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Self-care using apps for smartphones and other mobile device software: a systematic review of the literature using the example of diabetes mellitus

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1 Context

1.1 Background

Mobile electronic devices (MEDs) have found uses in healthcare since 1987[1] when the first handheld computers emerged. First described as tools for research, possible uses for clinicians and patients were quickly identified. Prior to 2007, mobile device applications for clinical use had been developed and evaluated for at least 15 years but with limited adoption outside specialist informatics centres. Handheld devices had found niches in some developed settings – for example to support hospital pharmacist documentation[2] – but had not become part of the routine for most clinicians. Real world applications for patients were even fewer: research programs appear not to have translated into practicable programs for wider use.

The advent of a new generation of increasingly sophisticated MEDs from 2007 onwards has renewed interest in this area. Smartphones and tablet computers boast responsive, bright touchscreens; improved battery lives; integrated sensors and connectivity that were unavailable in the previous generation of technology. The total cost of ownership remains moderately high but the price is competitive against desktop and laptop computing and is falling[3]. Unlike earlier MEDs which were used chiefly by business these are consumer commodities and we use the term consumer MED (cMED) to highlight this change (further defined in 3.1.3.2). In June 2010, 73.5% of contract phones sold in the UK were smartphones[3]. Suddenly, there are increasing numbers of patients potentially having *their own* device that might support medical functions.

Part of the interest in MEDs is the ability to extend their functionality with custom software programs. This capability has always existed for MEDs but has been popularised since 2008 under the banner of 'apps'. The launch of 'app stores' – web-based directories that catalogue and vet these add-on software programs – has helped raise their profile to the extent that by January 2011, one provider was able to report that it had served 10 billion apps to its customers[4].

Achieving safe, timely and effective care, accessible to all and centred on individuals needs[1] is an established feature of healthcare strategy in the UK[2,3] and internationally[4]. A sixth dimension of quality – efficiency – recognises that improvement must take place in health systems subject to increasing resource constraints[2,5]. This has triggered interest in self-care programmes[6] that may reduce the demand for direct interaction with healthcare providers and, by encouraging health promoting behaviour, reduce future demand for services. A proposed 'Information Revolution' for the NHS argues that a shift from meeting the information needs of healthcare professionals to those of patients will be needed if self-care is to become routine[5]. The repurposing of consumer products, for example using apps for MEDs, rather than the use of specialist or bespoke medical technologies has been identified as a potential enabler of self-care[5].

This protocol describes a systematic review of self-care apps for cMEDs that targets policy makers and clinicians interested in the readiness of health apps for safe, cost-effective adoption in chronic disease management. A large number of studies have been published that examine apps for healthcare (>2300, our data), many of which pre-date 2007 and consider older MED technologies. The size of this corpus makes it infeasible to summarise within a single review. Instead, we decided to identify a condition or demographic group that could form the basis of a more focused review but that would still be somehow representative of progress in the field as a whole. A scoping process was carried out in which a sample

of 1013 studies were reviewed to ascertain information about the breadth of populations, interventions, comparisons and outcomes that were assessed. Decision criteria to select the final focus area were not established in advance but relied on consensus discussion within the review group.

From this review process, diabetes mellitus was identified as a suitable focus. The following factors informed the choice:

- **Diabetes offered the largest number of research studies likely to offer unbiased assessments of efficacy.** A larger number of randomised studies relating to health apps were identified for diabetes than any other chronic condition.
- **Glucose control is a validated proxy for clinical outcomes.** Glucose control (and its proxy measurements e.g. glycosylated haemoglobin) has an established causal relationship with improvements in subsequent mortality and morbidity in diabetes[5]. This link offers a potential means to illustrate the clinical efficacy (or otherwise) of health apps as interventions. Equivalent links may be harder to demonstrate for other conditions.
- **Structured education programs and self-monitoring are recommended components of diabetes care.** 2010 SIGN guidance[6] (more up to date than the equivalent NICE guidance) recommends structured education for all children and adolescents, all individuals with type 2 diabetes and type 1 adults who fail to achieve glycaemic control (Grade A evidence). Self-monitoring (but not continuous monitoring) of blood glucose is recommended for patients who are using insulin and who know how to titrate their dose (Grade B evidence). The guidance also recommends tailored interventions for weight loss and exercise.
- **Diabetes is prevalent and costly.** A recent multinational cross-sectional study estimated that there were 347 million adults with diabetes in 2008, representing increase in prevalence of over 1.5% compared to 1980[7]. Although global trends suggest that increases will continue, this will probably be localised to some areas (e.g. Oceania[7]). Current spending of at least USD 376bn on diabetes prevention and management is forecast to exceed USD 490bn by 2030[8].
- **The cost challenges for diabetes mirror those for other chronic conditions.** At a time when it is unclear if resources will be available in many health economies to meet these increases, it may no longer be enough that treatment options are cost-effective: they should actually *cost less*. In this respect, diabetes highlights a common challenge for the future management of long term conditions and allied public health problems like obesity[9]. The scale of the 'diabetes epidemic' may be unusual but concerns about treatment costs, efficacy and quality, integration into practice, and the research agenda that should inform decisions about these are held in common.
- **A taxonomy of seven behavioural interventions[10]** (Figure 1.1) **and a model of self-care[11,12] have been described for diabetes.** This facilitates discussion of concepts relating to the role of apps in self-care.

Healthy eating
Being active
Condition monitoring
Medication compliance
Healthy coping
Reducing risk
Problem solving

Figure 1.1
AADE7 – The seven self-care behaviours for diabetes management

1.2 Description of the condition

Diabetes mellitus is a common, chronic disorder of insulin metabolism, characterised by persistently elevated blood glucose levels. The microvascular damage that results affects neurological function, the kidneys and heart and compromises peripheral blood supply. Sufferers are at increased risk of eyesight damage, renal failure, stroke and heart attack.

Two major forms of the condition are recognised. Type 1 diabetes is caused by autoimmune mediated pancreatic damage and consequent loss of insulin production. In the Type 2 condition, insulin production may be unaffected but the hormone is unable to appropriately stimulate cells to utilise circulating glucose, a phenomenon termed insulin resistance.

Key treatment goals in diabetes are to normalise blood glucose levels and reduce modifiable risk factors for cardiovascular disease. Where insulin production continues (Type 2 diabetes) initial therapy may focus on behavioural interventions to regulate diet and promote weight loss. Drug therapy consists of supplemental insulin (the mainstay for Type 1 diabetes) and agents that reduce peripheral insulin resistance.

