A systematic and integrated review of mobile based technology to promote active lifestyles in people with Type 2 Diabetes

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Abbreviations: (SDSCA) Summary of Diabetes Self-Care Awareness, (DMSES) Diabetes Management Self-Efficacy Scale, (HbA_{1c}) glycated haemoglobin, (CGM) continuous glucose monitor, (RCT) randomized controlled trial, (CRM) crossover repeated measures, (PDA) personal digital assistant

Keywords: Acceptability, effectiveness, feasibility, mHealth, technology, Diabetes

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Funding Source: The PhD project was funded through contribution from PAL technologies and the Partnership Contribution Fund which is a joint fund created by Capita IT Enterprise Services and the University of Strathclyde to provide education and employment benefits to students and graduates

Conflict-of-Interest Disclosure: None

Acknowledgements: None

Figures and Table Count: 4 tables and 1 figure

Abstract

Aim: Review studies examining the effectiveness, acceptability and feasibility of mobile-based technology for promoting active lifestyles in people with Type 2 Diabetes (T2D).

Background: Benefits of leading an active lifestyle following a diagnosis of T2D, including improved glycaemic control, have been reported. Studies examining the specific use of mobile-based technologies to promote an active lifestyle in T2D have not previously been reviewed.

Methods: Research studies examining effectiveness, feasibility or acceptability of mobile-based technology for active lifestyle promotion for T2D management were included (n = 9). The databases searched included: PubMed, Medline, ScienceDirect and ACM Digital Library (January 2005 to October 2015). Studies were categorised as: 1) informing, 2) monitoring, 3) provoking or 4) sustaining behaviour change.

Results: Technologies used included: Smartphone or tablet apps, Diabetes PDA, continuous glucose monitor and accelerometer, pedometer and a website delivered by a Smartphone. No papers examined the effectiveness of mobile-based technology in monitoring health behaviours and behaviour change. Four of the studies found mobile-based technology to be motivational and supportive for

behaviour change. The visual reinforcement was identified as motivational. The feasibility and acceptability of using mobile-based technology to provide sustained lifestyle change and the effectiveness of mobile-based technology in monitoring health behaviours and behaviour change has not been investigated. No studies examined all three of the outcomes or focused decreasing the participants' sedentary behaviour.

Conclusions: Limited research has examined the feasibility, acceptability and effectiveness of mobile-based technology to promote active lifestyles and subsequently good diabetes management in people with T2D.

Introduction

Several studies have reported the substantial benefits of leading an active lifestyle following a diagnosis of Type 2 Diabetes [1,2,3]. Research has reported significant improvements in glycaemic control in addition to numerous other physical, mental and social health benefits [1,2,3]. More recently, reduced sedentary time has also been shown to be effective in the lowering of blood glucose levels irrespective of physical activity levels in obese non-Diabetic adults [4]. Sedentary behaviour has been defined by the Sedentary Behaviour Research Network [5] as any waking activity in a sitting or reclining position with an energy expenditure of ≤ 1.5 metabolic equivalents. This is important as high levels of sedentary behaviour may negate acceptable levels of physical activity [6]. Thus current guidelines for an active lifestyle include recommended levels of both physical activity and sedentary time [7].

A systematic review and meta-analysis of 17 studies examining the effect of physical activity interventions on glycaemic control in people with Type 2 Diabetes was conducted by Avery and colleagues [1]. Behavioural interventions were shown to significantly increase objective and subjectively measured physical activity, in addition to clinically significant improvements in HbA_{1c} levels [1]. While this review demonstrates the potential for behavioural interventions to have a positive impact on glycaemic control in the context of physical activity however; most interventions are delivered face to face which limits the opportunity for widespread implementation.

Technology is becoming increasingly a part of people's everyday lives, in particular mobile-based technology. It is estimated that almost two billion people in the world own a smartphone giving them instant access to a variety of technology applications [8]. Mobile applications have been developed as an aid to improve almost every aspect of life, such as activity levels, diet and sleep patterns. Technology, such as computer programmes and wearable devices, are similarly being used more as a means of monitoring and managing conditions like diabetes. Studies have examined the use of a variety of technologies as a method of increasing physical activity in those with Type 2 Diabetes, such as telephone counselling [9] and personal data assistant-based self-monitoring [10]. Given the global increasing prevalence of diabetes technology offers a means of delivering interventions on a much larger scale and could potentially have a significant impact on diabetes management.

