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Investigating the use of mobile technology to promote active lifestyles and improved glycaemic control in individuals with Type 2 diabetes

by

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Declaration of authenticity and author's rights

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed:

Date:

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Abstract

The purpose of this thesis was to examine the potential of using mobile technology to promote active lifestyles and improved glycaemic control in individuals with Type 2 diabetes. Chapter 1 introduced the research area, thesis rationale, and the design and structure of the thesis. Five studies were undertaken as part of this thesis. This first (Chapter 2) was a systematic and integrated literature review examining the effectiveness, acceptability and feasibility of using mobile technology to promote active living in adults with Type 2 Diabetes. The second (Chapter 3) presented the challenges and solutions of combining glucose and activity data sets measured continuously using mobile technology. The third (Chapter 4) examined the physical activity, sedentary behaviour and glucose patterns of adults with Type 2 diabetes in a free-living setting using mobile technology. The fourth (Chapter 5) examined the individual glycaemic response in adults with Type 2 Diabetes to interrupting prolonged sedentary behaviour in a controlled setting. Study five (Chapter 6) explored the experiences of, and attitudes towards, using mobile technologies to promote active living in adults with Type 2 diabetes. The final chapter (Chapter 7) discussed the findings of these studies in the wider context of the thesis and how the findings can be used to positively impact diabetes care and future research.

Thesis contribution to knowledge

This thesis contributes new knowledge to the current literature in five different ways. These contributions are described below:

1. Development of a novel methodology for combining continuously measured activity and glucose data. This data is increasingly being collected using wearables and continuous glucose monitors, so it was important to develop a methodology which allows for this data to be processed, analysed and presented in a quick and meaningful way, both for researchers and users.

2. The identification of an individual glucose response to sedentary time and breaks in sedentary behaviour, in both a free living and controlled lab setting. These findings are important as they complement and add to recent findings suggesting an individual glucose response to food intake in people with Type 2 diabetes and suggest the current “one size fits all” approach to diabetes care may not be appropriate.

3. The continuous measurement during the lab study enabling the behaviour and relationship measured during the lab protocol period to be directly compared to the free living behaviour before and between intervention days, which is something the has not been examined in previous research. The 30 minute and 60 minute lab conditions were making participants more sedentary compared to their free living behaviour. The led to a compensation effect seen in the post-lab period on intervention days but not on free living days where participants were being more active in the post-lab period on intervention days.

4. People with Type 2 diabetes are keen to be more active and less sedentary if it will help their glucose management. However, it was felt that sedentary breaks more frequent than every 60 minutes are not feasible or acceptable to people with Type 2 diabetes, even if this frequency was best

for optimal glucose control. This, along with point 3, is an important consideration to be made when future interventions are being developed.

5. The integrated and systematic literature review in Chapter 2 highlights that previous literature has examined the effectiveness of mobile technology to change behaviour but the acceptability and feasibility of using such technology to promote sustained behaviour change has never been examined before. The qualitative study (Chapter 6) in this thesis examined this and found that people with Type 2 diabetes would use mobile technology to regain control of their diabetes management, however in order for the technology to be acceptable it must provide the user with real-time visual feedback and prompts to sit less should not feel regimented.

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Summary of publications, submitted manuscripts and presentations

Publications and manuscripts from this thesis

Study 1 (paper 1) **McMillan, K. A**., Kirk, A., Hewitt, A., & MacRury, S. (2017). A systematic and integrated review of mobile-based technology to promote active lifestyles in people with type 2 diabetes. *Journal of Diabetes Science and Technology,* 11(2), 299-307.

Study 2 (paper 2) **McMillan, K. A.**, Kirk, A., Hewitt, A., MacRury, S., & Lennon, M. (In Press). Methods for combining continuously measured glucose and activity data in people with Type 2 diabetes: Challenges and solutions. *Journal of Rehabilitation and Assistive Technologies Engineering.*

Study 3 **McMillan, K. A**., Kirk, A., Hewitt, A., Paing, AC., Chastin, SFM., Collier, A., & MacRury, S. (In Preparation). Physical activity and sedentary behaviour patterns and waking glucose in adults with Type 2 diabetes.

Study 5 **McMillan, K. A**., Kirk, A., Hewitt, A., & MacRury, S. (In Preparation). The experiences of, and attitudes toward, using mobile technology to promote active living in people with Type 2 diabetes.

Conference publications from this thesis

McMillan, KA., Kirk, A., Hewitt, A., MacRury, S. (2016). An integrated systematic review of mobile based technology to promote active lifestyles in people with Type 2 diabetes. *Diabetic Medicine*, 33 (S1).

McMillan, KA., Kirk, A., Hewitt, A., MacRury, S. (2017). Objective, continuous measurement of sedentary behaviour and glucose in people with Type 2 Diabetes. *Diabetic Medicine*, 34 (S1).

McMillan, KA., Kirk, A., Hewitt, A., Paing, AC., Chastin, SFM., Collier, A., MacRury, S. (2018). Sedentary time and sedentary bout duration and glucose in adults with Type 2 diabetes. *Diabetic Medicine*, 35 (S1).

Conference presentations from this thesis

McMillan, KA., Kirk, A., Hewitt, A., MacRury, S. (2016). An integrated systematic review of mobile based technology to promote active lifestyles in people with Type 2 diabetes. *Diabetic UK Annual Professional Conference, Glasgow, UK.*

McMillan, KA., Kirk, A., Hewitt, A., MacRury, S. (2017). Objective, continuous measurement of sedentary behaviour and glucose in people with Type 2 Diabetes. *Diabetic UK Annual Professional Conference, Manchester, UK.*

McMillan, KA., Kirk, A., Hewitt, A., MacRury, S. (2017). The relationship between sedentary bout duration and glucose in adults with Type 2 diabetes. *American College of Sports Medicine Annual Meeting, Denver, USA.*

McMillan, KA., Kirk, A., Hewitt, A., Paing, AC., Chastin, SFM., Collier, A., MacRury, S. (2017). Sedentary time and sedentary bout duration and glucose in adults with Type 2 diabetes. *Scottish Physical Activity Research Connections, Edinburgh, UK.*

McMillan, KA., Kirk, A., Hewitt, A., Paing, AC., Chastin, SFM., Collier, A., MacRury, S. (2018). Sedentary time and sedentary bout duration and glucose in adults with Type 2 diabetes. *Diabetic UK Annual Professional Conference, London, UK.*

Publications related to the Ph.D thesis

Paing, AC., **McMillan, KA**., Kirk, AF., Collier, A., Hewitt, A., Chastin, SFM. (Under Review). The associations of sedentary time and breaks in sedentary time with 24-hour glycaemic control Type 2 diabetes. *Preventive Medicine.*

Paing, AC., **McMillan, KA**., Kirk, AF., Collier, A., Hewitt, A., Chastin, SFM. (Under Review). Dose-response between frequency of breaks in sedentary time and glucose control in Type 2 diabetes. *Diabetic Medicine.*

Paing, AC., **McMillan, KA**., Kirk, AF., Collier, A., Hewitt, A., Chastin, SFM. (Under Review). Dose-response between frequency of interruption of sedentary time and fasting glucose, Dawn phenomenon and night-time glucose in Type 2 diabetes. *Diabetic Medicine.*

Publications not from this thesis

McCann, L., **McMillan, KA**., Hewitt, C. (In Press). e-Prehabilitation system of care for teenagers and young adults diagnosed with Cancer: Study Protocol. *Journal of Medical Internet Research: Research Protocols*

Pugh, G., Martin, A., Fois, L., Smith, E., **McMillan, KA**., McCann, L. (Submitted). Systematic review of electronic patient platforms to support adolescents and young adults with cancer. *Journal of Medical Research: Cancer.*

Conference publications not from this thesis

Paing, AC., **McMillan, KA**., Kirk, AF., Collier, A., Hewitt, A., Chastin, SFM. (2018). The associations of sedentary time and breaks in sedentary time with 24-hour glycaemic control Type 2 diabetes. *Diabetic Medicine*, 35 (S1).

Conference presentations not from this thesis

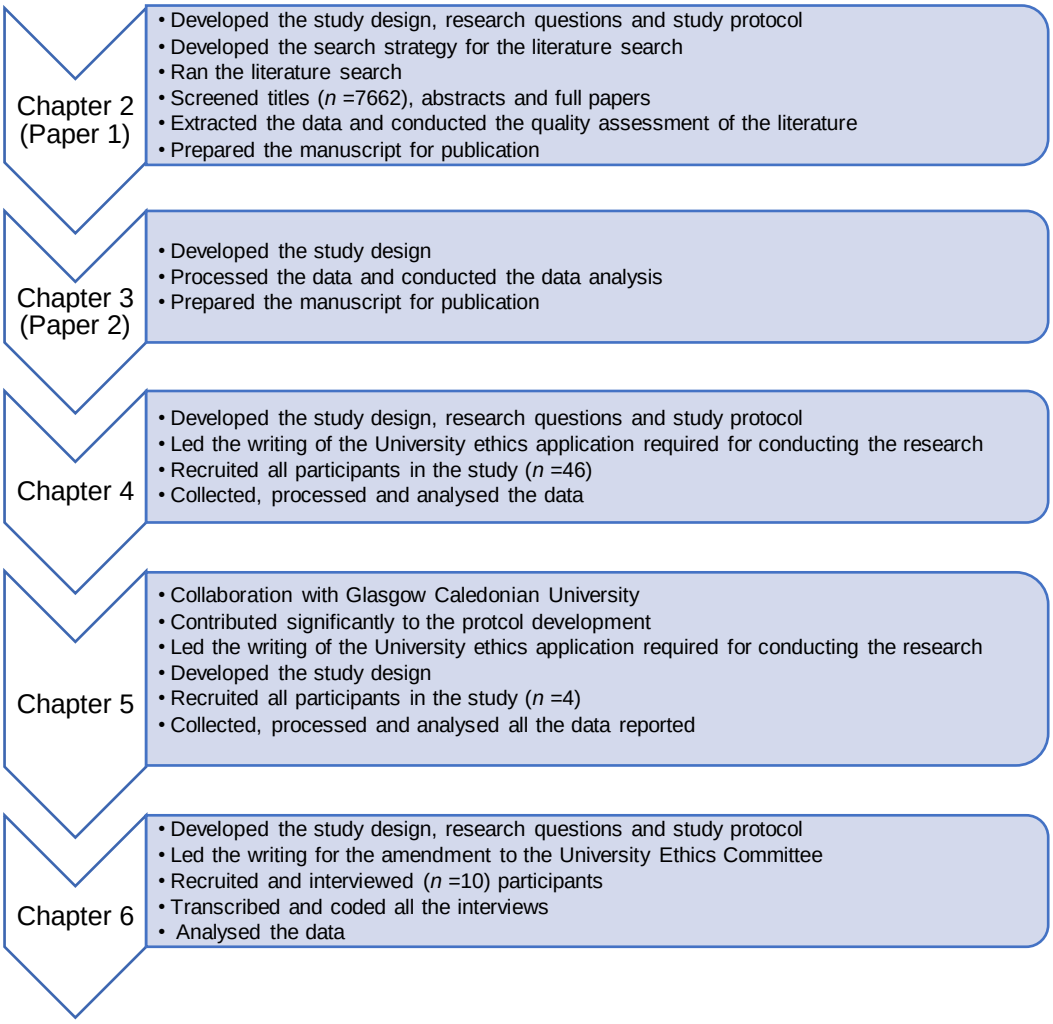
McMichan, L., Knowles, A-M., **McMillan, KA**., Rowe, D. (2015). Active chat: Development of an 8-week school-based intervention to increase physical activity and reduce sedentary behaviour in secondary school pupils. *International Society for Behavioural Nutrition and Physical Activity Annual Meeting, Edinburgh, UK.*

Mitchell, F., Martinez, S., Quaife, S., **McMillan, KA**., Beebe, L. (2017). Incentivized Cessation for Smokers with Type 2 Diabetes: A Pilot Randomized Controlled Trial Protocol. *Scottish Smoking Cessation Conference 2017, Glasgow, UK.*

Paing, AC., **McMillan, KA**., Kirk, AF., Collier, A., Hewitt, A., Chastin, SFM. (2018). The associations of sedentary time and breaks in sedentary time with 24-hour glycaemic control Type 2 diabetes. *Diabetic UK Annual Professional Conference, London, UK.*

Declaration of the student's contribution

The aim of this thesis was to answer a series of questions to investigate the potential of using mobile-based technology to promote active lifestyles and good glucose management in people with Type 2 diabetes. A further aim was to produce peer-reviewed publications to disseminated the findings from the research. As a result of this a number of co-authors were involved in the manuscript preparation and reviewing. The diagram below illustrates the significant contribution K McMillan made to studies 1-5 (Chapters 2-6) of this thesis. Co-authors on the manuscripts provided feedback and suggestions to improve drafts of the manuscripts. All conference presentations, with K McMillan listed as first author, were prepared, edited (after consultation with other authors) and presented by K McMillan.



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Chapter 1: Introduction

1. Introduction to diabetes

1.0 Overview

Type 2 diabetes accounts for approximately 90% of those who have diabetes (Diabetes UK, 2018). Lifestyle factors including overweight and obesity, poor diet and physical inactivity are associated with increased risk of Type 2 diabetes and significant changes in these factors, such as less manual jobs, over the last 50 years have been attributed to the rise in prevalence of Type 2 diabetes (Colberg et al., 2016; International Diabetes Federation (IDF), 2017). The prevalence of diabetes is increasing globally with the current estimation of 424.9million people diagnosed with diabetes expected to rise to almost 630million people worldwide by 2045 (IDF, 2017). The World Health Organisation recently identified Type 2 diabetes as a global problem and suggest more focus should be given to the treatment and management of Type 2 diabetes.

There is substantial evidence that leading a healthy lifestyle improves glucose control and reduces the risk of micro and macrovascular complications of diabetes (American Diabetes Association (ADA), 2018; Look AHEAD Research Group, 2010). However, recent research has shown that those with Type 2 diabetes often change very little about their lifestyle following their diagnosis (Chong, Ding, Byun, Comino, Bauman & Jalaludin, 2017). Increased levels of physical activity and reduced sedentary behaviour have been independently associated with improved management of Type 2 diabetes (ADA, 2018; Avery, Flynn, Wersch, Sniehotta and Trenell, 2012; Dempsey et al., 2016; Duvivier et al., 2017; Umpierre et al., 2011).

The majority of intervention studies thus far have focused on increasing physical activity or exercise in those with Type 2 diabetes and little focus has been given to reducing sedentary behaviour, regardless of the increasing evidence of the benefit of reduced sedentary behaviour on glucose (Avery et al., 2012; Umpierre et al., 2011). In a systematic review of

behavioural interventions (Avery et al., 2012), physical activity was increased in the intervention groups compared to usual care, however these changes in behaviour were not observed over a prolonged period of time, suggesting that more needs to be done to ensure sustained behaviour change.

A potential method for delivering effective, large scale interventions, for sustained behaviour change is the use of mobile technologies. To do so, it is first important to understand the effectiveness, acceptability and feasibility of using such technology to promote active living in Type 2 diabetes.

This chapter will review the current literature surrounding the management of Type 2 diabetes and the promotion of active lifestyles in order to improve Type 2 diabetes management. The areas of literature in this chapter reviewed are: 1) Introduction to diabetes, 2) Diagnosis and management of Type 2 diabetes, 3) Physical activity and Type 2 diabetes management, 4) Sedentary behaviour and Type 2 diabetes management, 5) Promoting active living in people with Type 2 diabetes, 6) Developing interventions, and finally the structure of the thesis will be discussed (7).

1.1 What is diabetes?

Diabetes Mellitus is a chronic metabolic condition characterised by high levels of glucose in the blood, known as hyperglycaemia (Diabetes UK, 2018). This is the result of poor insulin sensitivity or poor or no insulin secretion. Insulin is a hormone produced in the pancreas which controls the entry of glucose into the body's cells from the blood stream (IDF, 2017). When insufficient insulin is produced by the pancreas or the body's cells do not respond to the insulin that is produced, blood glucose rises and is known as hyperglycaemia (Diabetes UK, 2018). Chronic hyperglycaemia is associated with the development of several micro and macrovascular complications (IDF, 2017).

There are two main type of diabetes. The first, Type 1 diabetes, is an autoimmune disease where the pancreas does not produce insulin, resulting in absolute insulin deficiency (Diabetes UK, 2018). This is caused by an

autoimmune destruction of the insulin producing β-cells of the pancreas (Diabetes UK, 2018). The causes of Type 1 diabetes are not fully understood, but it is thought a combination of genetics and environmental factors may be influential (IDF, 2017). People with Type 1 diabetes require insulin therapy and onset is usually quite rapid, particularly during childhood or early adolescence. Type 1 diabetes accounts for approximately 10% of all diabetes cases (IDF, 2017). The second type of diabetes is, Type 2 diabetes. Type 2 diabetes accounts for around 90% of diabetes cases and is characterised by an inadequate secretion of insulin or a decrease in insulin sensitivity (IDF, 2017). Onset of Type 2 diabetes is usually slower than Type 1 and can go undiagnosed for years; it is much more common in those over 40 years old (IDF, 2017). However, worryingly there is an increasing trend in those much younger being diagnosed with Type 2 diabetes (IDF, 2017). The risk of developing Type 2 diabetes increases with age, family history and certain ethnicities (IDF, 2017), and overweight and obesity associated with lifestyle factors such as, poor diet and physical inactivity (IDF, 2017). There are other, less common types of diabetes including, gestational diabetes and maturity onset diabetes of the young (IDF, 2017); however, this thesis will focus on Type 2 diabetes.

1.2 Prevalence

The prevalence of diabetes is continuing to increase globally, making diabetes one of the most common chronic diseases (IDF, 2017). Diabetes has been identified by the World Health Organisation as a global public health problem now affecting almost 9% of the world's adult population. In 2017, the International Diabetes Federation estimated that 424.9million people worldwide have been diagnosed with diabetes, with this number projected to reach 628.6million by 2045. This does not reflect the true number of people living with diabetes however, as it is estimated that around 50% of all diabetes cases are undiagnosed and therefore untreated (IDF, 2017). About 79% of those with diabetes live in low to middle income countries. In the UK, the number of people with diabetes is thought to be

around 4.5million, this includes 1million people living with undiagnosed and untreated diabetes (Diabetes UK, 2018). With approximately 90% of people with diabetes having Type 2 diabetes, it is understandable that the World Health Organisation identified it as a global problem and why focus should be given to finding improved ways of treating and managing, in addition to preventing, Type 2 diabetes.

In addition to genetic predisposition, ethnicity, and socio-economic status, there have been many variables attributed to the increase in prevalence of Type 2 diabetes in recent years. People are living longer and are more likely to develop chronic diseases, such as Type 2 diabetes (Sicree & Shaw, 2007). Almost 20% of adults over the age of 65 years have diabetes and with the increasingly ageing population, it is expected that this will rise further (IDF, 2017). However, this does not account for the increase in much younger people being diagnosed. Significant changes in lifestyle in the last 50 years resulting in an increase in obesity, insufficient levels of physical activity and prolonged levels of sedentary time all contribute to the likelihood of developing Type 2 diabetes (Colberg et al., 2016; IDF, 2017).

1.3 Economic burden

The International Diabetes Federation estimate the global health expenditure on Diabetes was $USD 727 billion in 2017 and expect this to rise to $USD 776 billion by 2045 (IDF, 2017). The annual cost of Diabetes in the UK in 2011 was £23 billion, this was approximately 10% of the National Health Service's budget (Hex, Bartlett, wright, Taylor & Varley, 2012). With increasing prevalence, Hex et al. (2012) estimate that the annual cost of Diabetes in the UK will rise to almost £40 billion by 2035. The most effective way of lowering the costs associated with Type 2 diabetes is to prevent more people from developing it in the first place.

The Diabetes Prevention Study in Finland aimed to delay or prevent the onset of Type 2 diabetes in adults at high risk through a focused diet and physical activity intervention (Lindstrom et al., 1999). The randomised trial

began in 1993 with recruitment lasting until 1998 and the intervention period lasting until 2001 (Lindstrom et al., 2013). There were 522 middle-aged, overweight adults with impaired glucose tolerance who were randomised to either the control group (standard care) or an intensive lifestyle intervention group. The intensive lifestyle intervention group were offered individualised dietary advice from a nutritionist, circuit style resistance training sessions and advised to increase their overall physical activity. After the first year of intervention the intervention group compared to the control group had: greater weight loss (4.7±5.5kg vs 0.9±4.1kg p <0.001); lower fasting plasma glucose (5.9±0.7mmol/l vs 6.4±0.8mmol, p <0.001); and lower 2-hour post prandial glucose (7.8±1.8mmol/l vs 8.5±2.3mmol/l p <0.05) (Lindstrom et al., 2003). Relative risk reduction of Type 2 diabetes in the intervention group at the 7-year follow-up was 43%, authors attributed the achievement of intervention goals such as weight loss and increased physical activity to the relative risk reduction in the intervention group (Lindstrom et al., 2006). In the 13-year follow-up of the 4-year intervention (median follow-up was 9 years), those in the intervention group had an absolute risk reduction for Type 2 diabetes of 19.2% (Lindstrom et al., 2013).

The Diabetes Prevention Program (DPP) conducted in the USA from 1996-2001 consisted of 3 participant groups: 1) The lifestyle intervention group, 2) The Metformin intervention group and 3) The control group given a placebo (Diabetes Prevention Program Research Group, 2002). Those in the lifestyle intervention group joined the DPP Lifestyle Change Program where intensive training was provided and participants were encouraged to lose 7% of their body weight through diet (less fat and calories) and exercising for 150 minutes per week. Researchers met with participants 16 times in the first 24 weeks and then every two months with a phone call between visits thereafter. Participants in the Metformin intervention group took 850mg of Metformin twice a day and were provided with standard diet and activity advice. Those in the control group were given a placebo twice a day instead of Metformin and were provided with standard diet and activity advice. Following the intervention, incidence of Type 2 diabetes was 58% lower in the lifestyle

intervention group and 31% lower in the Metformin intervention group compared to the placebo. In the 10-year follow-up, those in the intervention group had a 34% risk reduction in Type 2 diabetes development and the onset of Type 2 diabetes was delayed by an average of 4 years compared to the placebo group (Diabetes Prevention Program Research Group, 2009). Interestingly, the intervention was successful in delaying Type 2 diabetes onset by 49% in those over 60 years old (Diabetes Prevention Program Research Group, 2009). The Metformin intervention group had an 18% delay developing Type 2 diabetes around 2 years later than the placebo group. At 15-years, 88% of the surviving cohort were followed up, diabetes incidence in the lifestyle intervention group was reduced by 27% (p <0.0001) and 18% in the Metformin group, compared to the placebo group (Diabetes Prevention Program Research Group, 2015).

Currently in the UK there is focus on investment into those at highest risk of developing Type 2 diabetes through a programme called the Diabetes Prevention Programme (NHS England, 2015). The Diabetes Prevention Programme is an evidence-based behaviour change programme developed by NHS England in conjunction with Public Health England and Diabetes UK. The programme's key aims are to reduce the number of people developing Type 2 diabetes and also reduce the incidence of complications related to diabetes (NHS England, 2015). The programme aims to achieve through three main goals: 1) Healthy diet, 2) Healthy weight and 3) Sufficient levels of physical activity. The Diabetes Prevention Programme was first started in 2015 and an outcome evaluation of the programme is currently underway (NHS England, 2015). A review of the cost effectiveness of the Diabetes Prevention Programme was conducted and it was concluded that the initial outlay for the programme would be recouped in 12 years, with a net saving of £1.28 for every £1 spent over 20 years (Thomas, Sadler, Breeze, Squires, Gillett & Brennan, 2017). The programme is most cost effective in obese individuals, those with a HbA1c of 6.2-6.4% and those between 40 and 74 years old (Thomas et al., 2017).

Whilst prevention programmes, such as those mentioned, are successful in delaying the onset of Type 2 diabetes and have been shown to be cost effective (Espeland et al., 2014; Thomas et al., 2017), perhaps consideration should be given towards similar programmes focused on management of Type 2 diabetes to tackle the high costs associated with diabetes related complications.