1.3 Description of the intervention

Health apps (short for applications) are software programs that are accessible through a cMED like a smartphone. A definition for apps has not been formally established. Using our scoping review we have developed our own definition of a health app that emphasises both technical and functional aspects (see 3.1.3.3).

Apps emerged as a distinct software category in 2008 when Apple, Inc. launched its iPhone App Store, an online repository from which apps may be downloaded for free or purchased. While the category is new, customised software for consumer mobile devices – pre-smartphone mobile phones and personal digital assistants – already existed. However, the iPhone was the first of a new generation of 'convergence' devices incorporating features of a mobile phone with that of a personal computer, the culmination of a trend of increasing sophistication in both traditional mobiles and electronic personal digital assistants (PDA). Since the 2007 launch of the iPhone there has been rapid evolution of smartphones and apps. All major mobile device manufacturers now offer their own App Store-equivalents. In addition, apps are now being made available on other portable computers and tablets and are likely to spread to traditional desktop computers[13].

On one of level of description, a health app is just one of several possible delivery methods for the behavioural components of a self-care intervention and so defines (part of) the context of those components (Figure 1.3). However, multifunction software may be capable of supporting several elements of intervention content that would normally have defined discrete components. Our scoping review suggests that app-based components tend to be a dominant feature for which other components play supporting roles (for example by providing skills to use the app). We therefore feel it also correct to recognise a category of 'app-based interventions' where an app is the main means of content delivery.

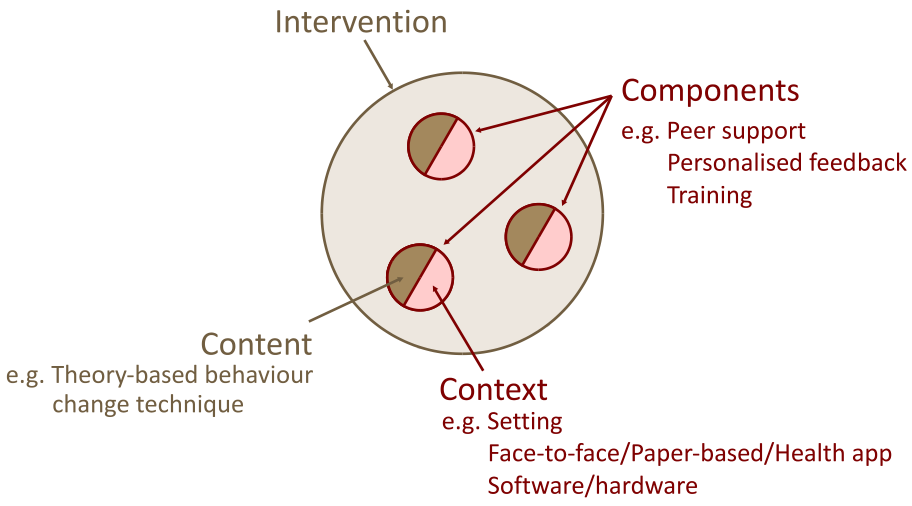

Figure 1.3

Conceptual diagram of an intervention

Reproduced from Edwards et al.,2010[14]. An intervention consists of multiple components. Each component has a content – which is intended to realise one or more goals of the intervention – and a context which represents the means of delivery, the setting and other contextual factors. Components may be interacting or substantially separate and may target different individuals at different times.

App-based interventions are, therefore, also correctly described behavioural self-care interventions. Seven self-care behaviours have been identified for diabetic patients (Figure 1.1). Underpinning these are education strategies that aim to provide patients with the skills to perform the requisite behaviours[15]. Lowering blood glucose improves mortality and morbidity[5] and blood glucose monitoring has been a recommended component of diabetes care for over a decade[16]. It is mandated when insulin is being used and is probably still effective in reducing blood glucose for those not on insulin[17,18]. While exercise also appears to improve glycaemic control[19], the positive impact of other interventions, e.g. diet[20] and treatment compliance[21] is less clear.

1.4 How the intervention might work

Theories of change provide a means within which to consider how behavioural interventions like self-care programs might work. The Information-Motivation-Behavioural Skills[22] (IMB) model proposes that information and motivation (recognised as distinct personal and social components) interact to promote the acquisition of specific skills that, collectively, influence behaviour and, ultimately, health outcomes. The IMB model was selected to consider how the intervention might work because:

- It was originally intended to influence the formulation and evaluation of behavioural interventions (aiming to modify HIV risk-behaviour s[23]) and describes a procedural approach for doing so. It was felt that this might offer a useful reference against which to compare the approaches used by studies included in the review when translating theory (and evidence) into app-based interventions.
- It emphasises the role of learning as part of the process of behavioural change[24] (e.g. in adopting and maintain self-care behaviours). Health apps for cMEDs offer the ability to collect information and use it to generate tailored feedback as part of a continuous learning process.
- An IMB model has been described for diabetes self-care and recently validated and is shown in Figure 1.5 (top panel). A causal connection between a particular health behaviour and one or more outcomes is an integral assumption in the model. For diabetes, this might be the link between glycaemic control and mortality mediated by the microvascular damage the hyperglycaemia contributes to or the relationship between weight reduction and endpoints mediated by changes in insulin resistance.

Apps may work by delivering content that targets particular elements of this model (Figure 1.5 bottom panel). For example, the information component may be supported by apps that as a conduit for information about diabetes self-care. This may be tailored to a particular recipient and supplemented with assessment mechanisms designed to reinforce learning. Specific behavioural skills may be communicated using multimedia (for example, demonstration videos) and supplemented by tools that simplify the task in practice like diaries or reminders. An app may contribute to motivation by helping users set and track their own goals and connect with others as a form of social support. A putative role for feedback of outcome information into the model is an addition the original IMB (and the diabetes-specific variant) and is untested. The IMB does not directly address factors that are likely to sustain behaviour over time, an issue that is likely to important for app-based interventions.