In order to gain knowledge and understanding of the topic area and the research conducted thus far, an integrative literature review approach was adopted. The integrated method has a systematic approach consisting of five stages: (1) problem formulation, (2) literature search, (3) evaluation of data, (4) data analysis, and (5) interpretation and presentation of results. This method allows for the inclusion of both empirical and theoretical literature, meaning the literature used is not restricted to a specific study design, such as randomized control studies [11]. This allows for an increased number of studies to be included in the review and a combination of diverse study methodologies to be

examined [12] to give a more thorough understanding of the research conducted so far.

Methods

Aims

This systematic, integrated literature review aimed to identify the mobile-based technologies that have been used in previous studies to promote active living in those with Type 2 Diabetes. The review focused on research examining the effectiveness, feasibility and acceptability of these technologies in order to identify gaps in the research and directions for future work.

Design

The integrated review was conducted using a modified methodological framework developed by Whittemore and Knafl [11]. This methodology has been successfully used in previous reviews in related areas, such as nursing [13]. The framework focused on five key phases: problem identification, literature search, data evaluation, data analysis and presentation of the findings [11].

Additionally, the research papers identified were categorised based on the objective/function of the mobile-based technology; this systematic presentation of the current evidence was used to illustrate specific gaps. The categories used were as follows 1) Inform - mobile-based technology used to provide health information to participants; 2) Monitor - mobile-based technology used to monitor health behaviours and

behaviour change; 3) Provoke - mobile-based technology used to initiate behaviour change (over a period of less than 6 months) or 4) Sustain - mobile-based technology used to support maintenance of behaviour change (over a period of 6 months or longer).

Inclusion and Exclusion Criteria

The inclusion and exclusion criteria for the literature search was developed using the PICOS framework for systematic reviews and is illustrated in Table 1.

Table 1: PICOS Framework

P	Participants with Type 2 Diabetes (studies including participants with T1D and T2D will be included but those solely with participants with T1D will be excluded).
I	Promotion of active lifestyle using mobile-based technology for T2D self-management. (mobile-based technology will include smartphone apps and wearable technology).
C	Any comparison.
O	Feasibility, acceptability or effectiveness.
S	Both empirical and theoretical research published in English from peer reviewed journals and conference papers. (experiments, systematic reviews and meta-analysis will be included. Expert opinion papers and non-systematic reviews will be excluded).

[a] P = population, I = intervention, C = comparison, O = outcome, S = study design