2. Diagnosis and management of Type 2 diabetes

2.1 Clinical diagnosis

The American Diabetes Association (ADA) (2010) and WHO (2011) identify four methods by which diabetes can be diagnosed; 1) A fasting plasma glucose, following no calorie intake for ≥8hours, of 7mmol/l or higher, 2) A random plasma glucose of ≥11.1mmol/l, 3) A 2-hour plasma glucose value of 11.1mmol/l following a 75g oral glucose tolerance test or, 4) A HbA_{1c} of ≥ 48mmom/mol (6.5%), a level of between 42- 47mmom/mol (5.7-6.4%) would indicate an increased risk of developing diabetes in the future. WHO recommend use of HbA_{1c} for diagnosis and screening of Type 2 diabetes (2011).

2.2 Methods for measuring glucose control

2.2.1 HbA1c

HbA_{1c} is the average glucose over a period of 8-12 weeks and is used as an indicator of long term glycaemic control. HbA_{1c} is reported as a percentage of glycated haemoglobin and is the most widely used measure of glycaemic control. It is currently recommended that those with Type 2 diabetes keep their HbA_{1c} level below 48 mmol/mol (6.5%) to reduce the risk of related complications, in particular diabetic retinopathy (WHO, 2011). The American Diabetes Association (2010) have suggested that the target HbA_{1c} should be even lower to reduce the risk of developing related conditions.

2.2.2 Daily mean glucose

Daily mean glucose is the average glucose level calculated using a minimum of 6 glucose readings over a 24-hour period. Makris and Spanau (2011) conducted a review of the literature to identify the extent to which mean glucose can be used to predict HbA_{1c}. Seven studies were reviewed in total and it was concluded that most studies confirm a close relationship between mean glucose and HbA_{1c}. Of the studies reviewed, only one study focused on those with Type 2 diabetes. In this study conducted by Makris et al. (2008), a strong relationship (R^2 = 0.87) between mean glucose and HbA_{1c} was reported. Although HbA_{1c} is the current gold standard for measuring long term glycaemic control, daily mean glucose could be used by those who use home blood glucose testing for self-management to give a good indication of glycaemic control.

2.2.3 Postprandial glucose

Postprandial glucose refers to glucose levels after a meal, often in the 2-hour period after a meal (Diabetes UK, 2018). Postprandial glucose excursions increase the risk of cardiovascular complications in those with Diabetes, particularly when this leads to hyperglycaemia (Monnier, Colette & Owen, 2012). Postprandial glucose excursions are important as they impact on HbA_{1c} by increasing mean glucose and additionally, increasing glucose variability due to the post meal spikes (Monnier & Colette, 2015; Valensi, Husemoen, Weatherall & Monnier, 2017). Authors reviewed the evidence of the contribution postprandial and basal hyperglycaemia had on over glucose exposure and incidence of diabetes complications (Monnier & Colette, 2015). They concluded that postprandial glucose is an important contributor to the overall management of Type 2 diabetes and is most impactful in those with perceived good glucose management or those with a HbA_{1c} of <8% (Monnier & Colette, 2015).

2.2.4 Glucose variability

Recent research has identified glucose variability as a possible contributor to developing vascular complications. Glucose variability relates to the level of variation in blood glucose rather than the average blood glucose level over a period of time (Monnier & Colette, 2018). Rodbard (2012) acknowledges that, although glucose variability was first examined in the 1970s, it has only recently been examined on a larger scale as continuous glucose monitoring has become more readily available.

Nalysnyk, Hernandez-Medina and Krishnarajah (2010) conducted a systematic review of the literature to assess the evidence of an association between glucose variability and developing vascular complications in people with Type 1 and those with Type 2 diabetes. Results suggest, in those with Type 2 diabetes, high variability in blood glucose levels is associated with developing long term micro and macrovascular complications, irrespective of HbA_{1c} levels (Nalysnyk et al., 2010). Monnier, Colette and Owens (2008) conducted a review of the literature and suggest high variability in blood glucose is more likely to cause long term vascular complications than high average blood glucose over a prolonged period of time. Glycaemic variability was positively and strongly associated with urinary excretion rate of 8-iso-PGF2α, a reliable marker of oxidative stress (r =0.86, p <0.001), suggesting that increased glucose variability is associated with increased oxidative stress (Monnier et al., 2008), which is associated with long term complications in Type 2 diabetes (Wright, Scism-Bacon & Glass, 2006). Gorst et al. (2015) conducted a systematic review and meta-analysis of 13 studies which examined the association between variability in HbA_{1c} in those with Type 2 diabetes. Variability was measured using several measurements of HbA_{1c} per patient; however, the method of calculating variability was not consistent across the studies reviewed. Authors determined that variability in HbA_{1c} is associated with higher risk of macrovascular events (1.21 [1.06-1.38]), cardiovascular disease (1.27 [1.15–1.40]), and mortality (1.34 [1.18–1.53]). In a large scale (n =4399) factorial randomised controlled trial called the ADVANCE trial, the effects of visit-to-visit variability in HbA_{1c} on

combined micro and macrovascular events and all-cause mortality in patients with Type 2 diabetes were explored (Hirakawa et al., 2014). HbA_{1c} measurements were taken at baseline, 3, 6, 12, 18 and 24 months and then every 6 months thereafter for up to 2 years. Glucose variability has also been shown to be significantly and positively associated with combined micro and macrovascular events (HR [95% CI]) (1.05 [1.01, 1.09]), (p =0.005) and all-cause mortality (1.11 [1.04, 1.17], p <0.001) (Hirakawa et al., 2014).

However, there is conflicting evidence as to the relationship between glucose variability and related complications (Siegelaar, Holleman, Hoekstra & De Vries, 2010). Siegelaar et al. (2010) suggest that glucose variability is a useful measure in certain populations, such as those who are critically ill in hospital and those treated with insulin who have severe hypoglycaemia but suggest that there is little evidence to support burden of measuring glucose variability in general; however, the recent development of consumer based continuous glucose monitors may make this more of an appealing prospect as they become more user-friendly and affordable.

One reason for a lack of evidence could be the difficulty in separating it from mean glucose (De Vries, 2013). High correlations between mean glucose and glucose variability have been identified (Rodbard, 2009), so correcting for mean glucose is important (De Vries, 2013). The recent emergence of continuous glucose monitoring does, however, provide more opportunities for the effect of glucose variability to be examined in further depth. Another possible reason for a lack of consensus on the importance of glucose variability is the lack of consistency across studies in the method used when measuring variability (De Vries, 2013).

As aforementioned, there are currently several methods used to measure glucose variability. Table 1.1 collates and summarises the current methods specifically developed and used to measure glucose variability.

Table 1.1: Summary of Current Measurement Methods for Glucose Variability

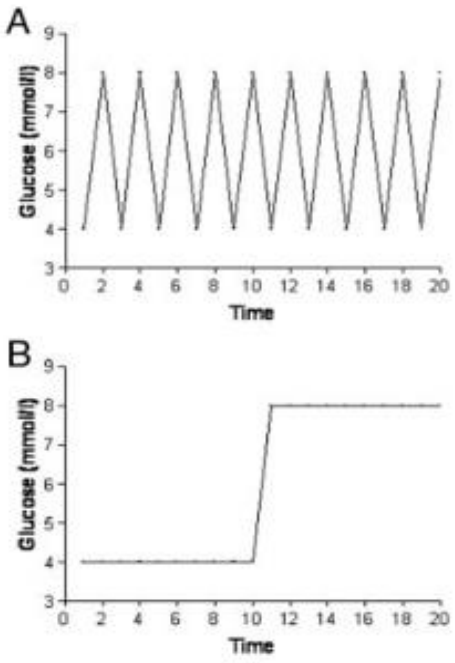
Measure	Acronym	Description
Mean average glucose	MAG	The average changes in glucose over time of measurement
Mean of daily differences	MODD	The glucose variability between consecutive days
Mean amplitude of glycaemic excursions	MAGE	The average differences between consecutive blood glucose value that are more than one standard deviations from the mean
Continuous overall net glycaemic action	CONGA	The measure of continuous glucose variability using continuous monitoring. Requires 288 glucose readings in a 24-hour period
Continuous overall net glycaemic action (*n*)	CONGA*n*	The measure of continuous glucose variability over (*n*) hours using continuous glucose monitoring

Standard deviation, range and coefficient of variation are also widely used and supported methods of measuring glucose variability (Rodbard, 2009; Skrha, Soupal, Skrha & Prazny, 2016) and are comparatively easy to calculate. Furthermore, there are several subtypes of standard deviation such as; standard deviation within days, between days and between daily means (Rodbard, 2012). There are, however, limitations to solely using standard deviation to measure glucose variability, particularly in continuous glucose data, such as very different glucose profiles having the same standard deviation value (Siegelaar et al., 2010). This is illustrated in Figure

1.1, taken from Siegelaar et al. (2010) which shows two glucose profiles with the same mean glucose and the same standard deviation but very different glucose profiles.

MAGE has regularly been described as the gold standard for measuring glucose variability and has been used to measure variability in glucose measured using continuous glucose monitoring (Cameron, Donath & Baghurst, 2010). CONGA was developed specifically for the measurement of glucose variability in continuously measure glucose (Service, 2013). Calculation for CONGA is difficult and Service (2013) argues that little is to be gained from using this method over simpler methods, such as standard deviation. CONGA*n* does not depend on 24-hour data or 288 glucose readings. CONGA*n* represents the SD of all valid differences between the current glucose observations an observation (*n*) hours earlier (Rawlings, Shi, Yuan, Brehm, Pop-Busui & Nelson, 2011). This section highlights the abundance of methods available to measure glucose variability and the benefits and limitations of some of the more commonly used methods.

Figure 1.1: Illustration of Two Glucose Profiles with Identical Mean Glucose and Glucose Standard Deviation



2.3 Methods for Type 2 diabetes glucose management

There are currently many ways to manage Type 2 diabetes, the method of treatment is decided on a patient by patient basis as it depends on the individual and the level of condition progression and medical intervention required (IDF, 2017). Treatment is aimed at good glucose control and maintaining a HbA_{1c} within a healthy range to minimise the risk of diabetes related complications (McGuire, Longson, Adler, Farmer & Lewin, 2016). Often it is possible for Type 2 diabetes to be managed through lifestyle alone (Dunstan et al., 2012; UKPDS Group, 1998); however, most people with Type 2 diabetes manage their condition with a combination of lifestyle and medications (Ripsin, Kang & Urban, 2009).

2.3.1 Lifestyle

There is substantial evidence that leading a healthy lifestyle improves glucose control and reduces the risk of diabetes complications (ADA, 2018; Look AHEAD (Action for Health in Diabetes) Research Group, 2010). A healthy lifestyle includes; a healthy diet, achieving a healthy weight, not smoking, sufficient physical activity and increasingly evidence is showing a decrease in prolonged sedentary time is also beneficial (ADA, 2018; Chong et al., 2017; Dunstan et al., 2012; Look AHEAD Research Group, 2010).

The Look AHEAD study, conducted from 2001-2012 was a multi-centre randomised controlled trial which examined whether intentional weight loss reduced cardiovascular morbidity and mortality in overweight adults with Type 2 diabetes (Look AHEAD Research Group, 2006). Participants were overweight adults with Type 2 diabetes (*n* =5145) and were randomised into one of two groups. The first group was the Diabetes Support and Education (DSE) group and participants in this group received normal medical care plus three educational sessions per year for the first four years of the study. The second group was the Lifestyle Intervention (ILI) group and participants received usual medical care alongside an intensive four-year programme designed to increase physical activity to >175minutes per week and reduce

initial weight by 7% or more (Look AHEAD Research Group, 2006). Participants were asked to engage in brisk walking or a similar aerobic activity. The activity program relied on unsupervised (at-home) exercise. In the first month, participants are instructed to walk for at least 50 minutes per week (Look AHEAD Research Group, 2006). Activity was increased to 125 minutes per week by month four and 175 min/wk by the 6^{th} month. Participants were also encouraged to increase their lifestyle activity by methods such as using stairs rather than elevators and using a pedometer, increase their steps by 250 steps per week until they reached a goal of 10,000 steps per day (Look AHEAD Research Group, 2006). These physical activity and exercise goals remained for the duration of the programme (5 years and beyond). In the first 6 months of the study, participants were encouraged to attend an individual session and three group sessions per month and replace two meals and one snack a day with liquid shakes and meal bars. In months 7-12, participants in the lifestyle intervention group attended 1 individual session and three group sessions per month and continued to replace one meal per day with a shake, the meal replacement was recommended for the duration of the 4-year study (Look AHEAD Research Group, 2006). In years 2-4, participants were given a variety of options including: one on-site visit per month with follow-up through phone or e-mail, refresher groups (6-8weeks) and motivational sessions were offered three times per year to help those participants who had gained back some weight.

After four years, results from the study showed the ILI group had greater reduction in weight (-6.15% vs -0.88%; $p < 0.001$), but still lower than the original target of a reduction by 7%, and HbA_{1c} (-0.36% vs -0.09%; $p <$ .001) and a greater increase in fitness (20.4% vs 5%, $p <0.001$) (Look AHEAD Research Group, 2010). The results from follow-up were published in 2013 (median follow-up was 9.6years) and showed a gradual regain of the weight lost in the ILI group (Belalcazar et al., 2013). Authors concluded that an intensive lifestyle intervention of this design did not reduce the occurrence of cardiovascular events in overweight adults with Type 2 diabetes

(Belalcazar et al., 2013). One possible reason for this could be that the use of meal replacement shakes throughout the 4-year study is not conducive to a normal lifestyle and may be successful short-term but not over a sustained period of time.

2.3.2 Medication

When lifestyle changes are not sufficient for managing blood-glucose, there are several antidiabetic drugs available for treating Type 2 diabetes (McGuire et al., 2016). Information on the different groups of antidiabetic drugs currently used, and what they are used for is provided in Table 1.2. Although these medications are effective, particularly in conjunction with a healthy lifestyle, in some cases, as the diabetes progresses, insulin therapy may become necessary.

Table 1.2: Antidiabetic drugs

Antidiabetic Drug Group	**Action**
Biguanides	Includes Metformin, usually the first drug considered for Type 2 diabetes treatment and increases glucose utilisation
Sulfonylureas	Stimulates insulin secretion
Dipeptidyl Peptidase-4 (DPP-4) Inhibitors	Stimulate insulin secretion by blocking the DPP-4 enzymes which destroy the incretin hormone, which help with insulin production
Incretin Mimetic (GLP-1 Agonists)	Stimulate insulin production by mimicking the incretin hormone
SGLT2 Inhibitors	Prevent the kidneys from reabsorbing glucose into the blood
Thiazolidinediones	Improves insulin sensitivity and protects insulin-producing cells in the pancreas
Glinides	Stimulates insulin secretion

2.4 Personalised approach to Type 2 diabetes management

Current measures for management of Type 2 diabetes, although assessed on a patient by patient basis, very much focus' on lifestyle and pharmaceutical therapy as the main methods of management. A recent article by van Ommen et al. (2018) discusses the possibility of a systems approach to diabetes management, focusing on a more personalised attitude to diabetes care and management, particularly surrounding diet content (van Ommen et al., 2018). This is consistent with a large cohort study conducted by Zeevi et al. (2015) where they examined the response to identical meals in an 800-person cohort at an individual level. High variability in response to these meals was observed between participants, suggesting that standardised dietary recommendations may not be suitable (Zeevi et al., 2015). Although this study was not conducted in people with Type 2 diabetes specifically, it does introduce the idea that current standard protocols and guidelines around diet and diabetes management may need reconsideration.

To add to this further, there has been increasing discussion surrounding the possibility of sub-types of Type 2 diabetes and the impact this may have on how the condition is managed (Ahlqvist et al., 2017). Four sub-types of Type 2 diabetes have recently been identified and are characterised based on an individual's BMI, age at diagnosis and current diabetes complications (Ahlqvist et al., 2017). Further research is needed to identify whether people with these different sub-types react differently to current methods of diabetes management.

2.5 Health implications of poor management

Poor glycaemic control can lead to an increased risk of cardiovascular disease, diabetic retinopathy, renal failure, peripheral neuropathy, amputation, liver disease and other disabling conditions (Inzucchi et al., 2015; Fox et al., 2015). Those with Type 2 diabetes are almost twice as likely to develop cardiovascular disease as those without and cardiovascular

disease accounts for 52% of fatalities in this group making it the leading cause of death in those with Diabetes. (UKPDS, 1998; Fox et al., 2015).

The UK Prospective Diabetes Study (UKDPS) (1998) was a randomised, prospective multicentre trial that examined whether intensive glycaemic control reduced the risk of complications in patients with Type 2 diabetes (*n* =3867). Participants were randomised into three treatment groups: conventional treatment, intensive sulphonylurea treatment and intensive insulin treatment. Over 10 years, the intensive treatment group showed better glycaemic control than the conventional treatment group (UKPDS, 1998). HbA_{1c} was 7% (6.2-8.2%) in the intensive treatment group and 7.9% (6.9-8.8%) in the conventional treatment group, which is an 11% reduction in HbA_{1c}. The risk of diabetes related microvascular complications was 12% higher in the conventional treatment group compared to intensive treatment (p = 0.029) (UKPDS, 1998).

Stratton et al. (2000) examined data from 3642 UKPDS patients with Type 2 diabetes and found every 1% reduction in HbA_{1c} was associated with a significant (p <0.0001) reduction in diabetes related deaths (21%), myocardial infarction, stroke and heart failure (14%) and microvascular complications (37%). It was concluded that complications in Type 2 diabetes are strongly associated with hyperglycaemia (Stratton et al., 2000). Holman, Paul, Bethel, Matthews and Neil (2008) conducted a 10-year follow-up of the UKPDS trial and found the benefits of intensive treatment were sustained over the 10-year period. Participants in the intensive sulphonylurea-insulin treatment group had a 13% (p =0.007) reduction in death, 15% reduction in myocardial infarction (p =0.01) and a 24% reduction in risk of microvascular disease (p =0.001) (Holman et al., 2008). Intensive Metformin treatment significantly (p <0.005) reduced the risk of death by 27% and myocardial infarction by 33% (p <0.005) (Holman et al., 2008). This study reported a greater effect on microvascular complications compared to macrovascular complications. This highlights the importance of using further strategies, such as the promotion of an active lifestyle, to improve the risk factors for cardiovascular disease and overall quality of life.

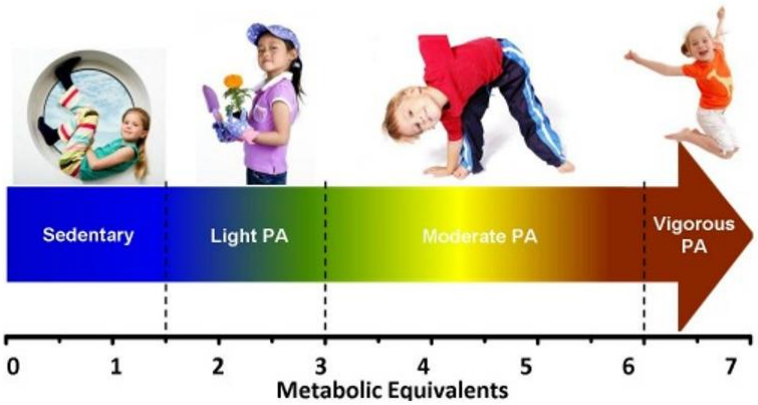
Additionally, those with Type 2 diabetes are at a high risk of depression and poor quality of life (Egede & Zheng, 2003; Goldney, Phillips, Fisher & Wilson, 2004). More recently, Semenkovich, Brown, Svrakic and Lustman (2015) discussed current literature surrounding the prevalence, impact and treatment of depression in those with Type 2 diabetes. Depression is associated with an increased risk of developing Type diabetes and a diagnosis of Type 2 diabetes can increase the risk of depression. Depression increases the risk of hyperglycaemia and micro and macrovascular complications in people with Type 2 diabetes (Semenkovich, Brown, Svrakic and Lustman, 2015). Lustman & Clouse (2007) conducted a review of the literature and found depression in those with diabetes was associated with poor glycaemic control, poor adherence to medication and diet regimes and a reduction in quality of life. This highlights the importance of understanding and appreciating both the physical and the mental effects of glycaemic control.

3. Physical activity and Type 2 diabetes management

3.1 Physical activity definition

Physical activity was defined by Casperson, Powel and Christenson (1985) as "*any bodily movement produced by the skeletal muscle that requires energy expenditure*" (p126). Physical activity is unstructured and should not be confused with exercise. Physical activity is best described on a continuum based on required metabolic equivalent tasks (METs). METs are used to describe the relative energy cost of an activity. Low intensity physical activity is 1.5-3 METs, an example of this would be slow walking. Moderate intensity physical activity is any activity which requires 3-6 METs and vigorous intensity physical activity is any activity requiring >6 METs. Figure 1.2 is taken from the Sedentary Behaviour Research Network (SBRN) and illustrates the energy expenditure continuum and where different intensities of physical activity fit into the continuum (SBRN, 2018).

Figure 1.2: Energy Expenditure Continuum



3.2 Physical activity guidelines and level of guideline achievement

3.2.1 Physical activity guidelines

The current guidelines for weekly physical activity for adults (19-64 years), including those with Type 2 diabetes, are for 150 minutes of moderate activity or 75 minutes of vigorous activity (Department of Health, 2011). The activity must be accumulated in bouts of 10 minutes or more and can be a combination of both moderate and vigorous physical activity, including daily living activities such as: walking to work, gardening, and climbing stairs (Department of Health, 2011). Additionally, on 2 days of the week, adults should also focus on activity that builds muscle strength, such as lifting weights or carrying heavy loads of shopping. In older adults (>65years), it is advised that any activity is better than no physical activity (Department of Health, 2011). Older adults should aim to achieve the same 150 minutes of moderate or 75 minutes of vigorous physical activity a week and should aim to be active, in some way, daily. Older adults should also include activity the builds strength and improves balance on at least two days per week (Department of Health, 2011). Activities that improve strength could include chair aerobics, and dancing or daily living activities like carrying heavy bags of shopping. Yoga and Tai Chi are examples of activities that can help with balance and co-ordination (Department of Health, 2011).

Physical activity is recognised as fundamental to good diabetes management and the American Diabetes Association (ADA, 2018) recently updated their physical activity guidelines for those with diabetes (ADA, 2018). Similar to the guidelines developed by WHO, it is recommended that those with diabetes accumulate 150 minutes of moderate activity or 75 minutes of vigorous activity per week. They also recommend not going more than two days in a row without being physically active and the activity should be spread out over at least three days of the week, as this is most beneficial to decreasing insulin resistance in people with Type 2 diabetes (ADA, 2018; Jellyman et al., 2015; Little et al., 2011). The ADA (2018) also advocates strength training, of any intensity, a minimum or two days per week, in order to improve glycaemic control.

3.2.2 Level of guideline achievement

In 2012, the *Lancet* published the first series on physical activity, highlighting the importance of physical activity in the prevention of non-communicable diseases, such as Type 2 diabetes (Hallal, Anderson, Bull, Guthold, Haskell, Ekelund & Lancet Physical Activity Series Working Group, 2012). Insufficient levels of physical activity have been identified by WHO as the 4th leading risk factor for all-cause mortality worldwide (WHO, 2011). Hallal et al. (2012) analysed self-reported physical activity data from 122 countries around the world, using the WHO global health observatory data repository. Authors estimate that 31.1% of adults (>15years) worldwide are physically inactive. Physical inactivity is higher in American and European regions, 43.3% and 34.8% respectively compared to Southeast Asia where around 17% of adults are estimated to be insufficiently activity, the variation in reported proportion may be due to the differing ages ranges used for adults across the different countries (Hallal et al., 2012). In most countries, women (33.9%) had higher levels of physical inactivity than men (27.9%). Insufficient physical activity is more prevalent in higher income countries and older adults (>60years) were reported to be less active than younger adults

(Hallal et al., 2012). It should be noted that these figures come from self-reported measures, which often lead to an overestimation in true levels of physical activity. Research using objective measurement of physical activity and sedentary behaviour suggest the number of people achieving the recommended physical activity is much lower and sedentary behaviour is higher than previously reported, particularly in older adults with Type 2 diabetes (Kennerly & Kirk, 2018). In a systematic review, Kennerly and Kirk (2018) examined the literature surrounding physical activity and sedentary behaviour levels in people with Type 2 diabetes. Of 349 studies identified in the systematic search, 29 studies were eligible for review, all studies reviewed measured physical activity, 20 used subjective methods, six used objective methods and three used a combination of both subjective and objective measurement methods (Kennerly & Kirk, 2018). Average step count was 5000 steps per day and objectively measured moderate to vigorous physical activity was around 30 minutes per day or less than 1% of the waking day. Authors conclude that regardless of measurement method, data reported, or study location, adults with Type 2 diabetes have low levels of physical activity and high levels of sedentary behaviour and are less active and more sedentary than those without Type 2 diabetes (Kennerly & Kirk, 2018).