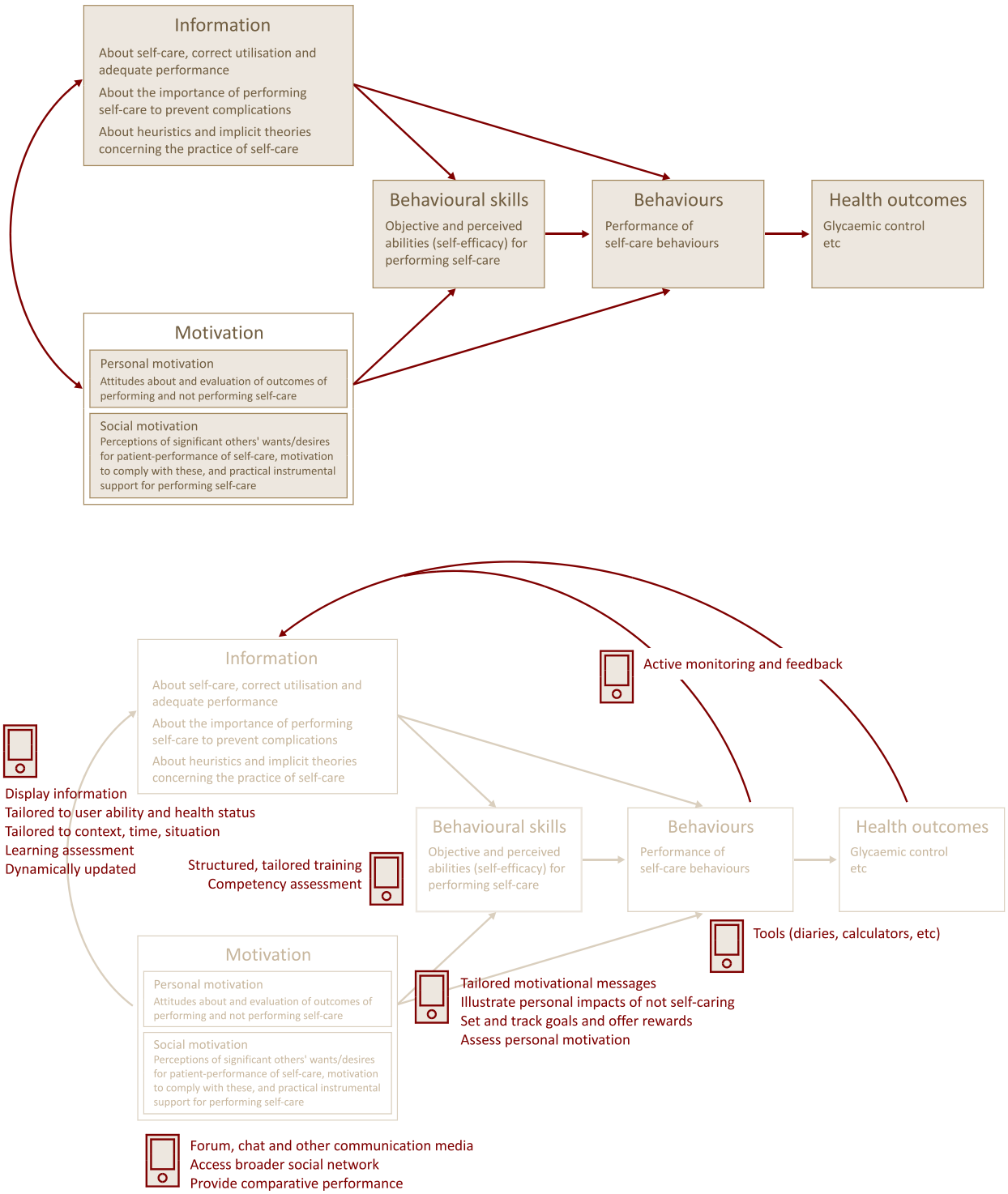

Figure 1.5

Information-Motivation-Behaviour (IMB) model for diabetes self-care

The top panel shows the un-annotated model described by Osborn[61]. The bottom panel is annotated to show potential uses for health apps. The model is explained in the text.

1.5 Adverse effects of the intervention

Self-care interventions may introduce new risks for patients, for example if incorrect management practices are adopted or if patients' usual contact with healthcare services is delayed because of erroneous advice. Diabetes self-care interventions that involve tailoring medication doses bring the risk of hypo- or hyper-glycaemic events.

A systematic review of home telehealth interventions for diabetes care suggested that these are perceived similarly or favourably compared to usual care[25]. Concerns about negative perceptions of reductions in face to face contact between patients and healthcare professionals do not appear to have been realised. Self-monitoring may cause inconvenience to patients but capacity issues for clinicians receiving potentially large amounts of additional clinical data may be more relevant.

Apps may confer particular risks related to technical reliability of the software and the hardware on which they run, the way they present and capture information, and possible unintended consequences of altering established ways of providing care.

1.6 Previous reviews

Past reviews have not identified health apps on cMEDs as a distinct intervention category and have focussed only on randomised trial and experimental evidence.

A systematic review covering publications up to February 2004 of interactive computer-assisted technology in diabetes care did not identify any cMED delivered interventions[26]. A similar review searching up to 2005 looking at new technologies for chronic disease management similarly failed to identify handheld computing interventions[27]. Of seven studies identified that concerned diabetes, none used cMEDs.

A systematic review[28] examined cell-phone use in diabetes self-care up to 2007 and found significant improvements in HbA1c in 9 out of 10 studies that reported it with mixed results for short-term blood glucose, cholesterol and weight. The heterogeneity of studies – which included all types of cell phone intervention and was dominated by text-message-based (SMS) solutions – precluded systematic synthesis of process of care measures like convenience and satisfaction but the authors did suggest these were generally favourable. The review did not recognise the six studies that involved some form of phone-accessible software as a distinct intervention category and the focus on cellular phones excluded the broader range of cMEDs. Because the review was based solely on MEDLINE data and was restricted to RCTs, quasi-experimental and pre-post designs, relevant studies may have been overlooked. A similar review by the same authors looking at cell phone use for chronic conditions more generally had the same limitations[29].

A systematic review of health technologies for monitoring and managing diabetes up to 2008[30] identified cell-phone based interventions as a distinct category but did not recognise the role of apps and was similarly dominated by SMS-interventions. Two studies involved interventions delivered by cMED software. One examined the impact of a game add-on to a PDA based diabetes management software on data collection and outcomes[31]. Knowledge improved and more data were submitted when the game was used but there was no significant change in HbA1c. The second, a small pilot (n=30) of the WellDoc diabetes management software for type 2 diabetes found the intervention to be

acceptable to clinicians and improvements in HbA1c associated with changes in insulin doses in those using the management software compared to controls[32].