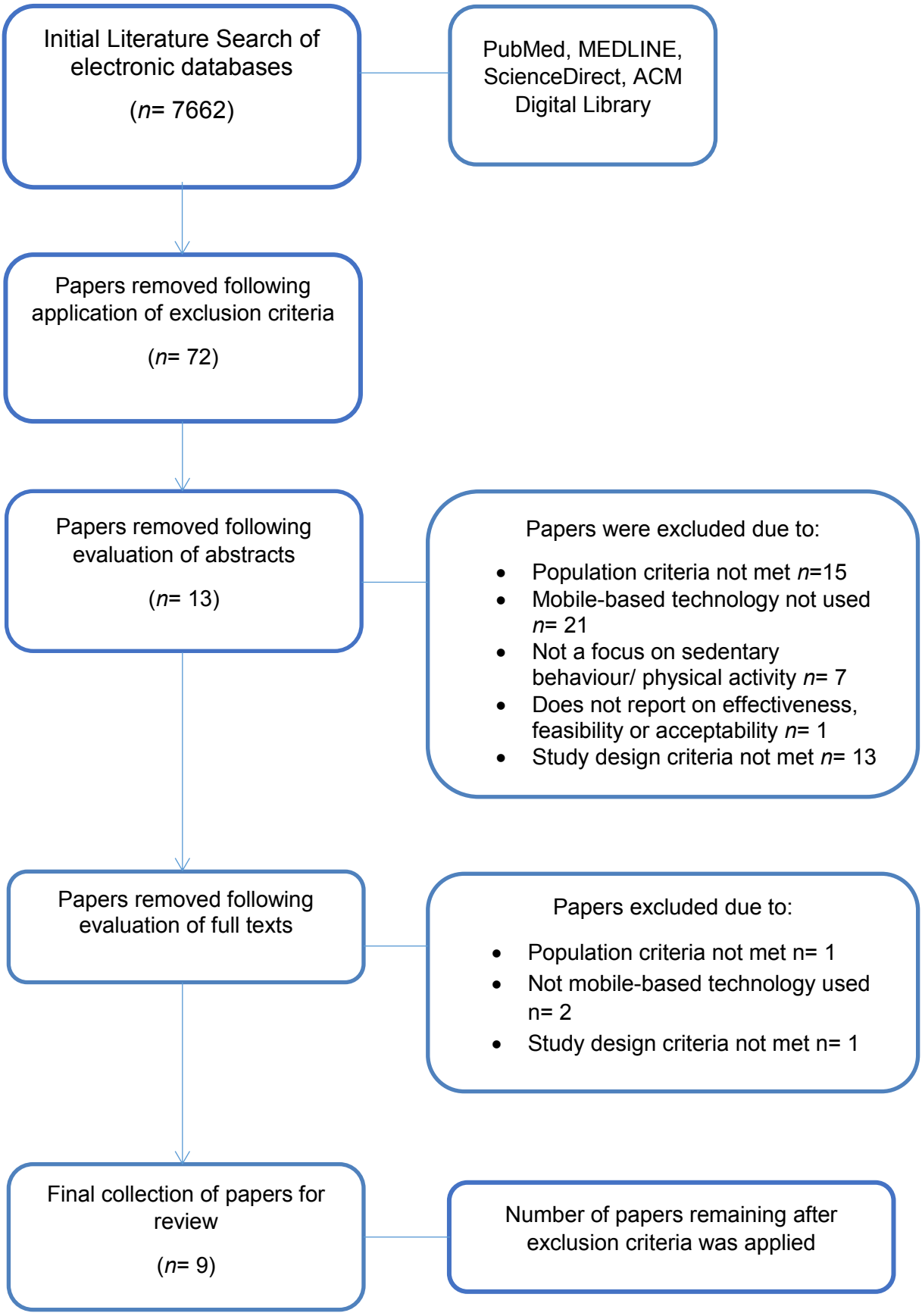
Search strategy

The following electronic databases were searched: PubMed, Medline, ScienceDirect and ACM Digital Library. A total of thirteen keywords and phrases were used in the literature search. These were: Mobile-based, technology, active living, physical activity, sedentary behaviour, sitting time/ bouts/ periods, lifestyle change, Type 2 Diabetes, blood glucose control/ management, glycaemic control, effective, feasible, acceptable. Reference lists were also reviewed to identify papers not found in the database search.

Search Outcome

Figure 1 illustrates the stages of the literature search. A total of 7662 papers were identified in the initial search of the online databases. Following the implementation of the inclusion criteria to the titles, 72 papers remained. The abstracts of the remaining papers were evaluated, leaving 13 studies. A total of four papers were removed following an evaluation of the full texts using the inclusion criteria, leaving nine papers identified as suitable for review. To ensure that the most relevant papers were included in the review and to reduce author bias, the first author reviewed the titles, abstracts and full papers using the inclusion criteria and the selected papers were crosschecked and agreed upon by the second and third authors.

Figure 1: Literature Search Exclusion Chart



Data Extraction

Each paper was reviewed and information extracted including: study design; sample size, mean age and HbA_{1c} of participants; measurement of diabetes self-management; technology used; outcome measured (effectiveness, feasibility, acceptability) and key study findings. This information is presented in Table 2. Papers were further collated and categorised into technologies which 1) Inform; 2) Monitor; 3) Provoke or 4) Sustain behaviour change. This information is presented in Table 3.