Objectively measured moderate to vigorous physical activity using data from the cross-sectional NHANES study conducted in America from 2003-2006 was analysed by Sparling and colleagues to examine the influence of age on physical activity and sedentary behaviour (Sparling, Howard, Dunstan & Owen, 2015). Time spent in moderate and vigorous physical activity per day was low in all age groups, with only those in the 20-29 years age group reaching the recommended 30 minutes per day (Sparling, Howard, Dunstan & Owen, 2015). Time spent in moderate and vigorous activity decreased with age, noticeably dropping in those >49 years old, with those in the 70-79 year age group achieving under 10 minutes of moderate physical activity per day (Sparling et al., 2015). A similar association between increasing age and physical activity was identified in a

UK study (Jefferis et al., 2014). Although these adults did not have Type 2 diabetes, with the association between age and Type 2 diabetes diagnosis it would suggest that physical activity levels in those with Type 2 diabetes would be similar.

Self-reported physical activity levels in those with diabetes were reported following analysis of data from the Medical Expenditure Panel Survey, which is a nationally representative survey of adults in the US with diabetes or at risk of developing diabetes (*n* =23283) (Morrato, Hill, Wyatt, Ghushchyan & Sullivan, 2007). A total of just 39% of those with diabetes, compared to 58% of those without diabetes, self-reported as achieving at least 30 minutes of moderate to vigorous physical activity on 3 days of the week. This was in line with physical activity guidelines at the time but is lower than the current guidelines advising 150 minutes of activity per week (Morrato et al., 2007). This would suggest that the proportion of those with diabetes meeting the current guidelines would be far less. Self-reported data was analysed from the National Health Interview Survey, which was collected in America between 2004 and 2011 (*n* = 36697) (Brawner, Churilla & Keteyian, 2016). Of the total sample, 9.3% reported having diabetes and of this subsample, 38.5±2.4% of men and 33.5±2.3% of women self-reported as achieving the recommended ≥150minutes per week of leisure time physical activity.

In 2012, Cooper et al. conducted secondary analysis on objective activity data collected during the Early Activity in Diabetes randomised controlled trial. The trial involved 528 participants who were recently diagnosed with Type 2 diabetes (<6months). Moderate to vigorous physical activity accounted for only 3.2% of time (25.1±19.3 minutes/day) (Cooper et al., 2012). Consistent with previous research, men were significantly (p <0.05) more physically activity than women, with men achieving an average of 27.7±20.3 and women 20.3±16.4 minutes per day over a minimum of three days wear time (Cooper et al., 2012).

With the level of physical activity, particularly moderate to vigorous physical activity, in older adults and in those with Type 2 diabetes so low, the promotion of physical activity, particularly in people with Type 2 diabetes, needs further exploration.

3.3 Physical activity in Type 2 diabetes management

Several systematic reviews have examined the effects of physical activity on glucose management (Avery et al., 2012; Thomas, Elliot & Naughton, 2006; Umpierre et al., 2011). Thomas et al. (2006) conducted a Cochrane review to examine the effects of structured exercise on Type 2 diabetes. A total of 14 randomised controlled trials, involving 377 participants were identified for inclusion in the review (Thomas et al., 2006). Authors found that, compared to no exercise in the control groups, exercise intervention significantly (p <0.05) reduced HbA_{1c} levels by 0.6% in those with Type 2 diabetes. One study examined the effect on quality of life but found no significant difference between groups.

Umpierre et al. (2011) conducted a systematic review and meta-analysis of randomised controlled trials, of at least 12-weeks duration, to examine the effect of structured exercise and physical activity interventions, with or without dietary advice, on HbA_{1c} levels in those with Type 2 diabetes. It was reported that structured exercise of more than 150 minutes per week were associated with a 0.89% reduction in HbA_{1c} and those under 150 minutes per week were associated with a 0.36% reduction in HbA_{1c} (Umpierre et al., 2011). Of the 47 studies included in the review, 24 examined the effect of physical activity interventions on HbA_{1c}. Overall, physical activity interventions were associated with a 0.43% [95% CI -0.59 to -0.28%] reduction in HbA_{1c}. Physical activity advice combined with dietary advice was also associated with a greater reduction in HbA_{1c} levels of 0.58% [95% CI -0.74 to -0.43%] in those with Type 2 diabetes compared to the control groups (Umpierre et al., 2011).

Avery and colleagues (2012) conducted a systematic review of randomised controlled trials (*n* = 17) to examine the effect of behavioural interventions, compared to usual care, on free living physical activity/ exercise, BMI and HbA_{1c} in those with Type 2 diabetes. It was concluded that behavioural interventions focusing on increasing free living physical activity result in clinically significant reductions in HbA_{1c} (–0.32%, 95% CI –0.44% to –0.21%) in those with Type 2 diabetes (Avery et al., 2012).

These systematic reviews of the literature highlight the importance of physical activity and structured exercise in the management of Type 2 diabetes. In the recent statement by the American Diabetes Association (2018), physical activity was highlighted as one of the key lifestyle components necessary for good glycaemic control and condition self-management in those with Type 2 diabetes. However, Chong et al. (2017) investigated whether people with Type 2 diabetes changed their lifestyle as a response to their diagnosis, including increasing their level of activity. Average follow-up was 3.3±0.9 years and in that time, no significant changes were shown to time spent walking, which increased by 12.82 minutes per week, or moderate to vigorous physical activity, which decreased by an average of 2.34 minutes per week. Although physical activity is a focus of Type 2 diabetes management, physical inactivity remains high, making it important to understand why this is and what can be done to improve the effectiveness of interventions.

4. Sedentary behaviour and Type 2 diabetes management

4.1 Sedentary behaviour definition

Figure 1.2 acknowledges sedentary behaviour at the lower end of the activity continuum, however, sedentary behaviour was defined by the SBRN (2018) as any waking activity in a sitting or lying position requiring ≤1.5METs. This definition was developed following an increase in research focused on the health implications of increased sedentary behaviour and inconsistencies in the use of “sedentary behaviour” in the literature (Dunstan et al., 2012;

Gibbs, Hergenroeder, Katzmarzyk, Lee & Jakicic, 2015; Owen, Healy, Matthews & Dunstan, 2010; Tremblay et al., 2010).

Tremblay and colleagues (2010) reported that individuals with high levels of sedentary behaviour can be at increased risk of chronic disease and mortality, regardless of their physical activity levels. Similarly, in 2011, a systematic review of the literature examined the findings of longitudinal studies (*n* =48) conducted since 1996 and reported on the relationship between sedentary behaviour and health outcomes (Thorp, Owen, Neuhaus & Dunstan, 2011). Sedentary behaviour can be examined in two main ways, total sedentary time and patterns of sedentary behaviour. Patterns of sedentary behaviour refers to the frequency an individual breaks their sedentary behaviour and the duration of bouts of both the sedentary behaviour and the break in sedentary behaviour. For example, two individuals may accumulate the same sedentary time in a day, but one may sit all day and move during the evening and the other may break their sedentary behaviour often and consistently throughout the day. Tremblay et al. (2010) concluded that sedentary time and patterns in sedentary time were associated with negative health outcomes, independent of physical activity levels. There is no link between sedentary behaviour and moderate to vigorous physical activity and it has been acknowledged that it is possible for individuals to achieve the recommended levels of physical activity and at the same time be highly sedentary (Owen et al., 2010; Tremblay et al., 2010). The research surrounding this area supports the theory that physical activity and sedentary behaviour should be recognised and measured as separate constructs (Ekelund et al., 2016; Tremblay et al., 2010).

4.2 Sedentary behaviour guidelines and levels

4.2.1 Sedentary behaviour guidelines

The guidelines for sedentary behaviour are not as detailed as those for physical activity, and they are a relatively new addition. The guidelines differ from country to country. In the U.K., the Department of Health (2011)

advises both adults and older adults to minimise the duration of time spent sedentary. It is encouraged that adults, including older adults, take the bus or train, rather than their car, and get off a stop early and walk. They go on to specify that time spent sitting watching television or using a computer should be kept to a minimum. It is also advised that sedentary time is broken up regularly with activity breaks, such as a walk around the garden or office, but the frequency or duration of these breaks is not discussed (Department of Health, 2011).

The ADA (2018) recently published updated guidelines acknowledging sedentary behaviour as a separate construct to physical activity. It is recommended that those with diabetes, in addition to regular physical activity, are sedentary as little as possible throughout the day. They go further to recommend breaking sedentary behaviour every 30 minutes with three minutes of light intensity activity, which may include activities such as: walking, stretching, leg lifts or extensions and torso twists (ADA, 2018).

4.2.2 Sedentary behaviour levels in those with Type 2 diabetes

The proportion of adults who self-reported as spending ≥4 hours per day sitting was 41.5% in the 122 countries. By region, people in America and Europe have the highest proportion of sitting for ≥4 hours per day (55.2% and 64.1% respectively) (Hallal et al., 2012). However, these results are from an adult population and not specifically people with Type 2 diabetes.

Cichosz et al. (2013) compared objectively measured sedentary behaviour in 100 people with Type 2 diabetes and in 100 people without diabetes. Participants wore an Actiheart accelerometer for up to 6 days, which measured their activity and also their heart rate during that period. It should be noted that this device is not specifically designed to measure sedentary behaviour. Authors reported that participants with Type 2 diabetes spent on average 926±44 minutes, or over 15 hours, per day sedentary which is significantly (p <0.001) more than those who did not have diabetes (898±70minutes per day). The high number of minutes spent sedentary could

be explained by the device used to measure the behaviour or the cut-points used to define sedentary behaviour. Additionally, the removal of sleep is not mentioned, which is important as sedentary behaviour is defined as being a waking behaviour.

In secondary data analysis conducted by Cooper et al. (2012), time spent sedentary was calculated for 528 participants with Type 2 diabetes from a randomised controlled trial. Participants wore the ActiGraph (ActiGraph Corporation, Florida, USA) accelerometer for 7 days. Authors reported that participants spent 61.5% of recorded time in sedentary behaviour, which calculated as an average of 8.1±1.3 hours per day (Cooper et al., 2012). Average number of breaks in sitting per day was 84.4±14.3.

These results noticeably differ to similar analysis reported by van der Berg et al. (2016). Van der Berg et al. (2016) reported results from the MAASTRICHT study, which was an observational, prospective, population-based, cohort study (Schram et al., 2014). Participants (n =714) were 40-75years old and had a diagnosis of Type 2 diabetes and wore and activPAL accelerometer for 8 consecutive days (van der Berg et al., 2016). Mean total sedentary time (hours) per day was 10.10, which was significantly (p <0.001) higher than those without diabetes who, on average, sat for just over 9 hours per day (van der Berg et al., 2016). Participants broke their sitting 51.7 times per day and had an average of 5.42 bouts of sedentary time that lasted longer than 30 minutes, although mean sedentary bout time was 12.62 minutes.

Regardless in the variation between the numbers presented in the three studies discussed, adults with Type 2 diabetes are spending too much time sedentary when compared to the current guidelines, which is consistent with findings from the systematic literature review conducted by Kennerly and Kirk (2018). This will have a detrimental effect on their health (ADA, 2018). The variation does highlight the importance of using the correct device to measure sedentary behaviour, and this will be discussed in further detail later in this thesis. The next section will discuss how sedentary behaviour has

been examined as a possible way of improving glycaemic control in those with Type 2 diabetes.

4.3 Sedentary behaviour in Type 2 diabetes management

Increased breaks in sedentary behaviour have been shown to be effective in the management of blood glucose levels, independent of physical activity levels (Dunstan et al., 2012; Tremblay, Colley, Saunders, Healy & Owen, 2010). Dunstan et al. (2012) examined the effects of sedentary breaks on post-prandial glucose in overweight and obese adults, who did not have a diagnosis of diabetes. Participants were fitted with a catheter and a blood sample was taken every hour to allow blood glucose to be tested (Dunstan et al., 2012). Participants also wore an accelerometer on their hip to measure physical activity. Uninterrupted sitting (5-hour treatment period) was compared to breaking sedentary behaviour with 2-minute bouts of either light intensity activity or moderate intensity activity every 20 minutes, in a randomised three-treatment cross-over trial. Postprandial glucose was significantly (p <0.01) lower in both the light intensity break (24.1%, 5.2mmol/L/h) and moderate intensity break (29.6%, 4.9mmol/L/h) conditions compared to uninterrupted sitting (6.9mmol/L/h) (Dunstan et al., 2012). Healy et al. (2008) found increased breaks in sedentary behaviour were beneficially associated with a lower 2-hour postprandial plasma glucose irrespective of total sedentary behaviour and moderate to vigorous physical activity, in overweight and obese but otherwise healthy adults.

In a more recent randomised cross-over trial, Larsen et al. (2015) investigated the effects sitting broken with bouts of light intensity walking over a 3-day period compared to a 3-day period of prolonged sitting on postprandial glucose in overweight and obese adults. Participants wore an ActiGraph accelerometer for the week prior to the lab conditions. Participants spent 3 days (8-hours/day) sitting uninterrupted, followed by a 12-day washout period (Larsen et al., 2015). Participants then spend another 3 days (8-hours/day) where sitting was interrupted every 20 minutes with 3 minutes of low intensity walking (3.2km/h). Postprandial glucose response was

significantly decreased (p <0.001) during the sedentary breaks condition days, with area under the curve 32% lower than the prolonged sitting condition days (Larsen et al., 2015). Although participants in both studies did not have Type 2 diabetes, the results highlight the need to investigate the relationship between sedentary breaks and glucose in those with Type 2 diabetes.

An active lifestyle, which includes increased physical activity and decreased sedentary behaviour, has been shown to improve cardiometabolic markers and glycaemic control in those without diabetes. Dempsey et al. (2016) suggest that focusing on breaking sedentary behaviour with light intensity physical activity may provide more opportunity for behaviour change than increasing moderate to vigorous physical activity.

Dempsey et al. (2016) compared prolonged sitting time, breaking sitting time with light intensity walking and breaking sitting time with simple resistance activities on cardiometabolic factors in adults with Type 2 diabetes. During the control day, participants sat, uninterrupted for 8 hours. During the two intervention days, participants broke their sitting every 30 minutes with 3 minutes of light intensity walking or simple resistance activities (Dempsey et al., 2016). Glucose was measured using a continuous glucose monitor. Both activity-break conditions reduced the iAUC for postprandial glucose (prolonged sitting mean 24.2mmol/h/L, light intensity walking mean 14.8mmol/h/L and simple resistance activities mean 14.7mmol/h/L). Further analysis of the data from this study examined the glucose response over a 22-hour period, including the laboratory period, the free living period after leaving the laboratory and the sleep period (Dempsey et al., 2017). Mean 22-hour glucose was significantly (p <0.001) lower than the prolonged sitting condition (11.6mmol/l±0.3mmol/l) in both the light intensity walking (8.9 ± 0.3 mmol/l) and simple resistance activities (8.7 ± 0.3 mmol/l). Interestingly, mean glucose maintained a lower level until the morning after the laboratory intervention for both break conditions and waking glucose for both conditions was -2.7±0.4mmol/l compared with the prolonged sitting condition (Dempsey et al., 2017).

In a similar randomised cross-over study, Duvivier et al. (2017) examined the effects of breaking sedentary behaviour on glycaemic control and insulin sensitivity in 19 participants with Type 2 diabetes. Participants completed three, four-day long conditions in a free living setting, the order of these conditions was randomised, and participants wore the activPAL accelerometer and the iPRO continuous glucose monitor (Duvivier et al., 2017). Condition A involved sitting for 14 hours per day and 4415 steps. Condition B was 4823 steps per day, 1.1 hour per day replaced with moderate to vigorous cycling and Condition C was 17502 steps with 4.7 hours per day of sitting replaced with standing and light intensity walking (Duvivier et al., 2017). 24-hour glucose area under the curve was significantly (p =0.002) lower in the sit less condition (C) compared to the sitting condition (A) and was lower in the condition B compared to the sitting condition but the difference was not significant (Duvivier et al., 2017). Authors concluded that breaking sitting with light intensity walking is a good alternative to structured exercise to promote glycaemic control in those with Type 2 diabetes. There is however, a noticeable difference in step count in Condition C compared to the other two conditions, which have similar step counts, making it difficult to know if the improved 24-hour glucose was due to increased sitting breaks or increased physical activity, or a combination of both.

Regular, short breaks of light intensity activity have been shown to improve postprandial glucose, in those with Type 2 diabetes (Dempsey et al., 2016; Duvivier et al., 2017; Grace et al., 2017); however, no research has investigated the relationship between daily sedentary behaviour patterns and glucose patterns over a 24-hour period using objective and continuous measurements. Additionally, it is important to understand the optimum frequency and content of sedentary behaviour breaks, in addition to the acceptability and feasibility of breaking sedentary behaviour in order to inform effective and sustainable behaviour interventions.

5. Promoting active living in people with Type 2 diabetes

The concept of active living acknowledges physical activity and sedentary behaviour as separate constructs. For the purpose of this thesis, active living is understood to incorporate increased physical activity and reduced levels of sedentary behaviour.

5.1 Interventions to promote active living

An active lifestyle has been associated with substantial benefits in glucose management in those with Type diabetes, however it has been acknowledged that people often change little about their lifestyle following their diagnosis (Chong et al., 2017), highlighting the importance of effective interventions to promote active lifestyles.

A three-arm randomized controlled trial compared the effectiveness of a 12-week physical activity intervention delivered by a GP in an individual consultation or by a behavioural expert in a group session (De Greef, Deforche, Tudor-Locke & Bourdeaudhuij, 2010). In total 67 participants were randomised into one of the two intervention groups or a control group who received no intervention. The intervention group who received the one-to-one GP consultations, received three sessions over the 12-week period and the other intervention group participated in three group sessions with a behavioural expert during the intervention period. Physical activity was measured using a pedometer and a self-report interview version of the International Physical Activity Questionnaire (De Greef, Deforche, Tudor-Locke & Bourdeaudhuij, 2010). Following the intervention, those attending the group counselling increased their daily steps by 1706, which was significantly (p <0.05) higher than the control group and the other intervention group. Additionally, their self-reported time spent physically active increased, while those in the control group reported a decrease in their physical activity (De Greef, Deforche, Tudor-Locke & Bourdeaudhuij, 2010). The social aspect of the group counselling appears to have had an impact on physical activity, however there was no follow-up from this intervention, so it is

unknown whether participants sustained the improvement shown immediately after the intervention.

De Greef et al. (2011) conducted another pedometer-based intervention in people with Type 2 diabetes, this time however, it focused on changing physical activity and sedentary behaviour. The intervention was 24-weeks long and 92 participants were randomised into an intervention group and a control group. The intervention group received one face-to-face session and seven follow-up phone calls and wore a pedometer. Physical activity and sedentary behaviour were measured at baseline using a pedometer and an Actigraph accelerometer at baseline, at the end of the 24-week intervention and up to one year after the intervention (De Greef et al., 2011). The intervention group significantly (p <0.05) increased their steps per day by 2744, their total physical activity by 23 minutes per day and reduced their sedentary time by 23 minutes/ day, post intervention. These improvements in physical activity and sedentary behaviour were preserved at one year follow-up (De Greef et al., 2011).

A systematic review of behavioural interventions conducted by Avery et al. (2012) found significant increases in physical activity in the intervention groups compared to usual care in both objectively measured and self-reported physical activity in 17 randomised controlled trials, including the two studies conducted by De Greef and colleagues (2010; 2011). These effects were observed in all follow-up periods except the 24-month follow-up, suggesting that more needs to be done in order to achieve long term, sustained behaviour change.

The majority of intervention studies have focused on increasing physical activity or exercise in people with Type 2 diabetes (Avery et al., 2012; Thomas et al., 2006; Umpierre et al., 2011). With increasing evidence of the positive associations between reduced sedentary behaviour and glycaemic control, future research should focus on developing interventions to promote active living, including increasing physical activity and reducing prolonged sedentary behaviour.

6. How can mobile technology help?

Technology is increasingly becoming part of people's everyday lives and technologies such as websites, computer programmes and wearable devices are being used more frequently as a means of monitoring and managing health conditions, including diabetes (Connelly, Kirk, Masthoff & MacRury, 2017; Cunningham, McAlpine & Wake, 2016). Technology that is used in this way to improve healthcare is referred to as digital health.

6.1 Digital Health

Digital health evolved from telehealth, where telecommunications were used to aid the delivery of healthcare and is the use of computer-based technologies to support improved and more efficient healthcare systems. Digital health encompasses both eHealth and mHealth (Cunningham, Wake, Waller & Morris, 2016). eHealth was defined by Eysenbach (2001) as internet-based technologies which can be used to support and monitor health behaviours. As technologies have progressed, mHealth has become increasingly common. mHealth describes technologies which are similarly designed to support and monitor health behaviour and aid the delivery of healthcare, but the technologies are mobile rather than computer or internet-based (Duggal, Brindle & Bagenal, 2018). mHealth can include smartphone or tablet apps and wearable devices.

In a recent editorial published in the *Lancet* (Lancet, 2017), it was estimated that the value of the global digital health market was already worth $25billion (£19bn). The mHealth app market is vast, with the number of health monitoring apps available to download doubling between 2015 and 2017 to approximately 320,000 apps (Lancet, 2017). This means that accessibility to mHealth is high, particularly given that most adults now own a smartphone and/or a tablet device, however most of these apps are designed for the consumer market and regulation is often nowhere near the levels required for endorsement by healthcare professionals, such as those working for the NHS (Duggal, Brindle & Bagenal, 2018; Lancet, 2017).

6.2 Examples of Digital Health

Digital health includes technologies that are currently being used in the clinical setting, such as: electronic patient records, appointment booking and reminder systems, medical consultations via video link, clinician and patient portals and more complex systems which use algorithms from large clinical datasets to support decision making in the healthcare setting (Duggal, Brindle & Bagenal, 2018). Digital health does not need to be restricted to a clinical setting and often is used within the home by patients themselves with the aim of reducing the need for users to interact with traditional services (Cunningham, Wake, Waller & Morris, 2016). This is of particular benefit to patients who live remotely or have reduced mobility and find it difficult to attend appointments. Examples of digital health used by patients outside the healthcare setting include blood pressure monitors and blood glucose monitors, information from which can be reported back to the clinician via an online patient portal (Cunningham, Wake, Waller & Morris, 2016). Technologies like those mentioned can enable participants to be more involved in the management of their conditions, such as Type 2 diabetes or Hypertension.

Additionally, there are mHealth technologies including apps and wearable devices available that enable the user to track and monitor most behaviours, including food intake, sleep quality and activity. This may not be officially part of their healthcare but can be used to manage or improve their overall health and wellbeing (Duggal, Brindle & Bagenal, 2018).

6.3 Examples of Digital Health in Diabetes

There are many examples of digital health technologies that have been developed to improve the treatment and management of diabetes. These include technologies designed to monitor sugar levels such as blood glucose monitors, continuous glucose monitors and more recently flash glucose monitors like the FreeStyle Libre. The progression in technology from blood glucose monitors, which involve finger prick testing of the blood to the most recent flash glucose monitors which include a sensor inserted into

the skin, which allows near continuous measurement of glucose levels has reduced the burden on patients. This has also allowed for the condition to be managed more closely by the patient themselves outside of the clinical setting and routine appointments.

There are also a vast number of apps available to download for people with diabetes. The focus of the apps varies and includes: carb counters, food trackers, medication trackers, medication reminders, recipe apps, self-management apps that encompass diet, medication and activity. Most of these apps are free to download for anybody with a smartphone or tablet and are not regulated as they are not designed for the consumer (Lancet, 2017), however there are a small number which have been assessed and subsequently endorsed by the NHS (NHS Apps Library, 2018).

6.4 Examples of Digital Health Solutions in Scottish Diabetes Care

The Scottish Care Information Diabetes Collaboration (SCI-Diabetes) is a single shared electronic patient record, which can be accessed by all healthcare professionals providing treatment for the patient (SCI-Diabetes, 2018). SCI-Diabetes provides real-time data entry, so the data is immediately available, encouraging cross-boundary support. Similarly, MyDiabetesMyWay is an electronic personal health record and self-management platform that integrates patient data from multiple sources. It includes an education resource website, goal setting functions, discussion groups and links with remote glucose monitoring. The key difference between SCI-Diabetes and MyDiabetesMyWay is that MyDiabetesMyWay is designed with patients and carers in mind allows patients to view their own clinic results with the aim of helping patients manage their own condition. SCI-Diabetes and MyDiabetesMyWay are examples of how technology can be used to integrate lots of data from multiple sources to support self-management of diabetes (Cunningham et al., 2016). However, more research is needed to explore how to use this data effectively and in a meaningful way for both clinicians and patients.