Another review up to 2008 examining home telehealth for diabetes management[25] identified two studies out of 21 in which cellular apps were used for data collection. A Chinese study comparing an intervention based on electronic diary with feedback against usual care found a non-significant improvement in HbA1c[33]. A cell-phone software extension to allow patients to submit glucose readings to a clinician prompted higher rates of recording but did not result in better HbA1c outcomes[34]. The search strategy requirement that studies index both of the terms 'home' and 'telehealth' may have limited the scope for identifying cMED-based studies: our scoping review suggests that there are other studies that could be included. Apps were not identified as distinct intervention category within this review. cMEDs may be suitable for home monitoring but their portability means that they are not constrained in the way that, for example, wired modems for data transmission are.

1.7 Why it is important to do this review

Apps may offer a potential low-cost solution for supporting self-care interventions. For policy makers and clinicians there is a need to understand whether this is an intervention category that can be considered for real-world use. No review has focussed specifically on issues of cost and efficacy using health apps for cMEDs. Possible quality and safety impacts have been suggested but there has been no systematic consideration of these.

The optimal timing of technology assessments for emerging technologies is the subject of debate[35]. Although smartphone app category is new, our recent scoping review shows that software interventions using MEDs are not. Bibliometric analysis of app-related publications (Figure 1.7) identified in the scoping review suggests that there is now a sizeable accrued corpus of literature.

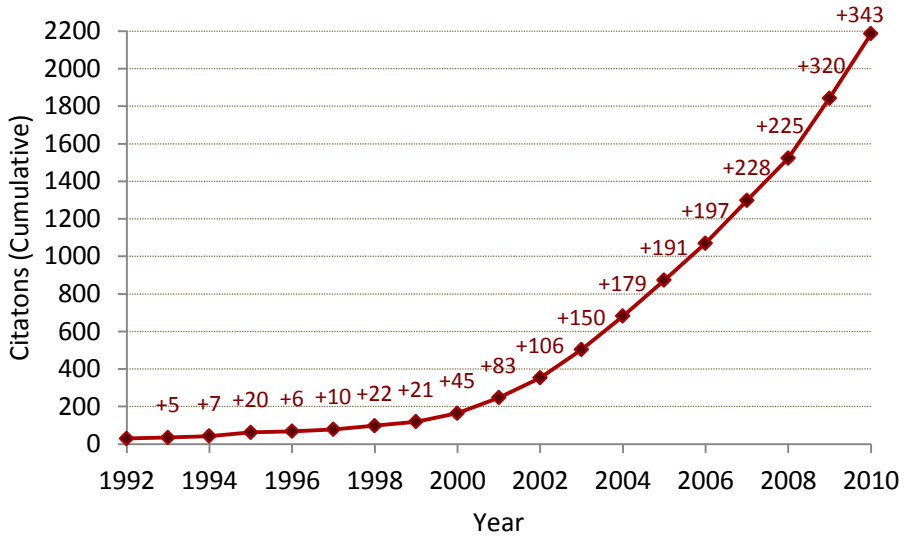

Figure 1.7

Cumulative number of health-app related citations, 1992-2010

Based on 2186 studies identified using the search and inclusion criteria for health apps and cMEDs defined in this protocol for which a publication date was available. Diabetes-specific and self-care criteria, however, were not applied to this dataset and the graph therefore reflects publications for all conditions. Each data point represents the cumulative total of all citations published up to the end of that year. The number of new citations generated in each year is shown as an annotation above the data point.

It is timely to assess the learning that has resulted from these and the extent to which it can inform the research agenda using the latest generation of devices.

2 Objectives and questions

2.1 Objectives

To assess the efficacy, cost and quality impacts of mobile health apps for self-care, using diabetes mellitus as an illustrative example.

2.2 Questions

- Can self-care using software installed on consumer-grade mobile devices result in improved objective measures of blood glucose control and quantitative outcomes in diabetes?
- Does self-care need to be supplemented with tailored therapy in order to achieve improvements in blood glucose control?
- Is mobile self-care a cost-effective way to improve blood glucose control and other intermediate outcomes in diabetes?
- Can self-care interventions delivered by apps result in improved skills, knowledge or psychosocial functioning?
- Do particular groups benefit more from self-care interventions delivered in this way? Does diabetes type influence the effectiveness, adoption or perception of these?
- Are any improvements sustained in the medium-term or long-term (defined in 3.1.4, below)?
- Does mobile self-monitoring of diabetes confer any risks to patients using the technology?
- Is mobile self-monitoring acceptable and accessible to patients and clinicians?
- What aspects of the design and implementation of self-care interventions maximise the likelihood that they will have desired outcomes?
- What gaps exist in knowledge that may affect policy makers and clinicians when assessing whether self-care apps are suitable for adoption?

2.3 Intended audience

Policy makers and clinicians wanting to know:

- How app-based interventions might integrate into the practice of healthcare in both developed and developing settings, using the example of diabetes;
- Whether app-based interventions are currently suitable for use in clinical practice for diabetes and if so, the nature and cost of these, the patients who are most likely to benefit and the means to deliver these interventions safely;
- Strategies for maximising the likelihood that such interventions will realise their intended benefits; and
- The risks and deficits in knowledge exist that might influence decisions about adopting these technologies.

Researchers working in this field.

3 Methods

3.1 Criteria for considering studies for this review

The criteria for including studies are summarised in table 3.1 and described in detail below.

Population	Individuals of any demographic background with diabetes mellitus in any setting (healthcare or otherwise)
Intervention	Any self-care intervention involving a health app for a mobile device
Comparisons	Intervention versus usual care; intervention variant versus intervention variant
Outcomes	HbA1c; Fasting Blood Glucose; Weight; Insulin Dose; Compliance; Acceptability; Safety; Technical Issues; Access and Equity Issues
Study Types	All study designs will be considered; some outcomes will only be extracted from particular study designs

Table 3.1
Summary of inclusion criteria

3.1.1 Types of studies

We will include any type of published material, including:

- Randomised controlled trials (RCTs, including randomised crossover studies);
- Quasi-experimental studies (including interrupted time series studies);
- Observational studies (cohort, case-control, cross-sectional studies);
- Qualitative studies (e.g. interviews, focus groups and case reports);
- Economic analyses;
- Opinion pieces (e.g. editorials, commentaries, letters and consensus statements);
- Inter-governmental and non-governmental agency reports;
- Media reports (e.g. newsprint, blog posts, press releases);
- Private industry reports (e.g. white papers, specifications);
- Partially published work (e.g. conference abstracts); and

we will also include any relevant unpublished work that we identify.

No study will be excluded on the basis of type. However, study design and quality characteristics will be used to determine whether certain outcomes will be extracted from a particular study (see 3.3.3.1 and 3.3.3, below).