Quality Assessment

There is no gold standard for assessing quality in an integrated review [11]. Quality assessment was conducted using an adapted tool developed by Guo, Whittemore and He [13] and the results are presented in Table 4.

Results

A total of nine papers were identified as suitable for review. Table 2 shows a summary of the information extracted from the papers. Of the nine papers, five studies used Smartphone or tablet apps, one used a Diabetes PDA, one used a combination of continuous glucose monitor and accelerometer, one used a pedometer and one used a website delivered by a Smartphone. All studies were focused on those with Type 2 Diabetes and samples size ranged from nine to 376 participants. Methods used to measure self-management included diet, physical activity, blood glucose testing, the Summary of Diabetes Self-Care Awareness (SDSCA) questionnaire and the Diabetes Management Self-Efficacy Scale (DMSES) questionnaire. The effectiveness of the technology was assessed in six studies while feasibility was examined in three of the studies. The acceptability of technology was examined in four studies and three studies examined more than one of these variables.

Table 2: A Summary of Research Studies Included in the Review

Author	Allen, Jacelon & Chipkin [19]	Arsand, Tatara, Ostengen & Hartvigsen [17]	Arsand et al. [14]	De Greef, Deforche, Tudor-Locke & Bourdeaudhuij [22]	Holmen et al. [18]	Hunt, Sanderson & Ellison [15]	Klein, Mogles & van Wissen [16]	Nes et al. [20]	Vuong et al. [21]
Title	Feasibility and acceptability of continuous glucose monitoring and accelerometer technology in exercising individuals with type 2 diabetes	Mobile phone-based self-management tools for type 2 diabetes: The Few Touch Application	Mobile health applications to assist patients with diabetes: Lessons learned and design implications	A cognitive – behavioural pedometer-based group intervention on physical activity and sedentary behaviour in individuals with type 2 diabetes	A mobile health intervention for self-management and lifestyle change for persons with type 2 diabetes, part 2: One-year results from the Norwegian randomized controlled trial RENEWING HEALTH	Support for diabetes using technology: A pilot study to improve self-management	Intelligent mobile support for therapy adherence and behaviour change	The development and feasibility of a web-based intervention with diaries and situational feedback via smartphone to support self-management in patients with diabetes type 2	Factors affecting acceptability and usability of technological approaches to diabetes self-management: A case study
Study Design	Mixed methods	Iterative	Narrative Review	RCT	RCT	CRM Pilot	Validation study Pilot	Intervention Pilot	Case Study
Sample Size	9	12	No Data	41	151	14	57	15	376
Age (Mean)	(56)	44-70 (56.2)	No Data	35-75	(58.6)	Over 19	28-80 (51.8)	46-71 (59.6)	(58)
HbA_{1c} (Mean)	115 ± 126	No Data	No Data	139 ± 22	146 ± 20	(118.6)	No Data	133 ± 20	No Data
Diabetes self-management outcomes	Physical Activity Continuous Glucose testing	Physical Activity Blood glucose testing	No Data	Blood glucose testing Physical Activity	Diet Medication Blood glucose testing	SDSCA questionnaire DMSES questionnaire	No Data	Fasting Blood glucose testing	Blood glucose testing