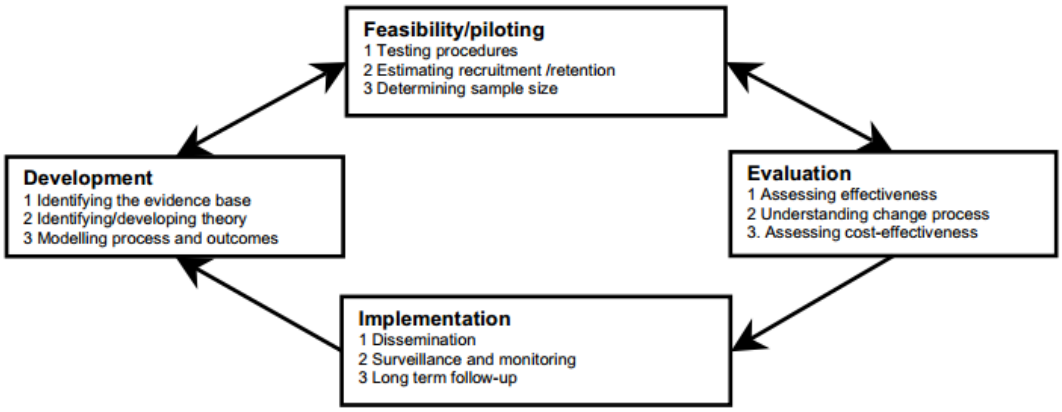
With the increasing prevalence in Type 2 diabetes and the increasing availability and mobility, technology offers a way of delivering effective interventions on a large scale (McMillan, Kirk, Hewitt & MacRury, 2016). To do so it is important understand what technologies are currently available and which are deemed to be the most effective and acceptable to users and how this technology can be integrated into current practice in diabetes management (Conway, Campbell, Forbes, Cunningham & Wake, 2016). The use of technology, particularly mobile-based technology, to promote active living and good glucose management in those with Type 2 diabetes in an effective, feasible and acceptable way, will be discussed further in a systematic and integrated literature review in Chapter 2 of this thesis.

7. Developing interventions

7.1 Medical Research Council Framework

The Medical Research Council (MRC) (Craig, Dieppe, MacIntyre, Michie, Nazareth, Petticrew, 2008) presents a framework for the development, evaluation and implementation of complex health interventions. Four key stages are identified by the MRC and they are: 1) Development of an evidence and theory based intervention 2) Piloting and feasibility testing of the intervention including protocols and recruitment strategies 3) Evaluation of the intervention including the effectiveness and the cost-effectiveness of running the intervention and 4) Implementation, which involves getting the findings from the intervention into practice or policy. The MRC highlight that there are often several integrating components in health interventions that need to be considered in order for an intervention to successfully reach the implementation stage (Craig et al., 2008). Figure 1.3 illustrates the four stages and the cyclical nature of the framework as presented by Craig et al. (2008). The work discussed in this thesis aligns with the development stage of the MRC framework, identifying and building the evidence base and theoretical background for a future intervention. The results from the studies described in this thesis will provide the building blocks necessary to develop an intervention which uses mobile technology to support active lifestyles in adults with Type 2 diabetes.

Figure 1.3: Key Elements from the MRC Framework for Development and Evaluation of Health Interventions



7.2 Mixed methods approach

Mixed methods refers to the use of quantitative and qualitative methods within the same body of research and is frequently used in behaviour research (Lopez-Fernandez & Molina-Azorin, 2011). The National Institute for Health research (NIH) advocate the use of a mixed methods approach to develop a more thorough and contextual understanding of a problem (NIH, 2011). This thesis includes a systematic integrated review of qualitative and quantitative research, two quantitative studies and one qualitative study. Collectively, with the other components of this thesis, these studies will provide a comprehensive evidence base for the development of an intervention using mobile-technology to promote active living for optimal glycaemic control in people with Type 2 diabetes.

8. Structure of the thesis

8.1 Thesis structure

This thesis consists of five studies (Chapters 2-6), each of these chapters will include an introduction and rationale for the study, methodology, results and discussion section. Chapter 2 has been peer-reviewed and published in the Journal of Diabetes Science and Technology and is therefore in manuscript format. Chapter 3 is also in manuscript format and

has been accepted for publication in the Journal of Rehabilitation and Assistive Technologies Engineering. Chapters 4-6 are written as chapters for this thesis and will be revised into manuscript format and submitted for publication once the thesis has been submitted. There is a discussion chapter, Chapter 7, where the findings from each study are discussed further within the wider context of the Ph.D thesis.

8.2 Thesis aims and research questions

The overall research aim is to investigate the potential to use mobile technology to promote active lifestyles and improved glycaemic control in individuals with Type 2 diabetes.

In Chapters 2-6, the following research questions have been addressed to achieve the overall aim of the thesis:

Chapter 2

1. What mobile-based technologies have been used to promote active lifestyles in those with Type 2 diabetes, and what is the effectiveness, feasibility and acceptability of the technologies identified?

Chapter 3

2. What are the best methods for collecting and combining continuously measured glucose and activity data in people with Type 2 diabetes?

Chapter 4

3. What are the patterns of physical activity, sedentary behaviour and glucose in people with Type 2 diabetes in a free living context?
4. What is the relationship between participant characteristics and their physical activity, sedentary behaviour and glucose patterns?
5. What is the relationship between free living physical activity and sedentary behaviour patterns and glycaemic excursions in people with Type 2 diabetes?

Chapter 5

6. What is the individualised glycaemic response to sedentary behaviour and breaks in sedentary behaviour in people with Type 2 diabetes, in a controlled setting?

Chapter 6

7. What are the experiences and attitudes of people with Type 2 diabetes of using active living as a way of achieving good glucose management?
8. What are the experiences and attitudes of people with Type 2 diabetes of using mobile technology to promote active living and good glucose management?

Chapter 2: Systematic and integrated review of mobile-based technology to promote active lifestyles in those with Type 2 diabetes

1. Preface

1.1 Introduction to mobile-based technology

1.1.1 Definition

Mobile-based technology can be a definition which covers a variety of portable technologies. For the purpose of this thesis, however, mobile-based technology will refer to portable electronic devices including mobile phones, tablets and wearable devices but will exclude laptops and computer programmes. Mobile-based technology is becoming increasingly part of our daily lives with an estimated 43% of people worldwide owning a smartphone (Poushter, 2016). Ofcom (Ofcom, 2018) reported that 76% of adults in the UK own a smartphone and 66% use their phone to access the internet. Increasingly, technology is being utilised as a means of improving health or quality of life including wearable devices that can monitor physical activity and sleep patterns and mobile apps which allow you to track your dietary intake. In a behavioural setting, mobile-based technologies can fit into one of four categories: 1) technology which is used to *monitor* behaviour, but not influence or change it in any way 2) technology which is aimed at *informing* the user about a certain behaviour or condition 3) technology aimed at *provoking* behaviour change and 4) technology that promotes *sustained* behaviour change over a prolonged period of time (≥6months).

With the increasing global availability of smartphones, tablets and wearable devices, these mobile-based technologies may provide a means of delivering interventions on a larger scale than has been feasible before and have the potential to significantly improve research and management of chronic illnesses, such as Type 2 diabetes.

1.1.2 Mobile-based technology in healthcare

Technology, in particular mobile technology, is increasingly being used in a healthcare setting and is often referred to as mobile health or mHealth or eHealth (Cunningham, Wake, Waller & Morris, 2014; Steinhubl, Muse and Topol, 2013). In 2011, the US Secretary for Health and Human Services emphasised the potential impact of mHealth on how healthcare is provided and received in the future. Steinhubl, Muse and Topol (2013) suggest that mHealth could offer better healthcare outcomes whilst lowering cost and reduce demands on clinicians. Kumar, Nilsen, Pavel & Srivastava (2013) also discuss the potential for mHealth to improve heath and care. However, authors emphasise the need for rigorous empirical and theoretical research examining an evidence-based approach to implementing mHealth and creating sustainable health information systems (Kumar et al., 2013; Steinhubl, Muse and Topol, 2013). Similarly, Estrin and Sim (2010) acknowledge the potential benefits of using mHealth to prevent and manage chronic conditions, particularly how mHealth enables patients to monitor, collect and share relevant data with their clinician without necessarily visiting the clinician. This could allow for quicker, more personalised treatment and could result in better long-term condition management. However, in a recent study conducted by Bauer, Rue, Keppel, Cole, Baldwin and Katon (2014) examining the use of mHealth in primary care patients, it was shown that older patients and those with chronic conditions were significantly (p <0.001) less likely to use mHealth. When smartphone ownership was considered in analysis these variables were no longer significant, suggesting owning a smartphone is more conducive to mHealth use than age or condition. Interestingly, Bauer et al. (2014) found patients did not see the need for their clinicians to know about their use of mHealth but acknowledged that further research into the reasons for this is required.

Mobile-based technology, or mHealth, could be a successful and cost-effective method for delivering healthcare in the future. Further research is required to examine both how mobile-based technology can be effective in prevention and management of chronic illness but should also focus on the

feasibility of using this type of technology on a large scale and what forms of technology are suitable and acceptable to different populations.

Due to the complex and multi-dimensional nature of physical activity behaviour and the within and between day variability, mobile based technology is particularly appropriate for monitoring physical activity and is often used within behaviour change interventions. A recent systematic review of 22 studies examined mobile-based technologies that have been used to monitor or promote physical activity (O'Reilly & Spruijt-Metz, 2013). A wide variety of technologies were identified including, mobile-phone based self-report questionnaires and journals, SMS prompts and worn physical activity monitors. Authors noted that the variety in devices and measurements of physical activity and sedentary behaviour made it difficult to define what had been successful. Interventions successful in promoting physical activity behaviour change used SMS communication, mobile journaling or a combination of both (O'Reilly & Spruijt, 2013). Authors acknowledged that more research was required in order to identify how worn activity sensors could be utilised most successfully in behaviour change and measurement.

Van der Weegen, Verwey, Spreeuwenberg, Tange, van der Weijden and de Witte (2013) examined the requirements when developing mobile-based technology to improve physical activity in those with chronic illness. The study incorporated a user-centred approach and data from patients and healthcare professionals was collected through interviews and focus groups. This information was used to aid the development of user-friendly and acceptable technology. Participants commented on how they would like visual feedback on their physical activity achievement each day and would prefer that feedback be reported in active minutes rather than calories burned. Participants also preferred the idea of wearing an activity monitor that connected to a smartphone app, allowing for real-time visual feedback. Authors concluded that a user-centred approach is important when considering usability and acceptability of such technology and increased the opportunity for success, although the need for the device and app to be

tested further in a randomised controlled trial to assess its effectiveness was also discussed (van der Weegen et al., 2013).

In 2016, the effect of a mass participation mHealth intervention aimed at increasing physical activity and reducing sitting time, called Stepathlon, was reported (Ganesan et al., 2016). The study included 69,219 participants from 64 countries and involved a team-based race where participants wore a pedometer and were encouraged to increase their daily steps in order to win. The participants were able to see and monitor progress via a multi-platform mobile app (Ganesan et al., 2016). Following the Stepathlon, participants recorded a significant increase (p <0.0001) in daily steps with an average increase of 3519 steps per day. Participants also recorded a decrease in sitting time by 45 minutes per day (p <0.0001). Results from this study highlight how mobile-based technology provides the opportunity to conduct successful, large scale and low-cost active living interventions.

King et al. (2016) showed the need to incorporate behaviour change theory and techniques when designing active lifestyle interventions involving mobile-based technology. In a mixed-methods, 8-week intervention, 95 older adults (>45 years old) were randomised into three groups. Each group was given a different mobile phone app to use, and the accelerometer within the smartphone, in addition to self-report methods, was used to measure daily physical activity and sedentary behaviour (King et al. 2016). Over an 8-week period, physical activity increased significantly more (p <0.05) in the intervention apps compared to the control app. Similarly, participants using the intervention apps reported significantly (p <0.001) less time sitting after the 8 weeks compared to those in the control group (King et al. 2016). Results from this study suggest that although the technology is important, the way in which the technology is used and implemented is equally as important if it is going to have a sustained effect on behaviour.

The literature discussed shows the already broad use of mobile-based technology in promoting active living, particularly in promoting increased physical activity. More recent studies have identified the importance of

focusing on both physical activity and sedentary behaviour (Ganesan et al., 2016, King et al., 2016). The large variety of mobile-based technologies available and the pace in which technology is advancing, particularly in comparison to the pace of scientific research, have been identified as difficulties (O'Reilly & Spruijt, 2013). However, mobile-based technology has been shown to have a positive impact on aspects of active living on a large scale (Ganesan et al., 2016), but incorporating evidence-based behaviour change theory to the development of both the technology and interventions has also been identified as beneficial (King et al., 2016).

Although this literature shows how mobile-based technology has been used previously to promote active living, none of these studies focused on physical activity or sedentary behaviour in people with Type 2 diabetes. The technology used in these studies also does not always match the description that has been given to mobile-based technology in this thesis. In order to fully understand what mobile-based technology has been used, and in what capacity it has been used, in those with Type 2 diabetes, a comprehensive review of the literature is required. To fully understand all the research in this area, an integrative methodology has been chosen for this review. The following section will introduce the integrative review and examine the process leading to the decision to use the integrative method for the literature review.

1.2 Integrated literature review

1.2.1 What is an integrated literature review?

An integrated literature review is a method used to examine and synthesise current theoretical and empirical literature surrounding a specific topic area (Whittemore & Knafl, 2005). This allows the researcher to evaluate the strength of the evidence available, identify gaps in the literature and identify the areas in which future research should be focused (Torraco, 2005). Additionally, the integrative method allows for the combination of diverse methodologies to be included (Whittemore & Knafl, 2005). This

allows for critique and examination of the variety of research methods and study designs used in previous research of a topic and gain insight into what methods have been most successful. Other, more restrictive, review methods may only partially review an area of research resulting in a misconception and reduced knowledge base surrounding a topic.

The integrative review differs from other methods, which are more commonly used and include: meta-analysis, systematic reviews, meta-synthesis and meta-studies (Torraco, 2005; Whittemore & Knafl, 2005). Meta-analysis reviews combine the evidence of multiple primary studies by employing statistical methods; this enhances the objectivity and validity of the review findings (Whittemore & Knafl, 2005). To conduct a meta-analysis, the study design must be comparable in all the studies. Systematic review is another common method and combines the evidence of multiple studies regarding a specific problem or topic and requires a well-specified question (Whittemore & Knafl, 2005). These methods are not suitable for the current review due to the apparent lack of primary studies and relatively new and multi-disciplinary nature of the research area. In order to have sufficient literature to review, either the research question is required to be broadened or the restriction of using only empirical, experimental studies must be altered. Integrative reviews are the most comprehensive form of review method, and this allows the researcher to review a diverse selection of literature whilst maintaining a strict and focused research question. Enabling the researcher to understand the topic of concern more fully, with a more complete understanding of the topic of interest rather than a focused understanding the findings of experimental research.

1.2.2 Justification for methodology

The purpose of this review was to examine all the research conducted thus far using mobile-based technology to promote active living in those with Type 2 diabetes. The promotion of active living includes increasing physical activity but also focusing on a reduction in sedentary behaviour, which is a

relatively new focus of research. Additionally, there was a desire to focus on mobile-based technology as defined as portable electronic devices including mobile phones, tablets and wearable devices but excludes laptops and computer programmes. A previous systematic literature review has investigated the use of technology in promoting physical activity in those with diabetes (Connelly, Kirk, Masthoff & MacRury, 2013); however, this review focused only on physical activity intervention studies with a randomised controlled study design and did not include studies focused on sedentary behaviour or those with other study designs. In order to fully understand the technology that has been used, this review will look at studies that have examined the effectiveness of the technology in addition to the acceptability and feasibility of the technology used. Exploring acceptability and feasibility is an important and often neglected aspect of research, particularly with behaviour change research involving technology. It is important to understand what is effective, however it is equally important to consider aspects of acceptability and feasibility, including cost effectiveness and whether the device or app is user-friendly. If technology is not found to be feasible or acceptable to targeted users, then it is less likely that they will use it. For these reasons, an integrative methodology was chosen for this literature review.

To maintain a structure to the review, a systematic and integrative methodological framework developed by Whittemore and Knafl (2005) was followed. Whittemore and Knafl (2005) identify a 5-stage process to use when conducting an integrated review: 1. Problem formulation, 2. Literature search, 3. Data extraction, 4. Analysis of the data and quality assessment, and 5. Interpretation of the results. Using this framework ensured that there was a level of quality maintained but there was more freedom when developing the inclusion and exclusion criteria. This meant certain aspects of the inclusion and exclusion criteria could be restricted, for example, the population group was maintained as those with Type 2 diabetes only. While other aspects were more flexible, the inclusion of both quantitative and

qualitative research, for example, to allow us to examine feasibility and acceptability.

The following section presents the Systematic and Integrated review of mobile-based technology to promote active lifestyles in those with Type 2 diabetes as formatted for and published in the Journal of Diabetes Science and Technology in 2017.

KM was responsible for: Developing the study design, research questions and study protocol; Developing the search strategy for the literature search; Running the literature search, screening titles (*n* =7662), abstracts and full papers; Extracting the data and conducting the quality assessment of the literature. KM prepared the manuscript for publication and AK, AH and SM provided feedback and suggestions on how to improve the manuscript.

2. Paper 1: A systematic and integrated review of mobile-based technology to promote active lifestyle in people with Type 2 diabetes.

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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 on 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 2.1.

Table 2.1: 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

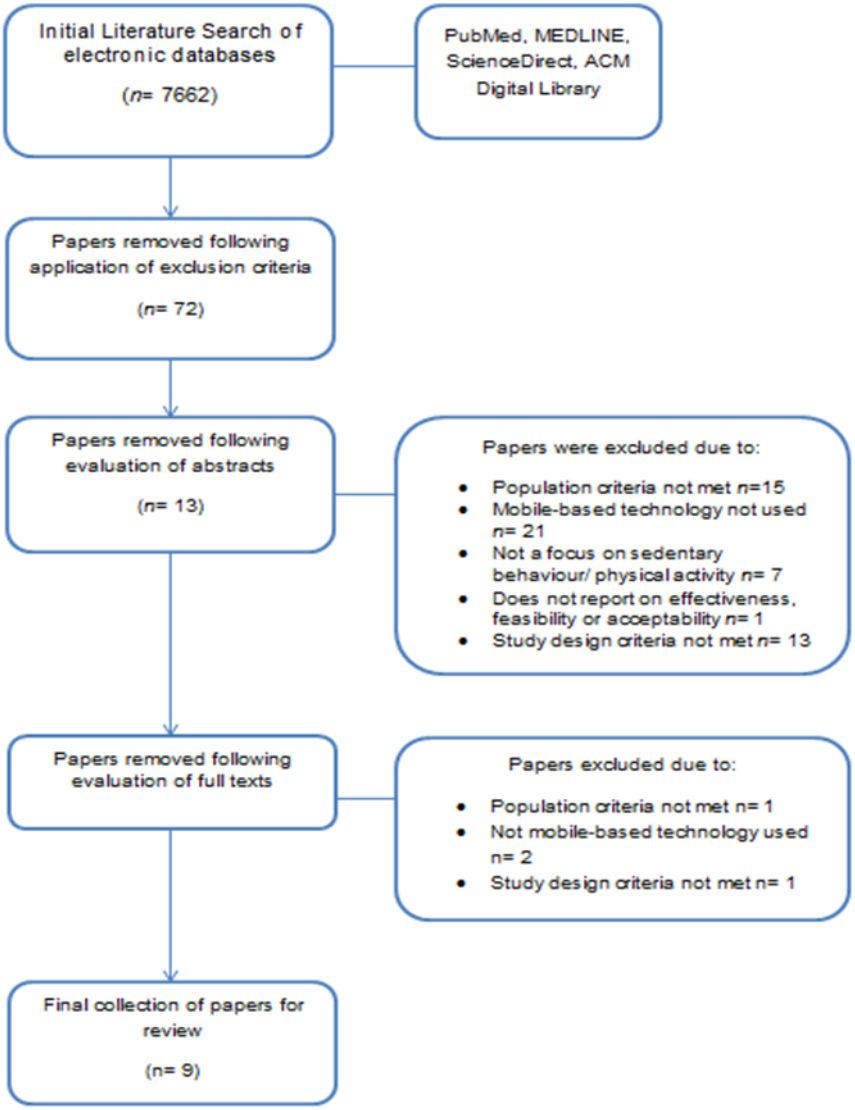
Search strategy

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 2.1 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 2.1: 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 2.3.

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 2.4.

Results

A total of nine papers were identified as suitable for review. Table 2.2 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 2.2: 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	Intervention Pilot	Case Study

							Pilot		
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	Developing an app that involves several sensors is feasible.	Concluded that mHealth apps will give patients the motivation	The use of a pedometer in conjunction with a cognitive behavioural intervention was effective	The change in HbA_{1c} did not differ between the groups after the 1-year	No difference in self-efficacy scores towards self-management between	Commitment and motivation towards behaviour change were identified	The intervention design was found to be feasible. The smartphone tool was	PDAs were not considered straightforward and user friendly

	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.	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.	to be more active in managing their health.	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.	intervention. The secondary outcome measures did not differ between groups after the 1-year intervention.	iPad App and journal study groups. Self-efficacy scores and glycaemic control (HbA_{1c}) were both very good to begin with.	as problem areas. eMate identified coping, social norms and cues as problems for commitment, motivation and awareness towards behaviour change.	found to be useful in supporting those with Type 2 diabetes to make lifestyle changes. No blood glucose was reported.	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 2.3: 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 2.3. 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 2.4 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 2.4: 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

There were two key limitations of this review; the terms used in the search strategy and the method used for the quality assessment. The terms used in the search strategy included reference to mobile-based technology but did not include some common keywords and phrases related to health technology, such as: digital health, mHealth, wearable, portable, app(s) and health technology. These terms are often referred to in the literature and their inclusion in the search strategy may have led to an increase in the number of relevant papers identified in the initial search and thus included in the current review. The literature search did include searching both health and technology focused databases, however, it is acknowledged that the terms used in the current search strategy may have led to important insights being missed. The second 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 2.4, 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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Chapter 3: Methods for combining continuously measured glucose and activity data in people with Type 2 diabetes: Challenges and solutions

1. Preface

This chapter, which is comprised primarily of Paper 2 with supporting commentary and context, discusses the challenges of combining continuously measured physical activity and sedentary behaviour data and glucose data, and presents the possible solutions in processing, combining and analysing these two potentially large datasets in meaningful ways.

The findings from this chapter provide the methodology used for processing and analysing the data used in Chapter 4 and Chapter 5 of this thesis, where the relationship between physical activity and sedentary behaviour and glucose was examined in a free living setting (Chapter 4) and a controlled setting (Chapter 5). Additionally, this chapter provides a guide for combining large, continuous datasets in future research. Material supplementary to the published manuscript (Table 3.2) provides a summary of the challenges identified and the possible solutions to these challenges.

1.1 Introduction to the mobile technology

Due to word count limitations set by the journal for the manuscript, only a short description of each device and why it was chosen was included in Paper 2. This section will provide more detail on what the devices measure, what data is captured and why these devices were chosen. The activPAL accelerometer and the FreeStyle Libre flash continuous glucose (FLGM) monitor were the devices used for the objective and continuous data collection in the studies described in this thesis.

1.1.1 What is the activPAL?

The activPAL™ is a small electronic device which contains an accelerometer and an inclinometer (measuring 53x35x7mm; weighing 15g) (PAL Technologies Ltd, Glasgow UK). The activPAL™ can distinguish between sitting/ lying, standing and stepping, and records step count and sit to stand transitions. Additionally, the device measures stepping speed (cadence) and estimates energy expenditure. The activPAL™ is the first validated single site device for quantifying postural allocation (PAL Technologies Ltd, Glasgow UK). The sampling frequency is 20Hz but 80Hz can be selected when initialising the device (Edwardson et al., 2016). The default sitting/upright time period to define a new posture is 10seconds, which is recommended by the PAL Technologies Ltd. However, during initialisation, this can be altered to anything between 1-100seconds (Edwardson et al., 2016).