Pilot studies and those reporting ongoing work will be included if they report data concerning any of the review outcomes (see 3.1.4, below). In all cases, study authors will be contacted to see if revised data have subsequently become available.

The timing of studies is effectively constrained by the availability of the technologies involved (see 3.3.1, below)

3.1.2 Types of participants

We will include all individuals with a diagnosis of either:

- Type 1 diabetes mellitus
- Type 2 diabetes mellitus
- Congenital diabetes of any cause including Maturity Onset Diabetes of the Young (MODY)

who are involved in self-care (see 3.1.3.1, below) in any setting (healthcare or otherwise).

Although we are supportive of the principle, we think it infeasible to require that diagnosis be confirmed according to a normative definition of diabetes (e.g. the WHO/IDF criteria[36]). Participants will therefore be included on the basis of whatever diagnostic criteria for diabetes mellitus were established by each study.

We will also include individuals without a diabetes diagnosis when:

- they are being used as an appropriate control or comparison to a group with diabetes;
- they are a parent of other caregiver for someone with diabetes.

We will not include individuals with gestational diabetes or those with steroid-induced diabetes.

No participant will be excluded on the basis of any other socio-demographic characteristic (e.g. age; gender; ethnicity; marital status; geographic location; employment status; education; income or health status).

3.1.3 Types of interventions

We will include any single or blended (defined further in 3.1.3.3, below) intervention that satisfies inclusion and exclusion criteria that define diabetes self-care (as the content of the intervention) and consumer mobile electronic devices (cMEDs) and apps (as the delivery mechanism for that intervention or intervention component).

Although we will include blended interventions as part of a comprehensive account of the types of intervention that have been tested, we will not include these in all analyses (see 3.4.3, below).

We will place no restriction on the setting within which the intervention is offered or received.

3.1.3.1 Diabetes self-care

We will **include** any intervention that aims to establish or promote one of the seven diabetes-specific self-care behaviours defined by the American Association of Diabetes Educators[10] (AADE7):

1) Maintaining a healthy diet;
2) Engaging in exercise and physical activity;
3) Monitoring of blood glucose and other bioparameters;
4) Adherence to diabetic medication;
5) Problem solving when faced with changes that will affect the condition;
6) Reducing risks by avoiding health-damaging behaviours, monitoring the condition and participation screening;
7) Healthy coping and motivation.

These domains are consistent with the WHO definition of self-care[37]:

> "Self-care in health refers to the activities individuals, families and communities undertake with the intention of enhancing health, preventing disease, limiting illness and restoring health. These activities are derived from knowledge and skills from the pool of both professional and lay experience. They are undertaken by lay people on their own behalf, either separately or in participative collaboration with professionals."

Qualifying interventions may aim to equip individuals with the skills necessary to initiate or sustain one of these behaviours; support individuals in performing them; or both.

We will include studies that compare different strategies for achieving a particular self-care practice and multi-component interventions that consider more than one self-care behaviour and where not all behaviours are delivered using a health app (defined in 3.13.3, below).

We will include studies where the intervention may be used by someone acting in place of patient (e.g. a parent or an informal carer).

We will also include any study that explores attitudes, perceptions, barriers and facilitators relating to these domains (e.g. qualitative interview studies).

We will **exclude** any intervention that either:

- lies outside these domains;

or falls within these domains but:

- does not involve study of diabetic patients or their care providers[38];
- is targeted only at health or allied professionals rather than patients (for example, PDA software for clinicians to monitor patient progress towards risk reduction[39]);
- also falls within the NIH definition of complementary or alternative medicine (CAM)[40]:

  "CAM [is] a group of diverse medical and health care systems, practices, and products that are not generally considered part of conventional medicine. Conventional medicine (also called Western or allopathic medicine) is medicine as practiced by holders of M.D. (medical doctor) and D.O. (doctor of osteopathy) degrees and by allied health professionals, such as physical therapists, psychologists, and registered nurses."

3.1.3.2 Consumer Mobile Electronic Devices (cMEDs)

We will **include** any intervention which satisfies our definition of a consumer mobile electronic device (cMED):

- Handheld – a single device with integrated display(s) and input mechanisms (touchpad, keyboard, touchscreen, microphone, accelerometer, etc.) that weighs less than 1kg and measures less than 300mm along its largest dimension;
- Mobile – has an internal power source and operates wholly or substantially without requiring any physical connections;
- General Purpose – supports computing functions that can run arbitrary software code (see the definition of app, 3.1.3.3, below);
- Instant On – device functions are immediately available to a user when the device is turned on;
- Consumer – is commercially available to anyone who can buy or use goods or services within an economy[41] without modification (other than the need to load specific software code).

This definition aims chiefly to identify a group of devices that share broadly similar usability characteristics, an important modifier of adoption (and ultimately efficacy) for eHealth interventions.

The focus on consumer devices anticipates that the cost of bespoke technology will make it less suitable for large scale interventions and that re-use of existing devices (and supporting infrastructure) may accelerate adoption.

The definition incorporates devices with both GSM and wireless connectivity (e.g. smartphones and legacy mobile phones) as well as those without (e.g. some personal digital assistants, PDAs). Tablet computers (e.g. the iPad, Apple Inc., Cupertino, USA) will be included as long as they satisfy the above criteria.

We will include any device where a bespoke physical connector may be used to transfer data to and from the device but where the device itself is wholly unaltered[42].

We will **exclude**:

- Bespoke hardware rather than consumer technology, e.g. Guardian[43];
- Consumer hardware that has been physically modified. This creates potential issues of cost and inertia while modifications are propagated to consumer devices;
- Desktop computers, laptops, netbooks. These devices (currently) offer interaction methods that are not directly comparable with those of handheld mobile devices (e.g. mouse vs touchscreen).

We acknowledge that apps are likely to become available on desktop computing devices but this does not reflect the current situation (May 2011) and the exclusion criteria reflect this.

3.1.3.3 Health apps

We use the term 'health app' to encompass any discrete piece of software for use on a cMED (satisfying the criteria specified in 3.1.3.2, above) that additionally fulfils the following criteria:

- The software can be accessed wholly through the mobile device but is not necessarily installed on that device (e.g. software accessible through a web browser on a mobile phone[44]);
- The software is an optional add-on to the standard features of the device; and
- Defines a distinct set of interactions between the user and the device. These interactions are typically realised in the visual user interface but may also include other interfaces (e.g. sound, speech) supported by the device;
- The software has one or more functions that are designed to help an individual initiate or sustain either:
    - Self-care (defined in 3.1.3.1); or
    - Health behaviour for which we use the WHO definition[45]:

      > "Any activity undertaken by an individual, regardless of actual or perceived health status, for the purpose of promoting, protecting or maintaining health, whether or not such behaviour is objectively effective towards that end."