Technology used	CGM Actigraph accelerometer	Mobile phone App	Mobile phone Apps	Pedometer	Mobile phone App	iPad App	Mobile phone App	Website delivered by Smartphone	Personal Digital Assistant (PDA)
Key study findings	The continuous glucose monitor recorded lower glucose levels following exercise. Visual data from the CGM was perceived as more relevant and helpful. Increased participant commitment to self-management following the use of the CGM.	Developing an app that involves several sensors is feasible. The blood glucose sensor was identified as the favoured aspect. Users liked the step count option. The 6-month user intervention showed the app to be motivational to users.	Concluded that mHealth apps will give patients the motivation to be more active in managing their health.	The use of a pedometer in conjunction with a cognitive behavioural intervention was effective in improving PA. Steps increased by 2000 per day and sedentary behaviour was decreased by 1 hour per day following the 12 week intervention. No intervention effect on the objective PA data. At 1 year, sedentary behaviour returned to baseline. No difference in HbA_{1c} between control and intervention groups.	The change in HbA_{1c} did not differ between the groups after the 1-year intervention. The secondary outcome measures did not differ between groups after the 1-year intervention.	No difference in self-efficacy scores towards self-management between iPad App and journal study groups. Self-efficacy scores and glycaemic control (HbA_{1c}) were both very good to begin with.	Commitment and motivation towards behaviour change were identified as problem areas. eMate identified coping, social norms and cues as problems for commitment, motivation and awareness towards behaviour change.	The intervention design was found to be feasible. The smartphone tool was found to be useful in supporting those with Type 2 diabetes to make lifestyle changes. No blood glucose was reported.	PDAs were not considered straightforward and user friendly according to participants. No blood glucose data was reported.

[a] HbA_{1c} = glycated haemoglobin, CGM = continuous glucose monitor, + = yes, - = no, RCT = randomized controlled trial, CRM = crossover repeated measures, PDA = personal digital assistant.

From the studies which used mobile phone or iPad apps, a variety of study designs were used and outcome variables measured. Three studies examined the effectiveness of mobile phone or iPad apps to provoke behaviour change [14,15,16]. Klein, Mogles and van Wissen [16] conducted a pilot study and developed an app for those with chronic illness, including those with Type 2 Diabetes, based on behaviour change theories. Similarly, Hunt, Sanderson and Ellison [15] conducted a pilot study examining the participant's self-efficacy towards self-management and found no statistically significant difference in outcome variables between the group who were asked to complete journals first and the group using the iPad app first. Authors acknowledged self-efficacy scores were high at baseline and mean HbA_{1c} for the whole sample was 6.5% which indicates good glycaemic control, leaving little room for improvement. The study conducted by Arsand et al. [14] differed slightly as it was a review of previous studies examining the effectiveness of mobile phone apps to assist diabetes patients. Arsand et al. [14] concluded that mobile phone apps increase motivation in those with diabetes to manage their health. The remaining two studies that used mobile phone apps were conducted by Arsand, Tatara, Ostengen and Hartvigsen [17] who used an iterative approach to develop an app focused on self-management tools for those with Type 2 Diabetes and Holmen et al. [18] who reported on the 1-year follow up results of a randomised controlled trial. From user feedback from a 6-month intervention through focus groups and interviews it was concluded that the app designed by Arsand et al. [17] had resulted in

some participants changing their medication and physical activity habits and the app had a motivational effect on those who had used it. Holmen et al. [18] found that those ≥63 years used the app more than the younger participants ($p = 0.045$) but there was no significant difference in HbA_{1c} levels between the control group and the intervention groups after 1-year. Although all studies here used an app, it is difficult to compare results as the apps developed and the outcome measures included were different across the studies.

Allen, Jacelon and Chipkin [19], Nes et al. [20] and Vuong et al. [21] all used technology that is categorised as monitoring in their studies. Allen, Jacelon and Chipkin [19] used a combination of continuous glucose monitoring and an accelerometer to examine whether the combined visual feedback from the devices would motivate participants to change their behaviour. The data from the glucose monitor and accelerometer showed moderate intensity physical activity lowered glucose levels by a mean of 63 (SD 38) mg/dl (range = 0-160 mg/dl) within 5 hours (range 0-12 hours); however it was not reported whether these findings were statistically significant. Results from the focus groups found participants felt the visual feedback from the devices increased their commitment to using physical activity for self-management. Nes et al. [20] conducted a pilot intervention using a website delivered through a smartphone. Authors reported the intervention design to be feasible and most participants reported positive lifestyle changes and found the smartphone tool useful and supportive towards self-management. Vuong et al. [21] examined factors which impact on acceptability and

usability of technology in diabetes management using a personal digital assistant (PDA). Participants felt the PDAs were difficult and complicated to use and were not user friendly. Vuong et al. [21] concluded that it is important to take individual perception into consideration and not develop a one size fits all approach to using technology. Additionally, using more popular devices, such as smartphones, would improve acceptability.