The device is worn on the front of the thigh and can be worn for up to 14 days at a time before it needs recharged. With waterproofing, the activPAL™ can be worn 24 hours per day and does not need to be removed for water-based activities. A continuous wear time protocol like this has been shown to increase wear time compliance (Tudor-Locke et al., 2015), something that can be a problem when using a waking wear time protocol with other devices, such as the ActiGraph accelerometer (Matthews, Hagstromer, Pober & Bowls, 2012). In order to measure sedentary behaviour, sleep time must be removed from the dataset. This can be done manually or using specially developed software which identifies patterns in the data and estimates sleep start and stop time.

When data from the activPAL™ is downloaded and exported, there are several output files produced by the software. There is a summary file, which presents the data summarised by hour, day or week. There are two event based output csv. files which provide more specific data (Edwardson et al., 2016). The events files list all the bouts of sitting/lying, standing and stepping in chronological order with a time stamp of when the event began and the duration of the bout in seconds.

1.1.2 Why the activPAL?

The activPAL™ is often referred to as the gold standard for objective sedentary behaviour measurement. Kozey-Keadle and colleagues (2011) validated wearable monitors for the measurement of sedentary behaviour. In the study, 20 overweight and inactive office workers were directly observed over two six hour periods whilst also wearing and activPAL™ and ActiGraph accelerometers. During this period, participants were asked to reduce their sitting time and their behaviour was coded as sedentary or non-sedentary through direct observation. On average the activPAL underestimated sitting time by 2.8% compared to 4.9% in the ActiGraph (Kozey-Keadle, Libertine, Lyden, Staudemayer and Freedson, 2011). The correlation between the activPAL™ and direct observation was R^2 =0.94 compared to the correlation with the ActiGraph, which was R^2 =0.39. These results are consistent with findings of other research (Grant, Ryan, Tigbe and Granat, 2006; Lyden, Kozy-Keadle, Staudemayer and Freedson, 2012). In the study conducted by Grant et al. (2006), 10 adults wore three activPAL™s and were directly observed where their behaviour was classed as sitting/lying, standing and stepping. Total agreement between the activPAL™ and direct observation of behaviour was 95.9%. The mean difference for time standing was 1.4% (limits of agreement −6.2% to 9.1%) and for time walking was −2.0% (limits of agreement −16.1% to 12.1%) (Grant et al., 2006).

The results in these studies highlight that the activPAL™ accurately measures sedentary time and breaks in sedentary time. With the focus of this research towards sedentary behaviour, the activPAL™ was selected.

1.1.3 What is the FreeStyle Libre?

The FreeStyle Libre Flash Glucose Monitoring System (FreeStyle Libre) (Abbott Diabetes Care, Alameda, CA) is a flash glucose monitor which measures glucose every 5 minutes and records it every 15 minutes for up to 14 days. Glucose is measured through the interstitial fluid, rather than plasma glucose. The FreeStyle Libre consists of a small sensor (35mmx5mm) and a reader (95mmx60mmx16mm, 65g) (Abbott FreeStyle

Libre, 2017). The sensor is attached to the subcutaneous tissue in the back of the upper arm. The user is required to scan the reader over the sensor every 8hours in order to download the data. Scanning the reader over the sensor produces real-time glucose data including current glucose reading and the trend the glucose is moving in (decreasing, increasing or remaining stable). The sensor is designed to be water resistant and therefore the user does not need to remove it.

The FreeStyle Libre is a consumer device, so is cheaper and more user friendly than other glucose monitors, such as those made by Dexcom (Dexcom Inc, San Diego, CA, USA) and Medtronic (Medtronic Inc, Northridge, CA, USA). The output from the FreeStyle Libre software includes summary outputs presented in user-friendly graphs and tables. Additionally, the raw datasets can be extracted as a text file where the 15-minute glucose reading is presented chronologically and is date and time stamped. The glucose level from the reader being scanned is also recorded and time stamped.

1.1.4 Why the FreeStyle Libre?

Continuous glucose monitors have been assessed in several studies now and it has been shown that, if used consistently, continuous glucose monitors are associated with improvements in HbA_{1c} and reductions in hypoglycaemia (Beck et al., 2017; Lind et al., 2017). It should be noted, however, that that FreeStyle Libre is not a continuous glucose monitor, it is a flash glucose monitor and does not measure glucose continuously. Rather, the FreeStyle Libre measures glucose every 5 minutes and records the average reading every 15 minutes, meaning this device cannot be directly compared to continuous glucose monitors that are currently available. The FreeStyle Libre does not require finger-prick glucose calibrations, removing the risk of inaccuracies due to user errors during the calibration (Hoss & Budiman, 2017), however, those with Type 1 diabetes are recommended to calibrate the FreeStyle Libre with regular checks using a blood glucose

monitor if they are ill or to comply with driving regulations (NICE, 2017). This is predominantly due to the fact that the FreeStyle Libre has been shown to become less accurate when glucose becomes very low or very high (Crabtree, Sathyapalan & Wilmot, 2018).

In a validation study, funded by Abbott Diabetes Care, and conducted by Bailey, Bode, Christiansen, Klaff and Alva (2015), the accuracy of the FreeStyle Libre was assessed. A total of 72 participants, with Type 1 or Type 2 diabetes, wore the FreeStyle Libre for 14 days. During this 14-day period, the participants visited the clinic on three occasions where venous blood samples were collected every 15-minutes over an 8-hour period (Bailey et al., 2015). Absolute relative deviation (ARD) was ≤10% in 55% of sensor, while approximately 10% of sensors had an ARD of ≥16%. It was concluded that the FreeStyle Libre was as accurate as capillary blood glucose and was not influenced by user BMI, age, type of diabetes or HbA_{1c} level (Bailey et al., 2015). In a similar independent study where 58 participants with Type 1 diabetes wore the FreeStyle Libre for 10-14days and measured their capillary bloody glucose 6 times per day, ARD for the full wear time was 13.2%.

In a recent narrative review, Leelarathna and Wilmot (2018) discuss the current evidence surrounding the accuracy of the FreeStyle Libre compared to real-time continuous glucose monitors. When compared directly to the Medtronic and Dexcom continuous glucose monitors, the FreeStyle Libre had the lowest ARD, 13.2% for the entire glycaemic range (Dexcom 16.8%, Medtronic 21.4%) (Aberer et al., 2017 as cited in Leelarathna & Wilmot, 2018). The accuracy of 17 commercially available blood glucose meters were assessed and mean ARD ranged from 5.6%-20.8%, with nine of the 17 having a mean ARD of over 12% (Ekhlaspour et al., 2017). Leelarathna and Wilmot (2018) discuss that, with a mean ARD of over 12%, there is a possibility that some blood glucose meters are less accurate than the FreeStyle Libre (mean ARD 11.4%).

The FreeStyle Libre was chosen as the most suitable device for measuring glucose in the studies described in this thesis for a number of

reasons including; accuracy, usability and cost. The FreeStyle Libre has been shown to be more or as accurate as currently available continuous glucose monitors and blood glucose monitors. It is a consumer device so is more user friendly, so it was decided it would be less of a burden for participants than the continuous glucose monitors discussed. And finally, the FreeStyle Libre is much cheaper than the Dexcom or Medtronic CGMs, which was an important consideration as there was very little funding available to the researcher for glucose monitors. Using the FreeStyle Libre meant the researcher was able to purchase more devices and therefore recruit more participants over a shorter time period, without compromising on the accuracy of the data collected.

The following section presents Paper 2, which has been formatted for publication (May 2018) and is currently in press in the peer-reviewed Journal of Rehabilitation and Assistive Technologies Engineering. KM was responsible for: Developing the study design, collecting, processing and analyzing the data. KM prepared the manuscript for publication and AK, AH, SM and ML provided feedback and suggestions on how to improve the manuscript.

2. Paper 2: Methods for combining continuously measured glucose and activity data in people with Type 2 diabetes: Challenges and solutions

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Abstract

Mobile technologies can generate a large amount of data, however limited focus has been given towards understanding this data and developing methodologies to combine and appropriately use relevant data sets. This paper presents the novel application of combining continuously measured glucose with continuous accelerometer measured physical activity and sedentary behaviour data and discusses the principles used and challenges faced in combining and analysing these two sets of data in the context of diabetes management. The background and rationale for exploring glucose, physical activity and sedentary behaviour in people with Type 2 diabetes is presented, the paper outlines the technologies used, the individual data extraction and finally the combined data analysis. A case study approach is used to illustrate the application of the combined data processing and analysis. The data analytic principles used could be transferred to different conditions where continuous data sets are being combined to help individuals or health professionals better manage and care for people with long term conditions. Future work should focus on generating validated techniques to visualise combined data sets and explore ways to present data back to the individual in an effective way to support health care management and rehabilitation.

Introduction

Mobile technology is increasingly being developed and made available in both the commercial and research setting, allowing continuous measurement of behaviour and health outcomes. There is opportunity to improve the management of many chronic conditions if this data could be collected, managed and analysed in meaningful ways. Limited focus however has been given towards understanding this data and developing methodologies to combine relevant data sets in ways that can improve long term condition management.

This paper presents the application of combining continuously measured glucose data and accelerometer measured physical activity and sedentary behaviour data and discusses the challenges faced and possible solutions in combining and analysing these two sets of data in meaningful ways. We start by presenting the background and rationale for exploring glucose, physical activity and sedentary behaviour, then outline the technologies used for this data collection, the individual data extraction and finally the combined data analysis approaches used. A case study approach was used to illustrate the application of the developed methodology.

With mobile technology increasingly being used to support health care management and rehabilitation, the challenges and solutions discussed could easily be transferred to conditions where continuous data sets are being combined to help individuals or health professionals better manage and care for people with long term conditions.

Background and rationale

Type 2 diabetes is a metabolic condition characterised by inadequate insulin sensitivity and/ or impaired insulin secretion and poor management can lead to serious and costly health complications [1]. The number of people worldwide with Type 2 diabetes is projected to reach 628.6million by 2045[1]. Lifestyle changes, such as incorporating a healthy balanced diet, increasing

levels of physical activity[2,3,4] and reducing prolonged sedentary behaviour[5] can contribute successfully to the management of Type 2 diabetes.

Ekelund et al.[6] report high levels of physical activity per day (~60-75minutes) reduces the risk of all-cause mortality in those sitting for more than eight hours per day. Suggesting that the negative impact of sitting for long periods of time can be nullified by high levels of moderate physical activity. As technology is progressing, people are increasingly finding themselves in settings where time being spent sedentary is the dominant behaviour. Matthews et al.[7] reported adults spend approximately 70% of their waking day in sedentary behaviours. A recent study conducted by Dempsey et al.[8] found when prolonged sitting down is broken up with regular, short (3 minute) breaks of light intensity physical activity, glucose profiles in those with Type 2 diabetes are improved and this improvement was shown to persist for at least a 24hour period[9].

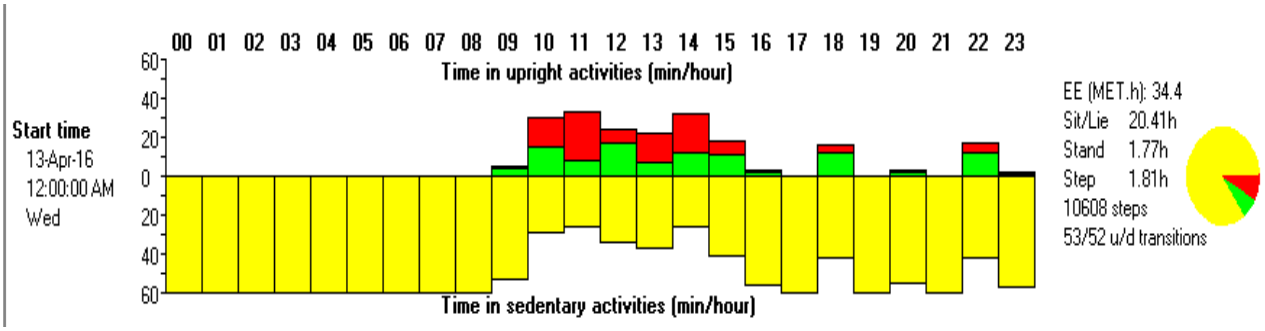
In summary, Type 2 diabetes is a chronic disease with increasing prevalence. Glucose management is important within Type 2 diabetes care to reduce risk of additional health complications and improve overall patient quality of life. Increasing physical activity and reducing prolonged sedentary behaviour both have favourable effects on glucose management and are recommended components of Type 2 diabetes care[10]. Mobile technologies are now available that independently provide continuous measurement of glucose, physical activity and sedentary behaviour. Developing methodologies to combine these data sets presents the opportunity for in depth exploration of the relationship between glucose, physical activity and sedentary behaviour and enables tailoring of physical activity and sedentary behaviour interventions for optimal glucose control and disease management in people with Type 2 diabetes.

Selected Technology

activPAL

Numerous wearable technologies are available to monitor physical activity and sedentary behaviour. The overall focus of our research was to investigate how patterns of sedentary behaviour affect glucose outcomes in people with Type 2 diabetes. With focus towards sedentary behaviour, the activPAL™ (PAL Technologies Ltd, Glasgow UK) was selected. In a study conducted by Kozey-Keadle et al.[11], the activPAL correlated with direct observation of sedentary time 94% of the time. The activPAL is a small electronic device (measuring 53x35x7mm; weighing 15g) worn on the front of the thigh, midway between the knee and the hip[12]. The activPAL is the first validated instrument to be developed to quantify postural allocation, allowing sedentary behaviour to be accurately identified[12]. The activPAL contains an accelerometer and an inclinometer, allowing the participant's physical activity and sedentary behaviour patterns to be measured in a free living context for up to 14 days at a time. Step count, cadence and postural transitions and energy expenditure estimates are also provided[12]. Figure 3.1 illustrates the hour by hour summary of activity over a 24-hour period. Each line symbolises an hour and the different colour shows the proportion of the hour spent sitting/lying (yellow), standing (green) and stepping (red). The summary output also provides information regarding 24-hour step count and the number of transitions from sitting to standing.

Figure 3.1: Example of summary data output showing behavioural categorisation by hour in a 24-hour period



The output from the activPAL contains periods categorised as sitting/lying that are not considered sedentary behaviour, such as sleep and non-wear[13]. Therefore, a 24-h wear protocol is used and a daily wear diary noting sleep time, wake time and any time where the device was removed and reattached is completed. This allows researchers to remove sleep prior to data analysis.

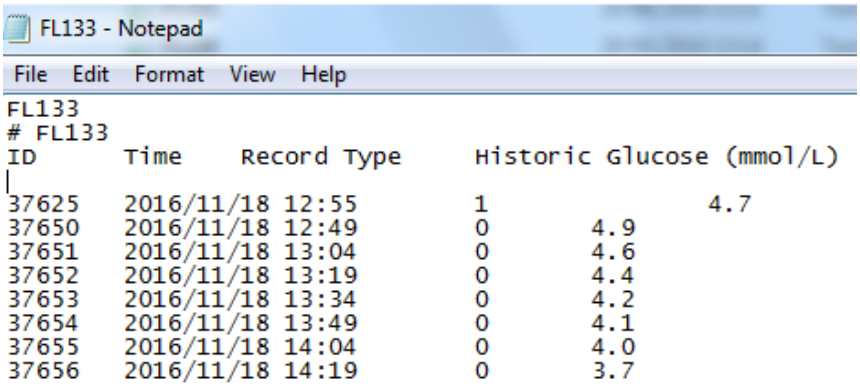
FreeStyle Libre

Flash Glucose Monitoring is one of the newest methods of glucose monitoring, providing multiple continuous glucose readings compared with conventional ad hoc capillary blood glucose data whilst being more affordable than continuous glucose monitors. The FreeStyle Libre is a flash glucose monitoring system that continuously measures a person's glucose through their interstitial fluid[14]. The FreeStyle Libre consists of a small sensor and a reader.

The sensor is applied to the arm where a thin flexible filament (5mm) is inserted just below the skin. The sensor measures glucose every minute but summarises this over 15 minutes continuously for up to 14 days with date and time also recorded. The sensor has the ability to store up to eight hours of data, therefore the reader must be scanned over the sensor in order to capture and store continuous data. The data can be uploaded from the

reader to desktop software and can be presented as summary data in user friendly graphs and tables or the raw data can be exported to a text file (Figure 3.2).

Figure 3.2 Example of FreeStyle Libre raw data output


FL133 - Notepad

File Edit Format View Help

FL133
FL133

ID	Time	Record Type	Historic Glucose (mmol/L)	
37625	2016/11/18 12:55	1		4.7
37650	2016/11/18 12:49	0	4.9	
37651	2016/11/18 13:04	0	4.6	
37652	2016/11/18 13:19	0	4.4	
37653	2016/11/18 13:34	0	4.2	
37654	2016/11/18 13:49	0	4.1	
37655	2016/11/18 14:04	0	4.0	
37656	2016/11/18 14:19	0	3.7	

The FreeStyle Libre is a relatively new device and is predominantly targeted at the consumer market. There are some factors that must be considered when interpreting the data from this device. The FreeStyle Libre is measuring glucose through the interstitial fluid and not through the blood so there is a physiological lag between the measurements and this lag can be different for each individual, making it difficult to account for. To address this, participants could provide blood glucose measures at regular intervals throughout the day, however it was decided that the participant burden would be too much. There have been some issues reported where the sensor fails to record at all, is not reading the glucose correctly or is producing unusually low readings. It should also be noted that the FreeStyle Libre only measures glucose levels, it does not provide any estimation of insulin sensitivity or beta cell function which might also provide important information to fully understanding glycaemic responses. It was decided when researching the available devices that the FreeStyle Libre was most suitable to this project, but the methods discussed could be used for any continuously measured glucose dataset.

Individual device data extraction

Prior to combining data sets, it was important to first screen the datasets and check for any anomalies or outliers and remove any unsuitable data. The challenge then presented was to extract manageable and meaningful information from a large data set without losing the context and detail held within the continuous objective dataset. Data extracted also needs to be relevant to current health care practice and research evidence to allow comparison of findings with data presented in clinical practice guidelines and relevant research studies.

Activity Data

Once the activPAL data was downloaded, the summary output files for each participant were checked to make sure the data was valid (for example no large periods of missing data) and that there was a minimum of 3 days of data, once the first and last days of recording were removed. A day was counted if there were 10-h or more recorded wear time. Data sets where there were less than 3 days of data or the device had not recorded were removed from the data set. This is in line with findings of Rich et al.[15] who suggested that data collected on two or more days is sufficient for providing reliable results. The activPAL categorises all behaviour in a sitting or lying position together, meaning that sleep time is categorised as sedentary behaviour[12]. In order to use sedentary behaviour as a meaningful variable, sleep time must be reliably identified and removed from the data set. Removing sleep time enables exploration of sedentary behaviour and physical activity patterns over the waking day period and calculation of daily proportion of waking time spent sitting, standing and stepping. Recent studies have examined the use of automated algorithms for identifying and removing sleep/ non-wear time[15], however, in the case of Winkler et al.[13] the automated method was validated against the usual method of the monitor-corrected diary and as yet, is not common practice. For the purpose of this study, sleep was removed manually using the sleep diary completed

by the participant. This is a high burden method, particularly with large datasets and therefore an automated method is currently being developed by researchers.

Sleep removal provides an overview of the waking day but gives no indication of the more specific daily pattern of behaviour, for example, periods of the day that were more active or sedentary than others rather than an average day. To look at sedentary behaviour in more depth, the proportion of time spent in each behaviour per hour was examined, allowing specific times of day to be isolated and compared. Research has identified that both total sedentary time and continuous uninterrupted periods of sedentary behaviour are detrimental to health[16]. Therefore, further analysis was conducted to isolate behaviour based on events to explore continuous periods of sedentary behaviour. This involved breaking the data into sedentary and non-sedentary behaviours and examining sedentary bouts of varying durations, for example, sedentary bouts ≥30minutes and ≥60minutes in duration. Breaking up the data into these smaller, more focused intervals allowed us to pull meaningful segments of information from a larger data set. Matlab was used to enable us to automate this process and allow data extraction from a large sample (i.e. up to 14 days of individual data and a target sample size for the full study of ~ 50 participants).

Glucose Data

As with the activPAL data, the glucose data from the FreeStyle Libre was downloaded and the summary output files were checked for accuracy and consistency. Once the first and last days of recording were removed, participants with less than 3 days of data, were removed from the data set. The data was also checked to make sure there were no issues with the sensor; as aforementioned there have been some issues reported where the sensor fails to record at all or is not reading the glucose correctly or producing unusually low readings. In these cases, the data was also removed from the data set. Sleep time was not removed from the glucose

data set, allowing for the data to be examined over a 24-hour period in addition to hourly and shorter, more specific bout durations.

For people with Type 2 diabetes, improved blood glucose control substantially decreases the development and progression of diabetic complications and improves overall patient quality of life[17]. HbA_{1c} is the most commonly used indicator for glucose control and is a measure of average glucose over a three-month period[18]. Another measure of glucose control is daily mean glucose, which is the average glucose level calculated using six glucose readings over a 24-hour period. Research has documented a close relationship between HbA_{1c} and daily mean glucose[19].

More recent research has identified daily glucose variability as a possible contributor to developing diabetes complications. Glucose variability is the measurement of variation in glucose levels in a day and should not be confused with postprandial glucose excursions, which is the measurement of glucose after a meal. Increased variability was shown to be associated with markers for cardiovascular damage in those with Type 2 diabetes[20] and it has been suggested that variability in glucose levels could be more damaging to long term health than consistently higher average glucose levels[21]. Wearable technology with continuous measurement offers a unique ability to explore within and between individual variability. Currently there is no consensus on the best measurement of glucose variability to use. Examples of parameters used are: Mean average glucose (MAG), the average changes in glucose over time of measurement; Mean of daily differences (MODD), the glucose variability between consecutive days; Continuous overall net glycaemic action (CONGAn), measure of continuous glucose variability using continuous monitoring and requires 288 glucose readings in a 24-hour period[22]; Mean amplitude of glycaemic excursions (MAGE), the average differences between consecutive blood glucose values that are more than one standard deviation from the mean.

More widely used measures of variability and dispersion, such as standard deviation, coefficient of variation and range have all been used to

measure glucose variability and are easily determined[22]. Standard deviation is easily calculated and is widely supported as a suitable method of measuring variability in glucose profiles[23].

It was decided that several measures of glucose variability would be included in the analysis to ensure the effect of sedentary behaviour and physical activity on glucose was fully examined. Although the data could have been analysed using all the above measures of variability, using too many methods would increase the chance of finding a false positive in the results. However, research identifies that both mean glucose and glucose variability can impact overall health of people with Type 2 diabetes. The following variables were therefore extracted and included in the preliminary analysis; daily mean glucose, standard deviation, range and coefficient of variance. Similar to the activPAL data, Matlab was used to allow the process of data extraction to be automated.

During the study, participants will complete a food and medication diary alongside the wear diary. This information would allow the relationship between sedentary behaviour patterns surrounding meal times and postprandial glucose. For the purpose of this paper however, it was decided that the focus would remain the combining of the activity and glucose datasets. The food diary data may be used in future analysis of the dataset.

Combining data sets

Once the data from each device was checked and extracted, the activity, glucose and demographic data sets were imported into Matlab where a final output file was produced for data analysis. We took a case study approach to present the individual and combined data analysis. Participant A was a 68year old retired male, with a BMI of 29.2kg/m^2, who has been diagnosed with Type 2 diabetes for 2 years. Participant A spent, on average, 70% of their waking day sitting/ lying, 18% standing still and just 12% of their day stepping, mean daily glucose was 7.53mmol/l. Table 3.1 illustrates results from the analysis of data from participant A where mean glucose,

standard deviation, range and coefficient of variance were examined in sedentary bouts of 30-60minutes and sedentary bouts ≥60minutes.

Table 3.1: Results from Analysis for Participant A

n =1	Mean Glucose	Standard Deviation	Range	Coefficient of Variation
30-60 minute bouts	7.51	0.32	0.52	0.04
≥60 minute bouts	7.58	0.46	1.28	0.07

Subsequent analysis with the full study sample (N =50) will explore the relationship between overall daily mean glucose and the daily proportion of time spent sitting/ lying during wake time. Additionally, the relationship between specific sedentary bout durations and mean glucose and glucose SD, range and coefficient of variation will be examined.

From preliminary analysis, examining the overall glucose response and sedentary bout duration is providing us with more meaningful results than isolating specific sedentary events and the glucose response within those events. Isolating sedentary bouts with a non-sedentary period pre and post-bout was more difficult than anticipated due to the variable nature of behaviour in a free living setting.