      A health behaviour is purposively adopted; behaviours that are adopted which have consequences for health as side-effects are not included in this definition[45].

We will **include** any intervention that fulfils these criteria. We will include studies where a health app is the sole means by which an intervention is delivered (which we term 'app-based interventions') as well as studies where a mobile device is used in conjunction with other means (e.g. telephone support) (which we term 'blended interventions'). Training in the use of a health app and technical support mechanisms (e.g. telephone support) will not by themselves be considered to constitute a blended intervention.

We will **exclude** any intervention that:

- Solely uses existing software feature of the device in a new way (e.g. using a calendar to set behavioural reminders[46]);
- Relies solely on messaging (e.g. ACASI, MMS, SMS[47]). The usability characteristics of this kind of intervention (threaded, conversational) differ from those offered by software with a defined user interface.
- Uses the mobile device simply as a transmitter rather than offering a distinctive interaction mode (e.g. using a mobile device to transmit information received from a blood glucose meter to a clinician): this is telemonitoring[48] rather than self-care.

3.1.4 Types of outcomes

It is infeasible to define outcomes that directly reflect comorbid burden and mortality for diabetes because these are affected by health behaviours and status maintained over periods of years rather than in the shorter term. However, because regulation of blood glucose is a clear determinant of morbidity and mortality in diabetes, measurements that assess blood glucose levels like glycosylated Haemoglobin A1c (HbA1c) in the shorter term indirectly capture these concepts.

We will

Primary Outcomes

- HbA1c Levels;
- Safety impacts associated with app-based self-care;
- Acceptability and psychosocial impacts on patients.

Secondary Outcomes

- Costs and cost-effectiveness of mobile self-care interventions;
- Compliance with self-care protocols and protocol components (e.g. reminders) including withdrawal;
- Other measurements of diabetes control (fasting blood glucose, serum fructosamine);
- Other relevant bioparameters (blood pressure, cholesterol, BMI);
- Insulin dose;
- Acceptability to clinicians and sponsoring organisations;
- Technical performance of mobile self-care technology;
- Equity and accessibility of mobile self-care interventions for different demographic groups;

We will use these and additional sources to compile details of:

- The scope of the types of diabetes self-care activity that health apps can support;
- The characteristics of users who may best be able to access the technology;
- Properties that are shared in common between health apps that appear to be important determinants for successful adoption, continued use or clinical efficacy;
- Barriers and facilitators to adoption for both consumers and providers which are pragmatic issues (derived from real-world experience) that act either to slow or speed utilisation of the technology in each group;
- Advantages and disadvantages of patient-facing apps compared to current care practices;
- Feasibility of apps as routine interventions for diabetes self-care.

We will include outcomes measured at completion of an intervention and any subsequent time points (follow-up). We define short-term follow-up as outcomes monitoring that completes within 30 days of the completion of the intervention, long-term follow-up as monitoring that continues 6 months after the completion of the intervention and medium-term follow-up as intermediate of the two.

We will not exclude any paper that reports outcomes that are not in this list however we will retain these only for qualitative synthesis and discussion.

3.2 Search methods for identification of studies

3.2.1 Electronic searches

We will search the following electronic databases:

- The Cochrane Consumers and Communication Review Group Specialised Register;
- The Cochrane Central Register of Controlled Trials (CENTRAL, The Cochrane Library);
- MEDLINE;
- EMBASE;
- PsycINFO;
- CINAHL;
- CAB Direct Global Health;
- Global Health Library;
- Compendex/Inspec/Referex;
- IEEEXplore;
- ACM Digital Library;
- CiteSeer[X];
- ERIC.

The detailed search strategies are presented in Appendix 1.

The searches will not be restricted by language.

Documents written prior to 1992 will not be included because neither smartphones nor personal digital assistants existed prior to this date[49,50]. Because of the rapid evolution of technology, studies prior to 2000 are expected to be less representative and will be interpreted with caution.

3.2.2 Searching other resources

We will search the grey literature and the following non-database sources:

- Mobile Active: a user-created directory of mobile health solutions;
- Google;
- Google Scholar;
- ProQuest Dissertations.

The detailed search strategies are presented in Appendix 1.

We will contact study authors where additional contextual information is required to clarify detail and where it is thought they may be able to identify other, new or ongoing studies relevant to the review.

We will also search reference lists of relevant studies and personal collections of articles.

Unlike studies identified from electronic databases, non-English articles in this group will be included only if there is an English abstract.

We will apply the same date restrictions as those used for electronic searches (see 3.3.1, above).

3.3 Data collection and extraction

3.3.1 Selection of studies

We will merge search results across electronic databases using reference management software EndNote (Thomson Reuters Corporation, New York, USA), and remove duplicate records of the same report.

Study selection will follow the process described in section 7.2.3 'A typical process for selecting studies' of the Cochrane Handbook of Systematic Reviews[51]. Two authors (KH and MvV) will independently screen titles and abstracts to remove irrelevant studies. Full text of retained studies will be retrieved and assessed against inclusion and exclusion criteria (see 3.1, above and published separately).

Any disagreement about study eligibility will be resolved by discussion with a third review author (LF). If it does not prove possible to resolve this, the study authors will be contacted for clarification.

All pilot studies and those reporting ongoing work will be followed-up by contacting the study authors to see if more recent or final data have subsequently been published.

3.3.2 Data extraction and management

We will adopt different approaches for data extraction depending on the study design:

- A structured extraction (see 3.3.3.1) will be used for randomised controlled trials; quasi-experimental studies; observational studies; economic analyses and partially published or unpublished work reporting quantitative outcomes.
- A qualitative thematic synthesis (see 3.3.3.2) will be used for the remaining study types.

Mixed methods synthesis has been advocated as a way of identifying contextual issues (from qualitative study) that may qualify interpretation of quantitative outcomes[52].

Allocation of a study into a design category will be made primarily on the basis of whatever design is claimed by the authors. Disagreements about study type will be resolved by discussion amongst the reviewers.

In addition, some outcomes will only be extracted from studies of a particular design (detailed in 3.3.2.1, below).

3.3.2.1 Structured data extraction

Pairs of authors (from KH, MvV, LCG and LF) will independently extract demographic and intervention characteristics using a structured form according to defined guidance (published separately). Common parameters that will be extracted from all studies are detailed in table 3.3.3.1 (overleaf).