The final study included in this review was a randomized controlled trial examining the effectiveness of a cognitive behaviour and pedometer intervention at sustained behaviour change in those with Type 2 Diabetes [22]. After the 12-week intervention, the intervention groups daily steps increased by 2000 more than the control group ($p<0.05$), however, after a year, steps per day in the intervention group had decreased significantly ($p<0.01$) showing the intervention was successful at increasing physical activity in the short term but not long term. Similar results were described for time spent inactive per day. The intervention group significantly reduced inactivity in the 12 weeks ($p<0.05$) but returned to baseline levels by 1 year.

Table 3: Study Categorisation Based on Technology Used

	Effective	Feasible	Acceptable
Informing	Arsand et al. [14]	Allen, Jacelon & Chipkin [19] Nes et al. [20]	Allen, Jacelon & Chipkin [19] Arsand et al. [14]
Monitoring		Allen, Jacelon & Chipkin [19] Arsand, Tatara, Ostengen & Hartvigsen [17] Nes et al. [20]	Allen, Jacelon & Chipkin [19] Arsand, Tatara, Ostengen & Hartvigsen [17] Vuong et al. [21]
Provoking	Arsand et al. [14] Hunt, Sanderson & Ellison [15] Klein, Mogles & van Wissen [16]	Arsand, Tatara, Ostengen & Hartvigsen [17]	Arsand, Tatara, Ostengen & Hartvigsen [17] Arsand et al. [14]
Sustaining	De Greef, Deforche, Tudor-Locke & Bourdeaudhuij [22] Holmen et al. [18]		

Gaps in the literature are identified in Table 3. Of the studies reviewed, none of the papers examined the effectiveness of mobile-based technology in monitoring health behaviours and behaviour change. Similarly, the feasibility and acceptability of using mobile-based technology to provide sustained lifestyle change has not been investigated. Most of the research (n=5) focused on the effectiveness of using mobile-based technology to provoke lifestyle change.

Table 4 presents the results of the quality assessment of papers using an adapted tool developed by Guo, Whittemore and He [13]. All nine studies presented a research question or hypothesis. Recruitment, demographics and sample size, where relevant, were reported in all nine studies. Power analysis was included for the two randomised controlled trials [18,22]. Five papers investigated effectiveness [14,15,16,18,22], three examined the acceptability [17,19,20] and four examined the feasibility [14,17,19]. A range of study designs and data analysis methods were included in this review.

Table 4: Study Quality Assessment

Author	Allen, Jacelon & Chipkin [19]	Arsand, Tatara, Ostengen & Hartvigsen [17]	Arsand et al. [14]	De Greef, Deforche, Tudor-Locke & De Bourdeaudhuij [22]	Holmen et al. [18]	Hunt, Sanderson & Ellison [15]	Klein, Mogles & van Wissen [16]	Nes et al. [20]	Vuong et al. [21]
Research question or hypothesis presented	+	+	+	+	+	+	+	+	+
Study design	Mixed Methods	Iterative	Narrative Review	RCT	RCT	CRM Pilot	Validation Study Pilot	Intervention Pilot	Case Study
Power analysis included	-	-	-	+	+	-	-	-	-
Recruitment reported	+	+	+	+	+	+	+	+	-
Demographic of the sample presented	+	+	+	+	+	+	+	+	+
Sample size (*n*)	9	10-15	NR	41	151	14	57	15	376
Effectiveness of the instrument described	-	-	+	+	+	+	+	-	-
Acceptability of the instrument described	+	+	-	-	-	-	-	+	-
Feasibility of the instrument described	+	+	+	-	-	-	-	-	+
Data analysis	Regression and content analysis of transcripts	Content analysis	Narrative	Repeated Measures	ANOVA, Regression	Mixed model analysis of variance Repeated Measures	Bivariate Pearson product-moment correlation	Content analysis	Content analysis of questionnaires/ transcripts

[a] + = yes, - = no, RCT = randomized controlled trial, CRM = crossover repeated measures, PDA = personal digital assistant. NR = Not Relevant.