Conclusions

The aim of this paper was to present the challenges associated with the novel application of combining continuously measured glucose and activity data for people with Type 2 diabetes, and to outline the rationale and principles followed in exploring the combined analysis. Authors suggest using

validated devices and visually checking summary data prior to processing and analysis, to check for any errors or unsuitable data. Although not used in this study, the use of heat maps, as described by Edwardson et al.[24] could enhance the robustness of the visual checking of data. It is important to identify specific and meaningful outcome variables prior to processing and analysis of the data and where possible, the use of automated methods for processing and combining datasets would remove a significant burden from the researcher.

We have discussed the process taken during individual data extraction and presented an individual case study of combined data analysis. The principles used could be transferred to different situations or health conditions where continuous data sets are being combined to help individuals or health professionals better manage and care for people with long term conditions.

Collecting and combining such rich data provides the opportunity for this analysis to be expanded to further explore the temporal patterns and relationships between physical activity, sedentary behaviour and glucose outcomes. A possible focus for this analysis could be significant daily events such as the timing and content of meals and the timing and dose of medication in addition to giving focus to different periods of the day.

Future work needs to give focus towards generating validated techniques to visualise combined data sets and exploring ways to present data back to the individual in an effective way to support health care management and rehabilitation. An automated algorithm for the removal of sleep and non-wear time from the activPAL data would be beneficial in larger datasets. Furthermore, the development of multisensory devices allowing measurement of physical activity, sedentary behaviour and glucose, in addition to other behaviours and health outcomes, will enable further exploration of the interaction of multiple behaviours and health outcomes.

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Table 3.2: Challenges Identified and Suggested Solutions When Combining Continuous Glucose and Activity Datasets

Challenges	**Solutions**
Choosing the right devices	- The FreeStyle Libre is a new device that measures glucose for up to 14days - The activPAL is a widely used, validated device that measures physical activity and sedentary behaviour
Reducing and preparing the data	- Summary data was visually checked and any unsuitable data was removed from the dataset prior to analysis. - Sleep time was removed manually from the activPAL data in order to use sedentary behaviour as a meaningful variable **-** Automated methods of sleep removal may be more appropriate in larger datasets and are currently being developed
Identifying meaningful variables	- Daily and hourly proportion of sedentary time, standing and physical activity were calculated and individual bouts of sedentary behaviour were identified - Daily mean glucose, standard deviation, range and coefficient of variation were identified
Combining datasets	- Glucose, sedentary behaviour and activity and demographic datasets were combined using an automated process in Matlab

Chapter 4: Investigating physical activity, sedentary behaviour and glucose patterns in those with Type 2 diabetes using objective and continuous measurement in a free living setting

1.0 Preface

Chapter 1 determined the need for the relationship between objective and continuously measured physical activity and sedentary behaviour and glucose in people with Type 2 diabetes in a free living setting to be examined. Chapter 2 identified that the effectiveness of using mobile technology to monitor behaviour in people with Type 2 diabetes was yet to be examined. Chapter 3 discussed the challenges and solutions put forward for processing, combining and analysing multiple, large continuous datasets. In this chapter, free living physical activity and sedentary behaviour patterns in people with Type 2 diabetes were measured using the activPAL accelerometer, which is a device that objectively measures activity for up to two weeks. Similarly, free living patterns in glucose were measured using a new consumer-based device, the FreeStyle Libre, over the same period of time. This allowed for the relationship, if any, between participant characteristics and the physical activity, sedentary behaviour and glucose datasets to be examined individually. This was followed by analysis examining the relationship between free living patterns in activity and glucose.

1. Introduction

Leading an active lifestyle is a recognised and recommended method of improving glucose management in those with Type 2 diabetes (American Diabetes Association (ADA), 2018). As discussed in chapter 1, an active lifestyle consists of recommended levels of physical activity and minimal time spent sedentary. Several studies have examined the effect of physical activity on glucose management in Type 2 diabetics (Avery, Flynn, Wersch, Sniehotta & Trenell, 2012; Umpierre et al., 2011). Dietary advice combined with physical activity advice was associated with higher reductions in HbA_{1c} levels in those with Type 2 diabetes compared to dietary advice alone (Umpierre et al., 2011). A systematic review of randomised controlled trials found that behavioural interventions focused on increasing free living physical activity resulted in significant reductions in HbA_{1c} levels in people with Type 2 diabetes (Avery et al., 2012). Similarly, studies have found that reducing sedentary time, irrespective of physical activity levels, has been shown to effectively manage glucose levels in overweight/obese but otherwise healthy adults. In adults with Type 2 diabetes, regular physical activity breaks in sedentary time significantly lowered glucose, compared to continuous prolonged sitting (Dempsey, Owen, Biddle & Dunstan, 2016).

Although an active lifestyle is recommended for glucose management, results from a recent study conducted by Van der Berg et al. (2016) show that those with Type 2 diabetes spend a significantly (p <0.01) higher proportion of their waking day sitting/lying than those without diabetes. Physical activity and sedentary behaviour was measured using objective methods, over a six-day period, in adults with normal glucose metabolism and those with Type 2 diabetes. Participants with Type 2 diabetes spent, on average, 64.5% or a little over 10 hours per day sitting/lying and just 10.7% of their day stepping, compared to adults without diabetes who spent just 57.6% or nine hours per day sitting/lying and 13.6% stepping. Both of these participant groups have higher than recommended levels of sitting (ADA, 2018), however, the focus of this Ph.D is active living in those who have Type 2 diabetes.

There have been studies that have objectively measured physical activity and sedentary behaviour in people with Type 2 diabetes in a free living setting (Van der Berg et al., 2016). Further studies have examined the relationship between objectively measured physical activity and sedentary behaviour and continuously measured glucose in a lab setting (Dempsey et al., 2016; Dempsey et al., 2017; Duvivier et al., 2017), but few have examined this relationship in a free living context. Therefore, the research questions for this study were:

1) What are the physical activity and sedentary behaviour patterns of people with Type 2 diabetes and what is the relationship, if any, between these variables and participant characteristics?
2) What are the patterns in daily mean glucose and glucose variability in people with Type 2 diabetes and what is the relationship, if any, between these variables and participant characteristics?
3) What is the relationship between patterns in physical activity or sedentary behaviour and patterns in mean glucose and glucose variability in people with Type 2 diabetes?

2. Methods

2.1 Participants

Participants were adults aged 18 years or over with diet and/or medication (not insulin therapy) controlled Type 2 diabetes. Exclusion criteria for participation included individuals: unable or unwilling to consent, under the age of 18 years of age, receiving insulin therapy, alcohol or substance misuse, with hepatic or renal dysfunction, with cancer or pregnant. Screening for exclusion criteria was repeated prior to providing consent to participate in the study.

Participants were recruited from the staff members of two Universities in Glasgow and from diabetes support groups. Recruitment methods included: social media, e-mails to University staff, information posters placed

around the Universities, diabetes support groups, local shops and word of mouth.

Individuals who showed an interest in the study by making contact with the researchers, were given written information about the study, including the inclusion and exclusion criteria. Once written informed consent was obtained from the participant, a date and time was arranged for participation to begin.

2.2 Ethics

Institutional ethical approval was obtained from the School of Psychological Science and Health Ethics Committee at the University of Strathclyde. All participants were informed that participation was voluntary, and they could withdraw, without consequence, at any time. Participants were informed that collected data would be kept anonymous, confidential and would be destroyed after a five-year period. This process is in line with the Data Protection Act (1998).

Study procedures were piloted prior to study initiation to ensure any issues with the instruments and methodology were identified and rectified prior to recruitment beginning.

2.3 Study Design

The study was of exploratory design, using objective and continuous measurements.

2.4 Measurement Devices

2.4.1 Physical Activity and Sedentary Behaviour

Physical activity and sedentary behaviour were measured using the activPAL accelerometer, a small electronic device measuring 53x35x7mm and weighing 15g. The activPAL^{TM} (PAL Technologies, Glasgow, Scotland) is a reliable and validated method of free living physical activity and sedentary behaviour measurement in adults (Atkin et al., 2012). The activPAL^{TM} is often described as the gold standard method for objective

measurement of sedentary behaviour and in a study conducted by Kozey-Keadle, Libertine, Lyden and Staudenmayer (2011) the activPAL correlated with direct observation of sedentary time 94% of the time, during two six-hour periods. The activPAL^{TM} can distinguish between sitting/lying, standing and stepping and records daily step count and sit to stand transitions. Additionally, the activPAL^{TM} output allows specific, time stamped, bouts of behaviour to be identified and isolated, such as extended bouts of sedentary behaviour.

2.4.2 Glucose

The method of glucose measurement was the FreeStyle Libre flash glucose monitor (Abbott Laboratories Limited), which is a consumer based continuous glucose monitor that measures glucose through the person's interstitial fluid. The device consists of two parts, a small sensor (35mmx5mm) that is inserted in the back of the arm where a thin flexible filament (5mm) is inserted just below the skin. The sensor measures the glucose every minute but summarises this over 15 minutes, for up to 14 days with time and date also recorded. The second part of the device is a small touch screen reader (95mmx60mmx16mm, 65g). The reader is swiped over the sensor in order to download the data from the sensor, this is required a minimum of every eight hours in order to guarantee continuous data from the device as the sensor has a maximum of eight hours memory. The FreeStyle Libre's performance and usability was assessed by Bailey, Bode, Chrisitansen, Klaff and Alva (2015), where the interstitial glucose results from the FreeStyle Libre were compared to capillary blood glucose results (eight measurements per day) over a 14-day period in 72 individuals with diabetes. Interstitial glucose results were highly correlated with the capillary blood glucose results, where absolute relative deviation (ADR) ≤10% in 55% of sensors and ≥16% in around 10% of sensors, the average was 11.4%. (Bailey et al., 2015).

2.5 Participant Visits

This study was conducted over two visits, each lasting approximately 1 hour. Visits were conducted at the University or another convenient place, such as the participants' home, or by posting the materials.

2.5.1 Visit one

During visit one, the participant was asked to complete a demographic questionnaire covering the participant's: age, gender, height, weight, diabetes duration, diabetes medication information, smoking status, employment status and education level. The participant's height and weight were measured, and BMI was calculated (weight in kilograms/height in metres^2). Participant waist circumference was measured using a tape measure around the participant's natural waistline.

The participant was then shown and fitted with the activPAL^{TM} accelerometer by the researcher. The activPAL^{TM} was wrapped in Tegaderm, a discreet medical adhesive, to waterproof the device and was attached to the middle of the participant's right thigh, midway between the hip and the knee, using a sheet of Tegaderm. All participants were required to wear the activPAL^{TM} monitor for a minimum of three days and up to 14 days and were asked not to remove the device other than to change the Tegaderm, or if their skin became irritated, during this time. This is in line with findings of Rich et al. (2013) who suggested that data collected on two or more days is sufficient for providing reliable results for physical activity. A minimum of three days wear was decided in order to cover recommendations from previous research and to go beyond this to ensure the minimum was captured. The maximum duration of 14 days was decided due to the activPAL^{TM} only measuring for a maximum of 14 days.

Following this, the participant was fitted with the sensor from the FreeStyle Libre to the back of the upper arm using the provided applicator. The participant was shown how to work the FreeStyle Libre reader and reminded to scan the reader over the device a minimum of every eight hours in order to download the data from the sensor. The sensor is designed to last

for 14 days and participants were asked to wear the sensor for a minimum of three days and up to the maximum 14 days.

Participants were asked to wear the activPAL™ and the FreeStyle Libre for the same duration to allow the datasets to be combined for data analysis. The FreeStyle Libre sensor is water resistant and therefore the participant was advised not to remove the device, unless their skin became irritated. The sensor was covered with a sheet of Tegaderm to provide more security and waterproofing as a precaution.

The participant was provided with a sleep diary and a food diary to complete for the duration of the study. Participants were also asked to record the date, time and dose of any diabetes medication they were taking. The participant was then asked to go about their normal daily living for 3-14 days before their second visit.

2.5.2 Visit two

During visit two, the activPAL™ and the FreeStyle Libre were removed, and the data was downloaded from both devices. The participant was shown the summary data from both devices and their participation in the study was finished.

2.5.3 Postal Participants

Where participants lived further away or were unable to attend the University of Strathclyde, the participant was asked if they would be happy to participate using a postal method. If the participant was happy to continue, the devices were setup and waterproofed, ready to be attached, and posted to the participant by special delivery with clear instructions on how to attach and remove the devices, and complete the demographic questionnaire and the sleep and food diaries. In addition, a stamped, addressed envelope for returning the devices and materials to the University of Strathclyde upon completion of participation was provided**.**

As above, once the devices were attached, the participant was asked to go about their normal daily living for three to 14 days whilst completing the

diaries. Once participation was completed, the participant was asked to remove the activPAL™ and FreeStyle Libre and return the devices and materials to the University of Strathclyde using the envelope provided.

2.6 Data Preparation and Analysis

For clarity, due to the large amount of data collected during this study and the nature of the data preparation and analysis, the analysis is reported in three clear parts. These three parts address each of the three research questions stated at the beginning of this chapter. Part A addressed the patterns in physical activity and sedentary behaviour and the relationship, if any, between these variables and participant characteristics. Part B examined the patterns in daily mean glucose and glucose variability and the relationship, if any, between these variables and participant characteristics. Part C combined these data sets and examined the relationship between patterns in physical activity or sedentary behaviour and patterns in mean glucose and glucose variability in those with Type 2 diabetes.

Data processing was conducted using Matlab and Microsoft Excel and analysis was conducted using R and is discussed in detail in Chapter 3.

2.6.1 Data Analysis – Part A

Using the activPAL™ summary file, average wake time (hours) spent sitting/lying, standing, stepping, step count and sit to stand transitions were calculated. Total proportion (% of time) of the waking day spent sitting/lying, standing and stepping were similarly calculated using Microsoft excel. This dataset was then split to examine whether there were differences between retired and non-retired participants' activity as previous research has identified differences in physical activity behaviour between retired and non-retired individuals (Barnett, van Sluijs, Ogilvie & Wareham, 2014; Touvier et al., 2010). Similarly, the dataset was split to examine whether there were differences between weekday and weekend day activity. Using the activPAL events output file, individual sedentary bouts were identified and categorised by duration (≤30minutes, 30-60minutes and >60minutes). These durations

were selected for this study based on previous research, which used a sedentary break frequency of every 30 minutes (Dempsey et al., 2016). Examining the proportion of bout durations shorter and longer than this provided valuable insight into the design of future intervention studies. If people with Type 2 diabetes are already regularly breaking their sedentary behaviour every 30 minutes, or more or less frequently, then this should be taken into account by researchers when designing future intervention studies.

To examine the relationship between participant wake time physical activity and sedentary behaviour patterns and their characteristics, multiple linear regression models were performed. Participant characteristics were the predictor variables with physical activity or sedentary behaviour measures being the outcome variables. Eight models were developed incrementally, exploring the effect of seven predictor variables (age, BMI, gender, waist circumference, retirement status, medication status and duration of Type 2 diabetes) on physical activity and sedentary behaviour outcome variables (sitting/lying, standing, stepping, step count, and sit to stand transitions).

2.6.2 Data Analysis – Part B

Daily mean glucose (mmol/L) was calculated for each participant for the duration of wear. Daily mean glucose is the average glucose value over a 24-hour period and is a recognised alternative to HbA_{1c} for measurement of glucose management in people with Type 2 diabetes (Makris et al., 2008; Makris & Spanau, 2011). In order to combine datasets in Part C, however, wake time mean glucose (mmol/L) was also calculated and this value was used for the analysis.

Glucose variability has been linked with the development of vascular complications in people with diabetes, irrespective of HbA_{1c} levels (Monnier, Colette & Owens, 2008; Nalysnyk, Hernandez-Medina & Krishnarajah, 2010). To examine whether the relationship between glucose variability and sedentary behaviour and physical activity was similar or different to that of mean glucose and sedentary behaviour and physical activity, several variability measures were included in the analysis. Variability measures

chosen for this study included standard measures of variability such as; standard deviation, range and coefficient of variation. Additionally, a variability measure specifically developed for glucose data was used. There are several methods for measuring glucose variability, including MAG, MODD, MAGE and CONGA*n* (Rawlings, Shi, Yuan, Brehm, Pop-Busui & Nelson, 2011; Service, 2013). In order to avoid an over-analysis of the data and confusion, it was decided that one glucose specific measure of variability would be used. CONGA*n* is the measurement of continuous glucose variability and represents the SD of all valid differences between the current glucose observations an observation (*n*) hours earlier (Rawlings et al., 2011). CONGA alongside standard deviation, range and coefficient of variation were used to analyse variability.

The relationship between participant characteristics and their wake time daily mean glucose and variability was examined using multiple linear regression models, with participant characteristics as the predictor variables and mean glucose or glucose variability as the outcome variables. Eight models were developed incrementally, exploring the effect of seven predictor variables (age, BMI, gender, waist circumference, retirement status, medication status and duration of diabetes) on mean glucose or glucose variability outcomes.

2.6.3 Data Analysis – Part C

To examine whether there was a linear relationship between overall proportion of daily physical activity and sedentary behaviour, including sedentary bout duration, with mean daily glucose and glucose variability, Pearson product correlation analysis was conducted. This analysis was conducted to understand the relationship in the group as the whole. To further examine this relationship at an individual level and to address the multi-level nature of the data, regression analysis at the level of the individual was conducted.

Multi-level data describes data that can be grouped or nested within a dataset (Peugh, 2010). In this study the data is multi-level as there are

multiple measurement days for each participant. One of the challenges of multi-level data is that each day of measurement is treated as independent, which is misleading and can result in predictors appearing to have a significant effect when this is not the case (Steenbergen & Jones, 2002). A possible solution to this is to take the mean across the measurement days for each participant; however, this does not consider the intra-participant variability of the data. Multi-level modelling is an approach that can be used to analyse grouped data, such as that collected in this study (Peugh, 2010). Multi-level modelling is often used in educational data or health data, where data may be collected across multiple classroom, school or hospitals (Peugh, 2010). The goal of multi-level analysis is to account for variation within the dependent variable (Steenbergen & Jones, 2002). Regression analysis at the individual level is the dependent variable regressed on the independent variable individually for each participant (Pfister, Schwarz, Carson & Jancyzk, 2013). This method of analysis is increasingly being used in studies such as the current one as it avoids some of the methodological problems of standard regression analysis of multi-level data and allows for the individual nature of the data to be examined. Therefore, individual regression analysis was conducted to further examine the relationship between sedentary behaviour and glucose at an individual participant level.

3. Results

3.1 Participant Demographics

Participants were adults (*N* = 38, mean age = 62.38 ± 10.38 years) with a mean BMI of 29.85 kg/m^2 (± 6.64). Most participants were female (*n* = 23, 61%) and the average duration of Type 2 diabetes since diagnosis was 6 years (± 4.84). Just over half (*n* = 20, 52.63%) of participants were retired and the majority (*n* = 27, 71.05%) were taking medication to manage their diabetes. Several participants reported their last known HbA_{1c} (*n* = 21, Mean = 47.04 ± 10.01 mmol/mol). The FreeStyle Libre estimated HbA_{1c} was available for most participants (*n* = 34, Mean = 41.98 ± 10.49 mmol/mol). Waist circumference was not calculated for all participants (*n* = 28) due to

some postal participants not completing the demographic questionnaire fully (see Table 4.1).

Table 4.1: Participant Descriptive Statistics

n = 38	Mean (SD)	*n* (%)
Age (Years)	62.38 (±10.48)	
Height (cm)	170.19 (±9.99)	
Weight (kg)	86.60 (±20.71)	
BMI (kg/m^2)	29.85 (±6.64)	
Male sex		15 (39)
Waist circumference (cm)	99.96 (±12.64)*	
Duration since diagnosis (Years)	6.02 (±4.84)	
Self-Reported HbA_{1c} (mmol/mol)	47.04 (10.01)**	
FreeStyle Libre HbA_{1c}	41.98 (10.49)***	
Retired		20 (52.63)
On Medication		27 (71.05)

Note. **n* = 28, ***n* = 21, ****n* = 34

3.2.1 Part A – Physical Activity and Sedentary Behaviour Patterns

Participants spent, on average, 10.07 (± 2.33) hours per day sitting/lying, 3.98 (± 1.77) hours standing and 1.60 (± 0.75) hours stepping (Table 4.2). Daily proportion of time spent sitting/lying was 64.32%, standing was 25.44% and stepping was 10.24% (Table 2). Mean daily step count was 7497 (± 3971) and mean sit to stand transitions were 49 (± 17).

Table 4.2: Daily Physical Activity and Sedentary Behaviour Patterns

n = 38	Time Sitting (h)	Time Standing (h)	Time Stepping (h)	Sleep Time (h)	Step Count	Sit to Stand Transitions
Mean	10.07	3.98	1.60	8.34	7497	49
SD	2.33	1.77	0.75	1.39	3971	17
Wake Time Proportion (%)	64.32	25.44	10.24	---	---	---

Table 4.3 shows differences in physical activity and sedentary behaviour patterns between weekdays and weekend days. Mean daily sitting remained around the same, at just over 10 hours per day. However, participants spent less time standing and stepping during the weekend (standing = 3.87 ± 1.77 hours, stepping = 1.51 ± 0.71 hours) compared to during the week (standing = 4.02 ± 1.75, stepping = 1.64 ± 0.75). On weekdays, daily proportion of wake time spent sitting/lying was 63.94%, standing was 25.65% and stepping was 10.41%. On weekend days, daily proportion of wake time spent sitting/lying was 65.36%, standing was 25.85% and stepping was 9.79%. Additionally, mean daily step count was around 800 steps higher during the week (7724 ± 4039 steps) compared to the weekend (6922 ± 3694) and participants transitioned from sitting to standing more often on a weekday (49 ± 17) than on a weekend day (47 ± 16). These differences could partially be attributed to the increased time spent sleeping at the weekend with participants sleeping around 20 minutes longer on a weekend day than on a week day.

Table 4.3: Weekday vs Weekend Day Physical Activity and Sedentary Behaviour Patterns

	Weekday				
	Time Sitting (h)	Time Standing (h)	Time Stepping (h)	Step Count	Sit to Stand Transitions
Mean	10.08	4.02	1.64	7724	49
SD	2.43	1.75	0.75	4039	17
Wake Time Proportion (%)	63.94	25.65	10.41	---	---
	Weekend Day				
	Time Sitting (h)	Time Standing (h)	Time Stepping (h)	Step Count	Sit to Stand Transitions
Mean	10.07	3.87	1.51	6922	47
SD	2.01	1.77	0.71	3694	16
Wake Time Proportion (%)	65.36	25.85	9.79	---	---

Differences between retired participants' (*n* = 20) and non-retired participants' (*n* = 18) physical activity and sedentary behaviour patterns are highlighted in Table 4.4. Although these results are not statistically significant, some differences between retired and non-retired participants were observed. Retired participants spent over an hour less time per day sitting (9.49 ± 2.03 hours) than those participants whom were not retired (10.74 ± 2.46 hours) and approximately 30 minutes more a day standing (Table 4.4). Time spent stepping was higher in those who are retired than not retired (1.75 ± 0.73 hours and 1.43 ± 0.73 hours respectively) and this is reflected in daily step count with retired participant's mean step count 8239 steps and non- retired participant's mean daily step count 6706 steps. Retired participants spent an average of 61.51% of their day sitting, 27.17% standing and 11.32% stepping, compared to non-retired participants who spent an average of 67.47% of their day sitting, 23.48% standing and 11.32% stepping.

Table 4.4: Retired vs Non-Retired Physical Activity and Sedentary Behaviour Patterns

	Retired				
	Time Sitting (h)	Time Standing (h)	Time Stepping (h)	Step Count	Sit to Stand Transitions
Mean	9.49	4.20	1.75	8239	50
SD	2.03	1.63	0.73	3889	15
Wake Time Proportion (%)	61.51	27.17	11.32	---	---
	Non-Retired				
	Time Sitting (h)	Time Standing (h)	Time Stepping (h)	Step Count	Sit to Stand Transitions
Mean	10.74	3.73	1.43	6706	47
SD	2.46	1.88	0.73	3916	19
Wake Time Proportion (%)	67.47	23.48	9.05	---	---

Using the events output file from the activPAL, sedentary bouts were identified and isolated. A total of 2788 wake time sedentary bouts were identified and placed in one of three categories based on their duration (Table 4.5). The first category was sedentary bouts of 30 minutes or less in duration and 880 (31.56%) bouts were in this category. A total of 1249 (44.80%) bouts were categorised as between 30 minutes and 60 minutes in duration and the remaining 659 (23.64%) bouts were greater than 60 minutes long.