Extracted data will be compared and disagreements solved by discussion with reference to third member of the team if necessary. When data are either missing or their presentation prevents extraction clarification will be sought from study authors.

General information	• Title • Authors • Source and publication status • Date published • Language • Date of review
Study methods	• Aim of study • Study design • Method of recruitment and setting • Inclusion and exclusion criteria • Details of control and comparison groups • Incentives for participation
Risk of bias assessment	See 3.3.3, below

Participants	• Description
	• Geographic setting
	• Place where intervention delivered
	• Study numbers (at recruitment, eligibility screening, randomisation and follow-up, by intervention group), details of power calculation
	• For the pooled set of participants (pooled controls and interventions):
	  - Demographic characteristics (mean age; %female; mean BMI; mean income; %secondary education; %BME groups)
	  - Diabetes characteristics (ratio of diabetes type; ratio of diabetic treatment modalities)
	  - Comorbidities
	• Assessment of baseline imbalance between groups

Providers	• Details of the health care worker(s) or systems responsible for providing or supporting the app
Intervention	• Name • AADE7 and behavioural intervention taxonomy type(s)[53] • Mode of interaction (no feedback; data entry and visualization without treatment recommendations; data entry with device-generated treatment recommendations; data entry, transmission to a healthcare worker to make treatment recommendations) • Hardware and software technologies used • Key software functions • Software installation process • Main receiver of intervention (patient; carer; healthcare worker) • Mode of data entry (manual; wireless e.g. from a connected monitoring device; etc.) • Training offered to patients • Training offered to providers • Frequency, duration and intensity of interaction with intervention • Measures of implementation fidelity and programme differentiation • Process and timing for data download from device • Security arrangements • Evidence of consideration of adoption factors in study design • Measures of adherence and protocol deviation
Measurements	• Time points at which measurements were taken • Measurements that were taken

Table 3.3.3.1

Common information that will be extracted from all included studies

Different methods will be used to extract different outcomes:

- Bioparameter proxies for efficacy (HbA1c, Blood Glucose, Weight/BMI) will only be extracted from RCTs, quasi-experimental studies and controlled before-after studies where the unit of allocation is an individual patient/caregiver.

  We will extract mean and standard deviations of measurements at baseline and post intervention (final measurement) for each patient group and details of any significance tests performed. When a study has more than one intervention arm that reports on the parameter of interest, the control arm will be divided equally between the arms for the purpose of comparison.

  Where an intention to treat analysis was not performed, we will attempt to recalculate figures to incorporate lost participants, contacting the study authors if necessary. Where standard deviations are not reported or where clustering has not been considered in the initial analysis, we will try to (re)calculate them or seek clarification from the study authors. When data are unavailable, we will attempt to use imputation (e.g. Last Observation Carried Forward, LOCF)

- Measures of compliance will be extracted from RCTs, quasi-experimental studies and controlled before-after studies where the unit of allocation is an individual patient/caregiver.

  Because we expect relatively few studies to report compliance over longer periods of time we will also extract measures of compliance from any study design with a duration of 8 weeks or longer.

  We will extract data expressed as the proportion of activities completed to those expected, the standard deviation of that proportion and details of any significance tests performed.

- Process measures other than compliance that modify interpretation of review outcomes (e.g. anti-diabetic treatment dosage) will also be extracted using appropriate summary statistics from RCTs, quasi-experimental studies and controlled before-after studies where the unit of allocation is an individual patient/caregiver.

- Financial outcomes (e.g. cost-effectiveness) will be extracted from any study that uses a formal method to estimate or asses these.

  Where possible we will extract information using normative comparators (e.g. Cost per Quality Adjusted Life Year, QALY).

- Descriptive outcomes relating to efficiency and patient-centredness will be extracted from any study where the clinical setting has been clearly defined. Qualitative studies exploring patient-centredness will be extracted separately (3.3.2.2, below).

- Outcomes relating to equity will be assessed from any study where the sociodemographic context has been defined. We will specifically explore whether attrition is related to sociodemographic characteristics and conduct subgroup analyses where appropriate[54].

- Access outcomes will be assessed from any study that defines them and any study where it is possible to infer how rates of patient contact have been affected by the intervention. Compliance and attrition rates will inform assessment of access.

- Outcomes relating to safety will be extracted from any study that reports on them.

  Where possible we will extract data expressed as the rate of adverse events in intervention and control groups. We will also extract descriptive data on the nature of adverse effects, any risks that were identified and recommendations or solutions to mitigate those risks.

- Descriptive and numerate outcomes relating to patient and provider perceptions of the intervention, quality of life and the feasibility of implementation will be extracted from feasibility studies and any study that identifies a specific method for soliciting feedback from users in its design (to avoid bias). Qualitative studies reporting acceptability will be extracted separately (3.3.2.2, below).

For each outcome, we will assess the type and quality of the analytical method used and whether there is evidence of selective reporting.

3.3.2.2 Qualitative thematic synthesis

A single author (KH) will perform a qualitative thematic synthesis[55] for the following study types:

- All studies that employ a recognised qualitative methodology and that explore acceptability and other attitudinal concerns like patient-centredness will be grouped and coded. The quality of included studies will be assessed (see 3.3.3, below). Results from qualitative studies will be presented in their own right but will also be used to qualify quantitative data.
- Peer-reviewed opinion pieces, intergovernmental and non-governmental agency reports and the discussion sections of quantitative studies will be pooled to consider each of the following dimensions:
  - Commentary on Effectiveness (rather than outcomes per se);
  - Acceptability;
  - Efficiency and Organisational Context;
  - Access and Equity;
  - Safety.

  In the event that there no more than 25 studies (this threshold is set arbitrarily) then all studies will be coded. If there are more, 25 articles will be selected at random for coding and further studies will then be selected in random batches of 10 until thematic saturation is reached. Coding will aim to identify high-level themes in each area that can be used to qualify any quantitative data that will be presented for each outcome.
- Other publication types like media reports and private industry reports will also be pooled and coded. Because of the high risk of bias in this content, presentation of this information will be separated from other results and highlighted as speculative.

The free text of included studies will be extracted and iteratively coded using NViVo (QSR International Pty Ltd, Doncaster, Australia).