Discussion

The main purpose of this systematic, integrated literature review was to examine published research for the use of mobile-based technology to promote active lifestyles in those with Type 2 Diabetes. The integrated framework allowed for a broad range of study design and methods to be included in the review, including quantitative and qualitative research. However, a total of only nine papers met the inclusion criteria for the review highlighting the need for more research to focus on this topic.

The two areas where most research has been conducted are the feasibility and acceptability of mobile-based technology when used to monitor behaviour [17,19,20,21]. In order to achieve sustained behaviour change, it is important to address the acceptability and feasibility of using technology to promote active living. Some studies have addressed this and the successful aspects from these studies could be used to inform a more effective and sustainable intervention to promote active living in the future. The overall limitations of the current literature, however, is the failure to examine the effectiveness, acceptability and feasibility of mobile-based technology together, as part of one study.

All the research that was included in this review focused on one or two of the outcome measures, none of the studies looked at the effectiveness, feasibility and acceptability of the mobile-based technology across all the categories. This is important to acknowledge as by not considering all three outcomes simultaneously in research

design, fails to address the question as to whether the technology and methods used to enhance active living would really be suitable or successful.

Identified Gaps in the Literature

We have illustrated three key gaps in the current literature: None of the papers included in this review explored the effectiveness of using mobile-based technology to monitor physical activity or sedentary behaviour and better diabetes management. Similarly, none of the research thus far has examined how feasible or acceptable it would be to use mobile-based technology to promote sustained behaviour change. This is the most important gap in the current research as prolonged, sustained behaviour change is the ideal outcome. In order to achieve this outcome, it is important to fully understand how mobile-based technology can be used in this area. None of the research has been conducted to specifically examine the use of technology when trying to change a person's sedentary behaviour. As aforementioned, it is important to examine physical activity and sedentary behaviour as two individual constructs as they are not influenced by the same variables and different methods may be required to change these behaviours [8].

This is particularly important when promoting sustained behaviour change as the technology may be effective in changing participant behaviour during an intervention but if it is not acceptable in terms of design, usability or cost to the individual, further use of the technology will not be sustained with the risk of reversion to a less active lifestyle.

Limitations of the Review

The main limitation of this review is that an adapted version of a quality assessment was completed rather than a validated quality assessment. The Cochrane Collaboration's risk of bias tool and the Effective Public Health Practice Project's quality assessment tool for quantitative studies were considered but ruled out as they were only suitable for quality assessment in intervention studies. Furthermore, a method developed by Nowlin and colleagues [23] was considered as an appropriate form of quality assessment as it does not measure quality based on study design but rather whether the study fulfils expectations. It was decided, however, that this method was too subjective to be used in the current review. This is due to the different study designs and there not being a suitable quality assessment tool available. This has been addressed in Table 4, where the data is presented in the context of the review research question and the main study outcomes allowing the reader to judge the quality of the papers reviewed. Further, the integrated methodology of the review allowed for a broad range of research to be included and this could be seen as a limitation as the varying study designs, technology used and outcomes measured made it difficult to compare studies.

Future Research Recommendations

Mobile-based technologies are increasingly being used for health monitoring and health improvement. Future interventions should be informed by research that has examined all three variables to identify

the most effective, feasible and acceptable mobile-technology methods in promoting and sustaining active lifestyles in those with Type 2 Diabetes. From the research in this review it is clear that technology should be tailored to the individual using it [21] and ideally include visual feedback of glucose and activity data to increase motivation towards self-management in those with Type 2 Diabetes [19]. The integration of behaviour change theories within mobile-based technologies may prove more effective in promoting active lifestyles than mobile-based technology alone [20].

Conclusion

Limited research has examined the feasibility, acceptability and effectiveness of mobile based technology to promote active lifestyles and consequently good Diabetes management in people with Type 2 Diabetes. Future research should examine the most effective, feasible and acceptable mobile-technology methods in promoting sustained active lifestyles in those with Type 2 Diabetes.

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