Table 4.5: Sedentary Behaviour Bout Patterns

n= 2788	Total number of bouts	Proportion of bouts (%)
≤30 minutes	880	31.56
>30 minutes ≤60 minutes	1249	44.80
>60 minutes	659	23.64

The relationships between the physical activity and sedentary behaviour measures (time sitting/lying, standing, stepping, step count, sit to stand transitions and sedentary bout duration) and participant characteristics were explored in a series of multiple regression models. A summary of the significant predictors of the dependent variables is provided in Table 4.6. There were no significant predictors identified for daily step count and daily sit to stand transitions. For more detailed information, the regression tables (Table 4.7-4.12) are presented in Appendix A.

Table 4.6: Summary of Significant Predictors of the Dependant Variables

	Time Sitting (h)	Time Standing (h)	Time Stepping (h)	Step Count	Sit to Stand Transitions	Sedentary Bout Duration
Age (years)		√	√			
BMI (kg/m^2)	√	√	√			
Gender	√	√	√			√
Waist Circumference (cm)	√	√				
Retirement Status	√		√			
Medication Status		√				√
Duration of Diabetes	√	√				
FreeStyle Libre HbA_{1c}	√		√			

Due to the differences identified in daily physical activity and sedentary behaviour patterns between those participants who were retired and those who were not retired, the data was split, and similar regression analysis was conducted on the two different groups. The full regression tables (4.15-4.24) for this analysis is provided in Appendix B. A summary of the significant predictors of the dependent variables are provided in Table 4.13 and Table 4.14.

Table 4.13: Summary of Significant Predictors of the Dependant Variables in Retired Participants

	Time Sitting (h)	Time Standing (h)	Time Stepping (h)	Step Count	Sit to Stand Transitions
Age (years)		√	√		√
BMI (kg/m^2)			√		√
Gender	√	√			√
Waist Circumference (cm)					
Medication Status	√	√			√
Duration of Diabetes					√
FreeStyle Libre HbA_{1c}	√		√		√

Table 4.14: Summary of Significant Predictors of the Dependant Variabiles in Non-Retired Participants

	Time Sitting (h)	Time Standing (h)	Time Stepping (h)	Step Count	Sit to Stand Transitions
Age (years)	√	√			
BMI (kg/m^2)	√	√			√
Gender	√	√		√	√
Waist Circumference (cm)	√	√	√	√	√
Medication Status	√	√	√		
Duration of Diabetes	√	√			
FreeStyle Libre HbA_{1c}					√

To summarise, the aim of Part A was to examine the physical activity and sedentary behaviour patterns of people with Type 2 diabetes and understand the relationship, if any, between these variables and participant characteristics. Participants spend almost 65% of their waking day sedentary and just 10% of the day moving. Almost 70% of sedentary bouts were over 30 minutes in duration, with around 45% of all wake time sedentary bouts were between 30 and 60 minutes in duration. Retired participants spent almost 8% less of their time sitting/lying, this is offset with increases in time spent both standing and stepping. Multiple regression analysis identified BMI and gender as significant (p <0.05) predictors of sitting time, standing time and sedentary time. Interestingly, no participant characteristics were identified as significant predictors of daily step count and daily sit to stand transitions. Participant characteristics were shown to be small to medium predictors of participant physical activity and sedentary behaviour variables. Multiple regression analysis showed stronger relationships between sitting/lying and standing time and participant characteristics in non-retired individuals compared to retired individuals.

3.2.3 Part B – Patterns in Mean Glucose and Glucose Variability

Mean glucose was calculated twice, once including sleep time (Mean Daily Glucose) and once with sleep time removed (Mean Wake Time Daily Glucose), see Table 4.24. Mean wake time daily glucose (mmol/l) was used for any future analysis in this chapter. Mean wake time daily glucose of the group was calculated as 7.40 ± 1.71mmol/l, with a minimum mean glucose value of 3.75mmol/l and a maximum mean glucose value of 13.65mmol/l. Mean wake time daily glucose will be referred to as mean glucose from now on.

Table 4.24: Mean Glucose Patterns

n = 38	Mean	SD	Min	Max
Mean Daily Glucose (mmol/l)	6.96	1.65	3.75	13.96
Mean Wake Time Daily Glucose (mmol/l)	7.40	1.71	3.75	13.65

Wake time glucose variability patterns were calculated for several measures of variability including: range, standard deviation, coefficient of variation and CONGA*n* (Table 4.25).

Table 4.25: Patterns of Daily Glucose Variability

n = 38	Mean	SD	Min	Max
Wake Time Daily Glucose Range	6.25	2.02	0.60	15.50
Wake Time Daily Glucose SD	1.60	0.53	0.19	3.85
Wake Time Daily Glucose CoV	0.22	0.06	0.04	0.50
Wake Time Daily Glucose CONGA*n*	1.12	0.38	0.08	2.48

Note. SD = Standard Deviation, CoV = Coefficient of variation, CONGA*n* = Continuous overall net glycaemic action (*n*)

Table 4.26 highlights differences in mean glucose and glucose variability patterns on weekdays compared to weekend days. There is no difference with mean glucose 7.39±1.69mmol/l on weekdays or on weekend days mean glucose,7.40±1.75mmol/l. The measures in glucose variability showed no difference between weekdays and weekend days (Table 4.26).

Similarly, the differences between retired and non-retired participants' glucose patterns were addressed in Table 4.27. Again, little difference was observed in mean glucose (retired = 7.49±1.41mmol/l and not retired = 7.29±1.98mmol/l) or glucose variability between those participants who were retired and those whom were not.

Table 4.26: Weekday vs Weekend Day Glucose Patterns

	Weekday				
	Mean Glucose (mmol/l)	Glucose Range	Glucose SD	Glucose CoV	Glucose CONGA*n*
Mean	7.39	6.28	1.60	0.22	1.13
SD	1.69	2.02	0.53	0.06	0.37
Min	3.75	0.60	0.19	0.04	0.08
Max	12.99	15.50	3.85	0.50	2.48
	Weekend Day				
	Mean Glucose (mmol/l)	Glucose Range	Glucose SD	Glucose CoV	Glucose CONGA*n*
Mean	7.40	6.16	1.59	0.22	1.10
SD	1.75	2.02	0.55	0.07	0.39
Min	4.48	1.00	0.24	0.05	0.16
Max	13.65	12.50	3.18	0.41	2.22

Note. SD = Standard Deviation, CoV = Coefficient of variation, CONGA = Continuous overall net glycaemic action (*n*)

Table 4.27: Retired vs Non-Retired Glucose Patterns

	Retired				
	Mean Glucose (mmol/l)	Glucose Range	Glucose SD	Glucose CoV	Glucose CONGA*n*
Mean	7.49	6.46	1.65	0.22	1.19
SD	1.41	1.80	0.47	0.06	0.33
Min	4.48	2.80	0.74	0.11	0.53
Max	12.99	15.50	3.85	0.42	2.22
	Non-Retired				
	Mean Glucose (mmol/l)	Glucose Range	Glucose SD	Glucose CoV	Glucose CONGA*n*
Mean	7.29	6.01	1.54	0.21	1.05
SD	1.98	2.21	0.58	0.07	0.41
Min	3.75	0.60	0.19	0.04	0.08
Max	13.65	14.00	3.29	0.50	2.48

Note. SD = Standard Deviation, CoV = Coefficient of variation, CONGA = Continuous overall net glycaemic action (*n*)

The relationships between mean glucose and glucose variability measures and participant characteristics were examined in several multiple regressions. A summary of the significant predictors of the dependent variables are provided in Table 4.28, the full results tables (4.29-4.33) can be found in Appendix C.

Table 4.28: Summary of Significant Predictors of the Dependant Variables

	Mean Glucose (mmol/l)	Glucose Range	Glucose SD	Glucose CoV	Glucose CONGA*n*
Age (years)					
BMI (kg/m^2)	√	√	√	√	√
Gender		√	√	√	√
Waist Circumference (cm)					
Retirement Status		√			
Medication Status					
Duration of Diabetes		√	√		√
Self-reported HbA_{1c}		√	√		

To summarise, the aim of Part B was to answer research question 2 by examining the patterns of daily mean glucose and glucose variability in people with Type 2 diabetes, and understand the relationship, if there was one, between participant characteristics and these patterns in glucose. Mean glucose was 7.4±1.71mmol/l, which is slightly above target, suggesting these participants had relatively well controlled diabetes. There was no difference between mean glucose and glucose variability when data was split into weekday and weekend or when the data was split by retirement status, unlike the physical activity and sedentary behaviour data. Following multiple regression analysis, the strongest relationship was between sitting/lying time and participant characteristics (R^2 = 0.58), with participant BMI as the only significant predictor of mean glucose levels. BMI was identified as a significiant predictor of all glucose variables and gender was a significant predictor of all glucose variability measure, but not mean glucose.

3.2.4 Part C – The relationship between patterns in physical activity and sedentary behaviour and patterns in glucose

This section examined the relationship between overall proportion of daily physical activity and sedentary behaviour, including sedentary bout duration, with mean daily glucose and glucose variability, Pearson product correlation analysis was conducted, and results are shown in Table 4.34. Sitting time was negatively and significantly (p <0.05) associated with mean glucose (r = -0.15), glucose range (r = -0.13), glucose standard deviation (r = -0.13) and glucose CONGA (r = -0.24). Time stepping, and daily step count were both positively and significantly (p <0.05) associated with glucose range, glucose standard deviation and glucose CONGA*n*. Sedentary bout duration is positively and significantly (p <0.05) associated with glucose range (r = 0.43), glucose standard deviation (r = 0.22) and glucose coefficient of variation (r = 0.22).

Table 4.34: Relationship between physical activity and sedentary behaviour and patterns in mean glucose and glucose variability

	Mean Glucose	**Glucose Range**	**Glucose SD**	**Glucose CoV**	**Glucose CONGA*n***
Sitting	-0.15*	-0.13*	-0.13*	0.01	-0.24*
Standing	0.15*	0.10*	0.10*	-0.05	0.19*
Stepping	0.06	0.13*	0.13*	0.09	0.24*
Step Count	0.02	0.12*	0.12*	0.11*	0.26*
Sit to Stand	0.05	0.03	0.03*	-0.04	0.05
Sedentary Bout Duration	0.01	0.43*	0.22*	0.22*	---

Note. * = p <0.05, SD = Standard Deviation, CoV = Coefficient of variation, CONGA*n* = Continuous overall net glycaemic action (*n*)

Regression analysis at the individual level was used to examine the relationship between sedentary time and mean glucose and glucose variability in each individual participant. Appendix D provides information on the relationship between sitting time and the glucose variables for each participant in Table 4.35. In 28 of the participants, increased sitting time was associated with increased mean glucose. In 10 participants increased sitting time was associated with decreased mean glucose. Participant characteristics were examined to identify anything that may explain why these 10 participants have a different relationship. Participant gender, age, BMI, medication status, retirement status and duration of diabetes were considered and there was nothing that clearly separates these 10 participants from the other 28 participants, suggesting something else is influencing the difference in relationship.

The dataset was further split by gender and retirement status to understand the findings from the individual analysis. Figure 4.1 illustrates the results for females (retired and non-retired) and Figure 4.2 illustrates the results for the male participants (retired and non-retired). Each line in Figures 4.1 and 4.2 is the regression line for an individual participant and represents the relationship between time spent sedentary and mean glucose.

Figure 4.1: The Relationship Between Daily Sitting Proportion and Mean Glucose in Retired and Non-Retired Females

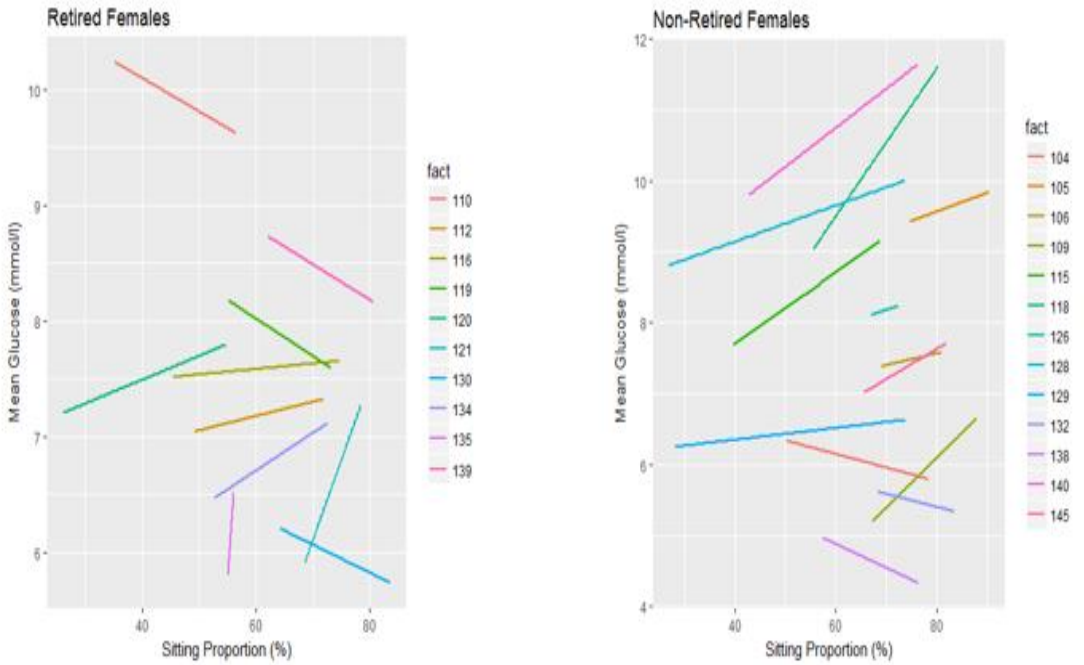
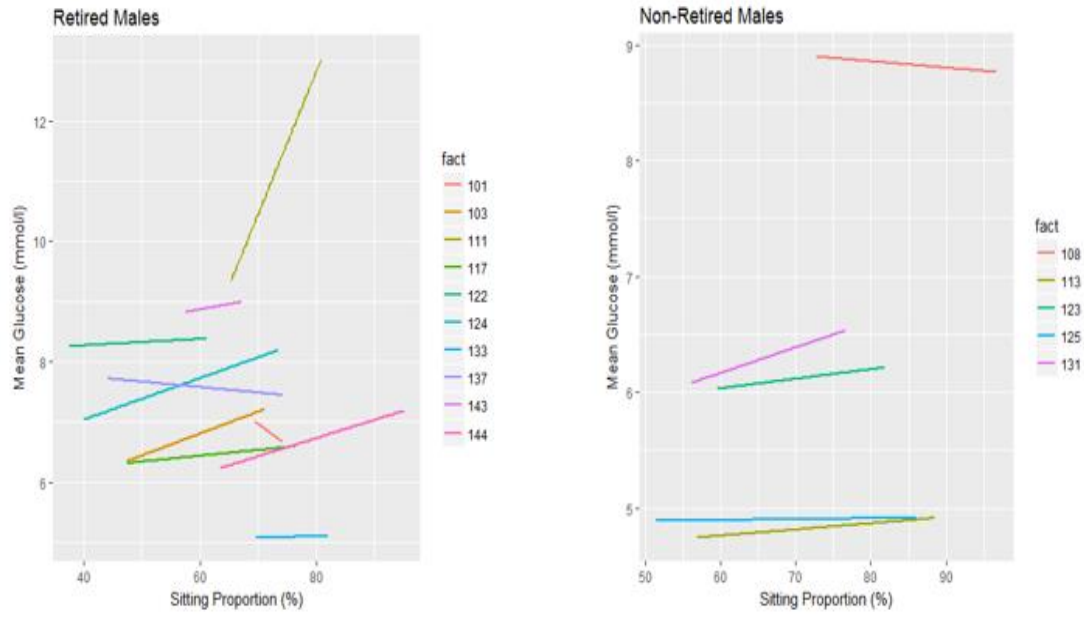


Figure 4.2: The Relationship Between Daily Sitting Proportion and Mean Glucose in Retired and Non-Retired Males



To address any differences in these relationships in retired and non-retired participants, the dataset was split into two groups and the analysis for the group as a whole was repeated. The results of this analysis are shown in Table 4.36.

Table 4.36: Retired vs Non-Retired: Relationship Between Physical Activity and Sedentary Behaviour and Patterns in Mean Glucose and Glucose Variability

	Retired *n* =20				
	Mean Glucose	Glucose Range	Glucose SD	Glucose CoV	Glucose CONGA*n*
Sitting	-0.23*	-0.23*	-0.16*	0.06	-0.33*
Standing	0.18*	0.19*	0.11	-0.07	0.28*
Stepping	0.21*	0.18*	0.16*	-0.01	0.23*
Step Count	0.19*	0.23*	0.17*	0.03	0.30*
Sit to Stand	0.11	-0.06	0.03	-0.04	0.04
Sedentary Bout Duration	0.02	0.42*	0.21*	0.21*	---
	Non-Retired *n* =18				
	Mean Glucose	Glucose Range	Glucose SD	Glucose CoV	Glucose CONGA*n*
Sitting	-0.08	-0.12	-0.08	-0.01	-0.12
Standing	0.13	0.10	0.07	-0.05	0.07
Stepping	-0.07	0.11	0.07	0.15*	0.17*
Step Count	-0.12	0.10	0.06	0.17*	0.18*
Sit to Stand	0.001	0.03	0.02	-0.04	0.03
Sedentary Bout Duration	0.02	0.44*	0.22*	0.23*	---

Note. * = p <0.05, SD = Standard Deviation, CoV = Coefficient of variation, CONGAn = Continuous overall net glycaemic action (n)

The relationship between sitting time and mean glucose and glucose variability is stronger in retired participants than in non-retired participants (Table 4.34), suggesting there is a stronger association between sedentary behaviour and patterns in glucose in those who are retired compared to

those who are working. Interestingly, the relationship between time stepping and daily step count with mean glucose is positive in retired participants and negative in non-retired participants.

The results of correlation analysis examining the relationship between physical activity, sedentary behaviour and glucose patterns when data is split into weekday and weekend are presented in Table 4.37.

Table 4.37: Weekday vs Weekend: Relationship Between Physical Activity and Sedentary Behaviour and Patterns in Mean Glucose and Glucose Variability

	Weekday				
	Mean Glucose	Glucose Range	Glucose SD	Glucose CoV	Glucose CONGA*n*
Sitting	-0.14*	-0.17*	-0.11*	0.01	-0.21*
Standing	0.15*	0.13*	0.09	-0.05	0.17*
Stepping	0.04	0.16*	0.11	0.09	0.22*
Step Count	0.01	0.18*	0.10	0.11	0.26*
Sit to Stand	0.10	-0.01	0.01	-0.10	-0.01
	Weekend				
	Mean Glucose	Glucose Range	Glucose SD	Glucose CoV	Glucose CONGA*n*
Sitting	-0.19*	-0.24*	-0.18*	-0.001	-0.30*
Standing	0.17*	0.20*	0.13	-0.03	0.24*
Stepping	0.11	0.17	0.18*	0.08	0.26*
Step Count	0.07	0.17	0.18	0.12	0.25*
Sit to Stand	-0.07	0.03	0.08	0.09	0.18

To summarise, Part C examined the relationship between patterns in physical activity and sedentary behaviour and patterns in mean glucose and glucose variability. Overall increased sitting time was associated with a

statistically significant, but very slight, decrease in mean glucose and glucose variability. These relationships were stronger in those who are retired compared to non-retired participants, but would still be considered small correlations. Overall increased sedentary bout duration was associated with increased glucose variability, particularly glucose range (r =0.43). There was no difference between retired and non-retired participants for sedentary bout duration.

Individual regression analysis was conducted to examine the relationship between sitting time and glucose for each individual participant, rather than as a whole group. This analysis showed 10 of the participants had a negative relationship between increased sitting time mean glucose, meaning the longer they were sedentary the lower their mean glucose became; the remaining 28 participants had the opposite association between sitting time and mean glucose. Participant characteristics were checked in an attempt to identify something about the 10 participants that would explain this, but there was no consistent characteristic/ or charateristics that would explain these results. For glucose variability, a similar split was observed with some participants having increased variability as sitting time increases and others having decreased variability; however, these differences are not consistent across variability measures or participants making it difficult to eplain these variations across participants.

4. Discussion

Analysis of the physical activity and sedentary behaviour variables showed participants were spending almost two thirds of their waking day (64.3%), or just over 10 hours, sitting or lying, 25.4% standing and 10.3% of their day stepping and an average of 49 sedentary breaks. This is consistent with findings from the MAASTRICHT study conducted by van der Berg et al. (2016). The study involved adults (40-75 years) with Type 2 diabetes (n = 714) wearing an activPAL accelerometer for 8 days to assess the relationship between amount and patterns of sedentary behaviour with Type 2 diabetes

(van der Berg et al., 2016). The study found that those with Type 2 diabetes spent 64.5% (10 hours) of their waking day sitting, 24.8% standing and 10.7% stepping and 53 sedentary breaks per day. Van der Berg et al. (2016) found the average duration of a sedentary bout was 12.62 minutes, however the current study found almost 45% of the 2788 sedentary bouts identified were between 30 and 60 minutes in duration, suggesting that participants were sedentary for longer periods of time without moving, something that could be reflected in the lower number of sedentary breaks in this group (49 per day) compared to the participants in the Maastricht study (51.7 per day).

Multiple regression analysis found a positive medium relationship between time spent sitting/lying and participant characteristics (R^2 = 0.31), with participant BMI, gender, waist circumference, retirement status, duration of Type 2 diabetes and FreeStyle Libre HbA_{1c} identified as significant (p <0.05) predictors. Participant age, retirement status and medication status were included in the model but were not significant predictors. The strongest relationship was between time spent standing and participants characteristics (R^2 = 0.43), the association between stepping time and daily step count and participant characteristics was not as strong (R^2 = 0.11 and R^2 = 0.19 respectively) and there was no relationship identified with sedentary bout duration. There was no consistency identified in the significant predictors of the variables.

Some exploratory analysis was conducted to identify any differences in physical activity and sedentary behaviour characteristics between weekdays and the weekend days, and similarly between retired and non-retired participants. Participants sleep for an average of 20 minutes longer at the weekend and spend a higher proportion of their day sitting at the weekend. Retired participants are more physically active than those who are still working, spending around one hour less a day sitting and achieving an average of 1500 steps more per day. Retired individuals spend a greater proportion of their day standing and stepping, resulting in only 61.5% of their day spent sitting compared to those who are non-retired spending 67.5% of theirs sitting. The differences between retired and non-retired participants

was also shown in the multiple regression analysis with a non-significant trend towards stronger relationships between sitting time (R^2 = 0.38) and standing time (R^2 = 0.56) and participant characteristics in non-retired participants compared to retired participants (R^2 = 0.30 and R^2 = 0.40 respectively). Participant BMI was identified as a significant predictor of both sitting and standing time in non-retired participants but not in retired participants. The increased physical activity is consistent with findings from a study described by Menai et al. (2014). The study was a 6-year longitudinal cohort study examining the changes in sedentary behaviour and physical activity according to retirement status. Participants completed the Modifiable Activity Questionnaire in 2001 and 2007 and results were compared. In participants transitioning from working to retirement, participants reported an increase in leisure time physical activity over the 6-years (Menai et al., 2014). However, participants reported an increase in leisure time sedentary behaviour almost three times higher than the increase in leisure time activity, which is contradicted by the findings from this study. Possible explanations for this could be the difference in measurement, Menai et al. (2014) used a self-report tool to measure physical activity and sedentary behaviour and the participants study did not have Type 2 diabetes.

Limited research has examined the differences between free living physical activity and sedentary behaviour levels related to retirement status in this population group, and no research has examined this using objective measurement of physical activity and sedentary behaviour. The novel findings from this study suggest considerations of retirement status should be made when designing future active living interventions.