3.3.3 Assessment of quality and risk of bias

To assess risk of bias in RCTs, pairs of authors (from KH, MvV, LCG and LF) will independently assess each included study and perform assessment of bias based on chapter 8 'Assessing risk of bias in included studies' in the Cochrane Handbook for Systematic Reviews of Interventions[51]. The following domains will be assessed: sequence generation; allocation concealment; blinding of participants, personnel and outcome assessors; incomplete outcome data; selective outcome reporting, other sources of bias and three additional domains that are recommended by the Cochrane EPOC group: imbalance of outcome measures at baseline; comparability of intervention and control group characteristics at baseline and protection against contamination. Where study processes are insufficiently described to assess bias or protocol deviation, the protocol will be requested from the original study authors. Risk of bias will then be summarised as 'yes' (indicating a low risk of bias in all domains), 'no' (indicating a high risk of bias in at least one of the domains) or 'unclear' (indicating an uncertain risk of bias in at least one of the domains). Any disagreement will be resolved by consensus with a third review author.

For assessing the risk of bias in economic studies we will follow the guidance in chapter 15 'Incorporating economics evidence' of the Cochrane Handbook[51].

Quality appraisal for qualitative studies remains controversial. We feel that the focus on empirical outcomes in this review justifies some sort of quality appraisal and will use the assessment questions framed by Mays and Pope[56] to assess qualitative studies.

Reporting bias will be assessed during analysis of outcomes (see 3.4.3, below).

3.4 Data collection and extraction

3.4.1 Describing the review process

The study selection process will be summarised using an adapted PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) flowchart.

Studies excluded after initial screening will be detailed in a table of characteristics of excluded studies that includes the reason for exclusion.

3.4.2 Narrative synthesis

We will present a narrative synthesis of included studies using the structure described in table 3.4.2. We will structure the narrative synthesis so that, when appropriate, information is segregated according to the type of diabetes and types of intervention being reported. We will also summarise included studies in a table of characteristics of included studies.

Study design	• Trial design • Risk of bias • Adherence to protocol (overlaps with Compliance outcome) • Conflict of interest
Participants	• Demographic and socioeconomic characteristics and context • Diabetes type • Other physiological/comorbid characteristics • Psychological characteristics • Self-care status prior to intervention
Interventions	• Setting • Taxonomic components of interventions • Frequency, intensity and durations of interventions • Role of training and other support in interventions • Types of technology used in interventions
Outcomes	• Primary and secondary outcomes • Meta-analysis (if performed, see 3.4.3, below)

Table 3.4.2
Structure of narrative synthesis

3.4.3 Summary and interpretation of outcomes

We will summarise the effects associated with quantitative outcomes in a summary of findings table.

We will use the GRADE approach to assess the impact of the quality of included studies on the interpretation of these outcomes, following the guidance in chapter 12 of the Cochrane Handbook[51]. This approach specifies four levels of quality: high, moderate, low and very low. RCTs will be considered as the highest quality rating. We will downgrade RCTs to moderate, low, or even very low quality evidence, depending on the presence of the five factors: limitations in design and implementation, indirectness of evidence, unexplained heterogeneity, imprecision of results and high probability of publication bias. Observational studies will be considered as lower quality of evidence but can be upgraded when they do not show a high risk of bias. The factors for upgrading evidence are: large magnitude of effect, all plausible confounding would reduce a demonstrated effect or suggest a spurious effect when results show no effect and dose-response gradient.

Studies will be considered for assessment of publication bias (and possible subgroup/meta-analysis, see section 3.3.6, below) if they are app-based (i.e. not multi-component) and homogeneous across:

- Intervention – the design invokes the same descriptive categories of the AADE7 behavioural taxonomy; were delivered in a similar way with similar support characteristics (i.e. training) and for a similar period of time;
- Quantitative outcome of either HbA1c, fasting blood glucose, BMI/weight or intervention adherence;
- Population characteristics – in terms of age group; gender balance; comorbidity; socioeconomic background; setting and ethnicity;
- Diabetes type (if relevant to the outcome).

Studies selected on the basis of face evidence for homogeneity (defined by the criteria above) will be evaluated for statistical heterogeneity using the I^2 statistic. If a result is obtained that is greater than 0.5 then the assumption of heterogeneity will be considered violated and publication bias will not be assessed (nor meta-analysis performed). Otherwise we will test for publication bias using a funnel plot regression weighted by the inverse of the pooled variance[57]. A regression slope of zero will be treated as suggestive of no publication bias. We recognise the limitation of current methods to assess publication bias with small numbers of studies[58]. If fewer than 10 studies are available for analysis then we will not test for publication bias and assume that publication bias could exist.

We will summarise qualitative outcomes in a separate table.

3.4.4 Meta-analysis

3.4.4.1 Criteria for performing a meta-analysis

A subgroup/meta-analysis will be performed if three or more studies are identified that satisfy the criteria and statistical tests for homogeneity and publication bias described in section 3.4.3 (above).

Homogeneity of intervention category type and outcome will be a necessary criterion for constituting a subgroup. Further division by demographic characteristics and diabetes type will be only considered if the grouping is of clinical/practical relevance and if there are adequate numbers of studies to do so.

Subgroups will be constituted at a participant-level by including all relevant studies. If further data is required, for example, to be able to separate out a particular patient group from data that are reported in pooled form within a study then we will contact the study authors for clarification. If this information cannot be obtained then the study will be excluded.

The decision to perform one or more meta-analyses will be taken at a meeting of all review authors.

3.4.4.2 Meta-analysis procedure

We will follow the guidelines for meta-analysis laid out in Chapter 9 'Analysing data and undertaking meta-analyses' of the Cochrane Handbook[51], using the RevMan Version 5.1 (The Nordic Cochrane Centre, Copenhagen, Denmark) to perform analysis. We will perform both fixed-effects and random-effects analysis in our analysis.

3.4.4.3 Meta-analysis presentation

We will report the meta-analysis procedure using the QUOROM approach[59] .

We will summarise data using Forest plots.

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Contributions of authors

KH and MvV developed the idea for a review of apps. KH wrote the search strategy and the protocol. MvV, LF, LCG and JC reviewed drafts and helped shape the final review. The data extraction form was created by MvV and revised by MvV and KH with input from LF and LCG. All other guidance was written by KH.

Searches and screening for the scoping review were carried out by KH and MvV.

Searches and screening will be carried out by KH and MvV.

Quantitative data extraction will be carried out jointly by KH, MvV. LCG and LF with input from JC to help resolve any areas of disagreement.

Qualitative data extraction will be carried out by KH.

Declarations of interest

None

Appendix 1

Medline (and other database) search strategies

Smartphone App
Search Strategy - Ver

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