaries and explains the implication of each category, displays BMI and what lifestyle measures required to managing it, specifies daily food for a man between 19-50 years.	Provides two different options for weight and height data (lbs. and feet/inches, kg and cm).Categorisation of questions into separate pages. Application starts with a short introduction to Type 2 Diabetes and the test intends to achieve. Has a Start Test button that is clicked to commence risk calculation process. Clicking the Back button at each stage takes you back to beginning the test all over again (design error).
Diabetes-risk-calculator (TonicMinds)	FINDRISC	Gender, Weight, Age Height, Waist size, Daily 30mins exercise, use of drugs for high blood pressure, under doctor's prescription, Record of family history, daily intake of fruits and vegetables.	Provided	Displays BMI and explains its implication. Specifies physical activities required to manage condition. Displays risk score on the results page.	Categorization of questions into different pages.
Diabetes-risk-calculator (Healthier Me)	FINDRISC	Gender, BMI, Age, Waist size, Daily 30mins exercise, use of drugs for high blood pressure, blood sugar level during pregnancy, Record of family history, daily intake of fruits and vegetables.	Not clearly given	Not provided	No categorization of questions. Everything just in one page. Provides an author's disclaimer at the end of test.
Lloydspharmacy-diabetes-check	Not documented	Gender, Weight, Age Height, Waist size, Ethnicity, Smoking status, alcohol consumption level, Daily 30mins exercise, high blood pressure, blood sugar level, Record of family history, daily intake of fruits and vegetables.	Not provided	Request user contact for emailing results. Provides web links to further information on Type 2 diabetes and also a location map to nearest Lloyds pharmacy based on user location. Requires user to accept Terms and Agreement before using apps. Results page with a notification of results sent via email as well. Regular notification/advertisement of related products and drugs to user via email.	App starts with a user agreement window with an Accept or Decline button. Questions categorized into three sections/pages. Provides a mini registration page from where email address and post code are extracted to be used for emailing results to user and providing a map to nearest Lloyds pharmacy to user if he indicates he wants such at the end of the test.

6. Future Scope of the Study

Our future research will aim at incorporating other validated risk scores to cover a larger population of users as well as introducing multi-lingual features within the app. Furthermore, the research intends to expand development to other OS platforms such as Windows and iOS enabled smart phones.

7. Discussion and Conclusion

Early detection of undiagnosed T2DM and those at risk is a very important step in the prevention and delayed progression from IGR to T2DM. Incorporating a validated risk score (the Leicester Practice Score) for a multi-ethnic UK population, a Smartphone app was developed for the early detection of T2DM and most importantly, the detection of IGR which allowed for preventative interventions such as lifestyle modification, thus offering a more cost effective means for reducing the rate of progression to T2DM and a nearly as close treatment strategy to drugs. In three simple steps, the users' risk level is assessed and a predicted score is given, taking away the need for paper questionnaires or gaining access to a General Practitioner (GP) in order to know ones risk level. With an adoption and consistent practice of suggested lifestyle modifications, there is a great chance that risk levels will appreciate, associated complications arising from T2DM will reduce, life expectancy will improve and the individual would live a normal healthy life. Every three months, a reminder is initiated on the app for a routine risk assessment check. GPs and other health care professionals are able to optimize their call time to other essential medical cases as the number of patients with T2DM calling at the health centers is significantly reduced.

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