The mean daily glucose was 6.96mmol/l, which is higher than is recommended for healthy individuals (4-6mmol/l) but within range for those with diabetes (4-7mmol/l) (IDF, 2017). When sleep time was removed, and wake time mean glucose was calculated, this rose to 7.40mmol/l which is slightly above the recommendations by the IDF (2017) for those with Type 2 diabetes but would still suggest glucose was relatively controlled amongst participants. This could be reflected in the recruitment methods used in this

study, participants were recruited through social media and diabetes support groups, which may have led to participants who are more motivated and committed to managing their glucose. Unlike with physical activity and sedentary behaviour, further analysis showed little difference between participant mean glucose and glucose variability during the week compared to the weekend, and there was similarly little difference between retired and non-retired participants. Regression analysis identified the strongest relationship was between mean glucose and participants characteristics with BMI as the only significant predictor in a model that also included: age, gender, waist circumference, retirement status, medication status, duration of diabetes and self-reported HbA_{1c}. Participant BMI, gender and duration of diabetes were identified as significant predictors in regression models for glucose variability measures (range, standard deviation, coefficient of variation and CONGA*n*).

The correlation analysis was conducted using data from all the participants as one group, to identify whether there was a relationship between the physical activity and sedentary behaviour variables and the participants' glucose. Increased proportion of time spent sitting associated with decreased mean glucose. Similar studies investigating the effect of breaking prolonged sedentary behaviour have found interrupting prolonged sitting time in those with Type 2 diabetes lead to a decrease in mean glucose, which persisted for up to 22 hours (Dempsey et al., 2016; Dempsey et al., 2017; Duvivier et al., 2017). Dunstan et al. (2012) found regular activity breaks in sedentary behaviour lead to significant (p <0.01) reductions in glucose area under the curve. However, participants in this study were overweight and obese adults and did not have Type 2 diabetes. The difference in study design could explain the differences in findings between the current study findings and those by Dempsey et al. (2016) and Dunstan et al. (2012), both studies were controlled lab-based studies where participants were provided with standardised meals compared to the current study where food intake was not controlled. Sedentary bout duration has no relationship with mean glucose, suggesting that it is the total sedentary time

accumulated throughout the day, rather than prolonged bouts that has an impact on mean glucose. This is also shown where there is no relationship between the number of sit to stand transitions, or breaks in sedentary behaviour, and mean glucose.

Increased time spent sitting was associated with a significant (p <0.05) decrease in glucose variability. Interestingly, increased sedentary bout duration was associated with significantly increased glucose range (r = 0.43), standard deviation (r = 0.22) and coefficient of variation (r = 0.22). These results imply that increased time spent sitting throughout the day leads to lower variation in an individuals' glucose, however if this time is accumulated in fewer but longer bouts of sedentariness, it is associated with increased glucose variability. This could possibly be explained if these prolonged bouts included meal times, which would have an effect on glucose variability and is something that was not examined in this study.

To examine the relationship between sitting time and mean glucose further, individual regression analysis was conducted. This accounted for the multi-level data collected in this study and provided a more thorough understanding and insight to the individual nature of the effect of sedentary behaviour on glucose in this population.

As discussed previously, the relationship between sitting time and mean glucose as a whole group showed increased sitting was associated with decreased mean glucose. The individual regression coefficients show only 10 of the 38 participants have this relationship between sitting time and mean glucose and were influencing the results for the whole group. Increased sitting time in the remaining 28 participants was associated with increased mean glucose. This individuality is quite clearly shown in figures 4.1 and 4.2, there is also noticeable variability between participants who have the same direction of relationship, showing that there is variability in strength of the relationship also. Participants' demographics (gender, age, BMI, medication status, retirement status and duration of diabetes) were checked in an attempt to identify anything that may explain the difference in trend for

these 10 participants, and there was nothing that clearly separated these individuals from the other 28 participants. It was expected that there would be a similar trend in the individual relationships between sitting time and the glucose variability measures, this was not the case. The differences in trends in the glucose variability measures was evenly split with 19 participants showing a positive association between sitting time and glucose range and 19 participants with a negative association. Not all 10 participants with a different relationship with mean glucose showed a different relationship with glucose variability, further strengthening the evidence of how individual these responses are.

As with the physical activity and sedentary behaviour datasets, the combined dataset was split into a retired and a non-retired group and analysis was repeated for the whole group. The trends shown remained the same for sitting/lying time, however the relationship between sitting time and mean glucose and glucose variability was stronger in the retired group (r = -0.23) compared the non-retired group (r =-0.08). There was no difference between groups in the sedentary bout duration relationship with mean glucose or glucose variability, further highlighting the importance to examine both total time spent sedentary and patterns of sedentary behaviour.

A similar individual glucose response was reported in a large cohort (n =800) study examining the effect of meal content on glucose. The participants in this study did not have Type 2 diabetes, however the response to identical meals were assessed and high variability in glucose response was shown between participants. Additionally, four sub-types of Type 2 diabetes have recently been identified and Ahlqvist and colleagues (2017) have suggested that different sub-types may respond differently to food, activity and medication but acknowledged that further research is required to understand this fully. Although the findings from this study are novel and have not be reported in previous research, overall there is growing evidence to support a more personalised approach to diabetes care (Ahlqvist et al., 2017; Zeevi et al., 2015) and incorporating mobile technology could provide a mechanism for this tailored approach to care.

5. Strengths and Limitations

A key strength of this study is the objective and continuous measurement of physical activity, sedentary behaviour and glucose. This, along with a sample size of 38, with an average wear time of 6.5 days per participant, enabled a large amount of data to be collected and thereby increasing the rigor of our findings. It is acknowledged that the free living design of the study allowed no control over participant meal content or timing or medication dose and timing, however participant food and medication diaries were collected so future analysis of this dataset should examine the effect of food and mealtimes on these relationships. The purpose of this study however, was to examine the data in a free living context and therefore not control for these factors to try and explore normal living behaviour. Collecting data in a free living context is more reflective of habitual behaviour in those with Type 2 diabetes, this is an important consideration to have when developing interventions to support positive habitual lifestyle behaviour.

6. Conclusions

This study has investigated the physical activity and sedentary behaviour characteristics and their relationship with glucose in those with Type 2 diabetes. Findings from this study highlight the individual nature of Type 2 diabetes and the relationship between physical activity and sedentary behaviour characteristics and glucose, particularly when analyses were repeated for each individual participant. These findings support the need for this type of continuous, mobile-based, feedback to enable the user to tailor their own behaviour to improve the management of their diabetes. Future research should examine participant thoughts and feelings towards the use of such technology as a means of managing their diabetes better. The impact that food intake and meal times may be having on these relationships, perhaps in a lab-based and controlled setting, should also be investigated in future research.

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Chapter 5: Further investigation of the glycaemic response to interrupting prolonged sedentary behaviour in people with Type 2 diabetes in a lab setting.

1.0 Preface

In Chapter 4 an individualised glucose response to free living sedentary time was identified between participants. A small number of participants from the previous free living study participated in this study, where their movement was controlled and manipulated in addition to the content and timing of their meals being controlled. This enabled further examination of the relationship between breaks in sedentary behaviour and glucose in a more controlled setting.

Previous research has examined the effect of differing frequencies of breaks in sedentary behaviour on glucose in people with Type 2 diabetes, however, this has often been compared to a control day where participants were asked to sit continuously for a prolonged period of time. In this study the relationship was examined and compared to a free living day to give more insight into the direct differences, or similarities, between free living and controlled behaviour and the effect that had on an individual's glucose. Additionally, the use of an n-of-1 approach allows for a much more comprehensive look at the individual response. This is a method that is being used increasingly in pharmaceutical and health research but is a novel approach in this specific area of research.

The research described in this chapter was part of a collaboration with another Ph.D student from Glasgow Caledonian University. The full dataset was not used in the analysis as this was the focus of the other Ph.D. Instead, a subset of this data was used to further examine the glucose response to breaks in sedentary behaviour in a controlled setting. KM contributed significantly to the study design and protocol development. KM developed the research questions, wrote the ethics application for University Ethics and

recruited all participants in the study (*n* =4). KM collected, processed and analysed all the data reported in this chapter.

1. Introduction

Reduced total sedentary time and increased breaks in sedentary behaviour have been identified in many studies, and in both non-diabetic and diabetic populations, as beneficial for the prevention and management of Type 2 diabetes (Dempsey et al., 2016; Dunstan et al., 2012; Duvivier et al., 2017). Dempsey et al. (2016) compared prolonged sitting time, breaks in sitting time with light intensity walking, and breaks in sitting time with resistance activities on the impact the three conditions had on cardiometabolic factors in people with Type 2 diabetes. Authors reported both break conditions reduced the iAUC for postprandial glucose compared to the prolonged sitting condition (prolonged sitting mean 24.2mmol/h/L, light intensity walking mean 14.8mmol/h/L and simple resistance activities mean 14.7mmol/h/L) (Dempsey et al., 2016). This reduction was maintained over a prolonged period (22 hours) after the lab intervention was finished (Dempsey et al., 2017). Interestingly, these studies did not compare the effects of the intervention with the effects of free living behaviour, the control was a period of uninterrupted sitting over a prolonged period of time. The results from Chapter 4 suggest that a prolonged period of uninterrupted sitting of ~8hours is not reflective of normal behaviour in this population.

The concept of individualised response to standard movement patterns has been introduced previously. The HERITAGE family study conducted in the USA and Canada in the 1990s aimed to identify the role of the genotype in hormonal, cardiovascular and metabolic response to aerobic exercise training over a 20-week intervention period (Bouchard, Leon, Rao, Skinner, Wilmore &Gagnon, 1995). As part of this study, the effects of exercise training on glucose homeostasis were measured (Boule et al., 2005). Participants (*n* =596, women =316, men =280), were categorised as male or female and black or white for analysis, did not have diabetes, mean age ranged from 33.1-36.5 years old and BMI ranged from 24.7-27.7kg/m^2. Participants completed three 60-minute sessions per week on a cycle ergometer. An intravenous glucose tolerance test was conducted prior to the training program beginning and repeated at the end of the training program.

Improvements in all glucose tolerance variables were shown, including a significant (p <0.001) 10% increase in insulin sensitivity (Boule et al., 2005). However, high inter-participant variability in the effects of the exercise program were reported by authors. Regardless of race, men had larger improvements in insulin sensitivity than women (Boule et al., 2005). Although this study was conducted in a heterogeneous sedentary sample who did not have Type 2 diabetes, the results suggest the response to exercise training on glucose may be individual. Other studies have also found this, and this individualised response has been identified across numerous health outcomes (Ahlqvist et al., 2017; Zeevi et al., 2015), so the concept of individualised response is not a new concept but rather an under explored one. Advances in technology, such as continuous glucose monitors and wearable activity monitors, lend to exploring this individualised response in more detail.

In Chapter 4 an individualised glycaemic response to sedentary time and breaks in sedentary time was identified within a free living context. Initial investigations into participant characteristics did not explain these responses. The analysis of the relationship between sedentary behaviour and glycaemic response on the group as a whole, showed a slightly negative, but statistically significant relationship between proportion of time spent sitting and mean glucose (p <0.05). When this relationship was investigated on an individual participant basis, however, the results showed that 10 of the 38 participants had a negative relationship between sedentary behaviour and mean glucose, meaning as sedentary behaviour increased mean glucose decreased, while 28 participants had a more expected association between sedentary behaviour and mean glucose, meaning as sedentary behaviour increased mean glucose increased.

To examine these relationships further a final study was conducted to examine the individual glucose response to breaks in sedentary behaviour in people with Type 2 diabetes. During this study, food content, sedentary time and breaks in sedentary behaviour were controlled. This is something that was not done in the free living study and the controlled environment gave an

opportunity to explore the findings from the previous study (Chapter 4) in more detail. A small number of participants from the free living study also participated in the current lab based study. As the aim of the study was to build on the findings from previous studies and examine the relationship between sedentary behaviour and patterns and glucose at an individual level, along with the small sample size, it was decided the best methodology would be a series of n-of-1 studies.

N-of-1 studies are used to test the effects of an intervention based on repeated measurement of variables in an individual over time (McDonald et al., 2017). N-of-1 methodologies have been used frequently in health behaviour studies and are recommended by the Medical Research Council for the development and testing of interventions (Craig, Dieppe, MacIntyre, Michie, Nazareth & Petticrew, 2008). Often health behaviour studies draw conclusions on the effectiveness of an intervention on the group and do not account from the individual variations within that group (McDonald et al., 2017). This was highlighted in Chapter 4 when the individual analysis provided very different results to the analysis on the whole group. McDonald, Araujo-Soares and Sniehotta (2016) discuss the importance of n-of-1 studies in the personalisation of interventions in order to increase the chance of successful behaviour change. In the case of the overall aim of the Ph.D, to successfully change behaviour and promote active living as a means to improve management of diabetes, it is first important to understand the relationship between sedentary behaviour and glucose on an individual level.

1.1 Aims

The aim of this chapter was to use an n-of-1 approach to investigate the individualised glycaemic response to sedentary behaviour and breaks in sedentary behaviour in a controlled lab setting.

2. Methods

2.1 Study Design

To reduce participant burden and to collect data in an efficient and effective manner, a randomised three-treatment, two-period balanced

incomplete block trial study design was used (Senn & Senn, 2002). This design has been used regularly in pharmaceutical trials and more recently in research similar to the current study (Henson et al., 2015). Participants were randomised to complete two of the following three treatment conditions: 1) Sitting with 3-minutes of light intensity walking every 60 minutes, 2) Sitting with 3-minutes of light intensity walking every 30 minutes and 3) Sitting with 3-minutes of light intensity walking every 15 minutes. Block randomisation sequence was used, and the participant was blind to trial condition and order until the first lab condition day.

2.2 Participants

Participants were recruited to this study after participating in the previous free living study, where they were recruited from Diabetes support groups in Glasgow and the surrounding area. Inclusion criteria for this study included: diagnosis of Type 2 diabetes, 35-75 years old, medication (not insulin) or diet-controlled diabetes, a BMI of over 25kg/m^2. Participants were excluded due to the following: insulin therapy, pregnancy, renal disease, liver disease, cancer, alcohol or substance misuse, mobility issues or other complications related to their diabetes.

A total of 12 participants were recruited to participate in this study and four participants were identified as participating in the freeliving study so were included in the analysis for this chapter. Two participants were identified as having an unexpected relationship between sedentary time and mean glucose, where increased sedentary time was associated with lower wake time mean glucose, and the remaining two participants identified as suitable for inclusion had the expected relationship, where increased sedentary was associated with increased wake time mean glucose, in the free living study.

2.3 Ethics

Ethical approval was granted by the Strathclyde University Ethics Committee and all participants provided informed consent prior to data collection starting.

2.4 Data Collection

Data collection for this study consisted of five periods over a 15-day experimental period: 1) Pre-monitoring, 2) Intervention day one, 3) Washout period, 4) Intervention day two, 5) Post-monitoring period. During the 15-day experimental period, participants were asked to refrain from smoking, alcohol, caffeine and moderate to vigorous physical activity. For the two intervention days, participants were provided with three standardised meals and a snack, picked by the participant from a list provided by the researcher (Appendix E) and asked to only eat the food provided.

The activPAL^{TM} accelerometer was used the measure physical activity and sedentary behaviour. The activPAL^{TM} was chosen as it can accurately distinguish between sitting/lying, standing and stepping and is often referred to as the gold standard for continuous sedentary behaviour measurement (Grant, Ryan, Tigbe & Granat, 2006; Kozey-Keadle, Libertine, Lyden, Staudemayer and Freedson, 2011). The FreeStyle Libre was used to measure glucose during the study. The FreeStyle Libre is a validated and accurate glucose monitor with a lower participant burden than other available continuous glucose monitors and blood glucose monitors (Bailey, Bode, Christiansen, Klaff & Alva, 2015; Leelarathna & Wilmot, 2018). Both the activPAL and FreeStyle Libre record for up to 14 days, meaning once the devices were attached at beginning of the study, they were left for the duration of data collection.

1) Pre-monitoring period

On day one, participants were asked to provide up to one hour of their time to meet with the researcher, either at the University or another convenient location. During visit one, participants completed a demographic questionnaire and were fitted with the activPAL^{TM} accelerometer and the FreeStyle Libre Flash Continuous Glucose Monitor by the researcher. Participants were also provided with a sleep diary and a validated 24-hour diet recall and medication diary and were asked to complete this daily for the duration of their participation in the study.

Participants were instructed to scan their blood glucose every eight hours using the FreeStyle Libre, complete the diaries provided and go about their normal daily lives.

2) Intervention day one

On day five, intervention one took place. Participants were asked to attend the University at 0800 hours after an overnight fast from 2200 hours. The participants sat from 0800-0900 to achieve a physiological steady state. At 0900 the participant ate their standardised breakfast. After this, the participant performed 3minutes of light intensity walking every 60, 30 or 15 minutes of sitting. This sequence continued until the end of the intervention period at 1600hours. As per the timing of each condition, the researcher instructed the participant to stand and walk at a light pace (approximately 3.2km/hour) on a marked 10 metre walkway. At the end of the 3 minutes the participant was asked to resume their sitting. This sequence was repeated until the end of the intervention period. The participant ate their standardised lunch at 12.36 hours. At the end of the intervention period, participants were provided with their standardised dinner and a snack and asked to eat this between 1830 and 2030hours. Participants were asked to record the time they ate dinner and replicate this after intervention day two.

3) Washout period

As an acute bout of physical activity has been shown to have a carryover effect on glucose and insulin sensitivity for up to 72hours, there was a washout period of five days between the two intervention days (Latouche et al., 2012). Participants were asked to go about their normal daily life, whilst still completing the two diaries.

4) Intervention day two

On day 11, the participant returned to the University at 0800 hours after an overnight fast from 2200 hours to complete the second intervention period. Every procedure in the second intervention period was the same as the first, except from the condition the participant performed. The participant

performed one of the two conditions not performed during the first intervention period.

5) Post monitoring period.

Following the second intervention day, from days 12-15, the participants continued to wear the activPAL™, the continuous glucose monitor and complete the diaries provided. After day 15 participants were asked to provide up to one hour of their time to meet with the researcher for the removal of the two devices and to give the researcher the completed diaries. After that, the experimental period ended for the participant.

2.5 Data Analysis

Data for each participant was analysed and reported separately. The two intervention days and a free living day from the pre-monitoring period were identified for each participant. Using the participant diaries, the dataset was cut into lab duration and post-lab to self-reported bedtime periods. Mean glucose was reported, for the previous time frames identified, and glucose standard deviation was used to measure glucose variability. Time spent sedentary, proportion of sedentary time, time stepping and mean hourly sit to stand transitions were calculated for the lab period and the period after the lab to self-reported sleep time. Additionally, the differences between lab conditions and the free living day patterns in glucose were observed.

3. Results

3.1 Participant Characteristics

The demographic characteristics for each participant are shown in Table 5.1. Participant A was a 69 year old retired male with a BMI of 27.5kg/m^2, making him overweight. Participant A was prescribed 500mg of Metformin twice daily and had been diagnosed with Type 2 diabetes for three years at the time of participation. Participant A had an average (over 3 measurements) blood pressure of 152/87mmHg and had a waist circumference of 109cm. Participant B was a 59 year old self-employed

female with a BMI of 34.6kg/m^2, making her obese. Participant B was prescribed 500mg of Metformin once per day and had been diagnosed with Type 2 diabetes for five years. Participant B had an average blood pressure of 142/86mmHg and a waist circumference of 119cm. In the analysis of the free living data in Chapter 4, participants' A and B had an unexpected relationship with sedentary behaviour and mean glucose where increased sedentary time was associated with reduced mean glucose during the waking day. Participant C was a 73 year old retired male with a BMI of 26.4kg/m^2, making him overweight. Participant C was taking 2x500mg of Metformin daily and had been diagnosed with Type 2 diabetes for eight years at the time of participation. Participant C had an average blood pressure of 142/74mmHg and a waist circumference of 94cm. Participant D was a 65 year old retired male with a BMI of 27.5kg/m^2 and was prescribed 4x500mg of Metformin daily. Participant D had been diagnosed with Type 2 diabetes for 10 years, had an average blood pressure of 129/79mmHg and a waist circumference of 93cm. Participants C and D had a more expected relationship between their sedentary behaviour and their glucose where increased sedentary time was associated with increased mean glucose.

Table 5.1: Individual Participant Characteristics

Participant	**A**	**B**	**C**	**D**
Sex (male/female)	Male	Female	Male	Male
Age (years)	69	59	73	65
BMI (kg/m^2)	27.5	34.6	26.4	27.5
Waist Circumference (cm)	109	119	94	93
Diabetes Medication	2x500mg Metformin	1x500mg Metformin	2x500mg Metformin	2x1000mg Metformin
Retirement Status	Retired	Self-employed	Retired	Retired
Blood Pressure (mmHg)	152/87	142/86	142/74	129/79
Relationship in Free living study	Unexpected	Unexpected	Expected	Expected

3.2 Glucose Response during Lab Period

Each participant completed two intervention conditions in the lab, five days apart, where their breaks in sedentary behaviour and food consumption were controlled. For each participant the differences between glucose profiles during lab days and compared to the same time period on a free living day are discussed. These differences are illustrated in Table 5.2. Additionally, the difference in activity and sedentary behaviour between the two controlled lab days and a free living day over the same time period are discussed (Table 5.2).

Table 5.2: Lab Duration Activity and Glucose

Participant	Day	Activity				Glucose			
		Time Sitting/lying (h)	Sitting/lying Proportion (%)	Time Stepping (mins)	Mean Sit to Stand Transitions per hour	Mean (mmol/l)	SD (mmol/l)	Min (mmol/l)	Max (mmol/l)
Participant A	60 Minute Lab	6.7	83.75	18	1	6.00	1.39	4.20	9.40
	30 Minute Lab	6.4	80	36	2	5.93	1.19	4.30	8.30
	Free living Day	5.95	74.25	57	2.63	5.71	0.73	4.40	6.70
Participant B	60 Minute Lab	6.7	83.75	18	1	6.55	1.31	4.60	10.20
	30 Minute Lab	6.4	80	36	2	6.69	1.10	4.90	9.30
	Free living Day	5.42	67.75	38.4	2.88	4.47	0.83	5.60	8.90
Participant C	60 Minute Lab	6.7	83.75	18	1	6.72	1.09	4.70	8.40
	15 Minute Lab	5.85	73.13	69	3	6.50	1.65	3.30	9.30
	Free living Day	6.10	76.25	36	3	6.47	2.30	3.40	11.70
Participant D	60 Minute Lab	6.7	83.75	18	1	8.22	1.91	4.90	10.50
	30 Minute Lab	6.4	80	36	2	8.34	1.21	6.40	10.40
	Free living Day	6.05	75.63	27.6	2.5	8.38	2.89	3.60	12.80

3.2.1 Participant A

Participant A completed the 60 and 30-minute protocols. During the 60-minute protocol the participant broke sitting 6 times and accumulated 6.7hours of sitting, which is 83.75% of the time, and 18 minutes of walking. During the 30-minute protocol the participant broke sitting 12 times, walking for 36 minutes and sitting for 80% of the time or 6.4hours. During the same time period on a free living day where sedentary behaviour and food were not controlled, the participant spent 5.95hours sitting (74.25%), 57minutes walking and broke their sitting an average of 2.63 times per hour (Table 5.2).

Figure 5.1 illustrates Participant A's glucose profile for the duration of the lab conditions. Mean glucose during the 60-minute lab period was 6mmol/l compared with 5.93mmol/l during the 30-minute lab period. The glucose spike observed after breakfast during the 60-minute protocol is higher than that of the 30-minute protocol and although the glucose lowers to just about 4mmol/l prior to lunch, the decrease after breakfast is more gradual in the 30-minute protocol than the 60-minute. Similarly, the glucose lowers after lunch more steadily in the 30-minute protocol than the 60-minute one, however, the difference in peak is not seen after lunch like it was after breakfast. In comparison, mean glucose for the same 8 hour period during a free living day was 5.71mmol/l and the high peaks observed after breakfast and lunch during the lab conditions were not seen (Figure 5.2). Glucose did not go above 7mmol/l during the free living day, whereas it rose above 7mmol/l after breakfast and lunch during both lab conditions. Although there is little notable difference between mean glucose during the free living day and the lab conditions, particularly the 30-minute condition, there is a noticeable visual difference in variability. Glucose standard deviation was 1.39mmol/l and 1.19mmol/l in the 60-minute and 30-minute lab days compared to 0.73mmol/l during the free living day (Table 5.2).

During the free living day, the content and timing of the participant's meals were not controlled, and Participant A ate their breakfast around 90minutes earlier than on the two lab condition days. Although Participant A reported taking 2x500mg of Metformin per day, the timing was not noted in

their diary during the lab or free living days, making it difficult to know any impact this may or may not have had on the glucose response.

Figure 5.1: Participant A Glucose Profile for 60-Minute and 30-Minute lab

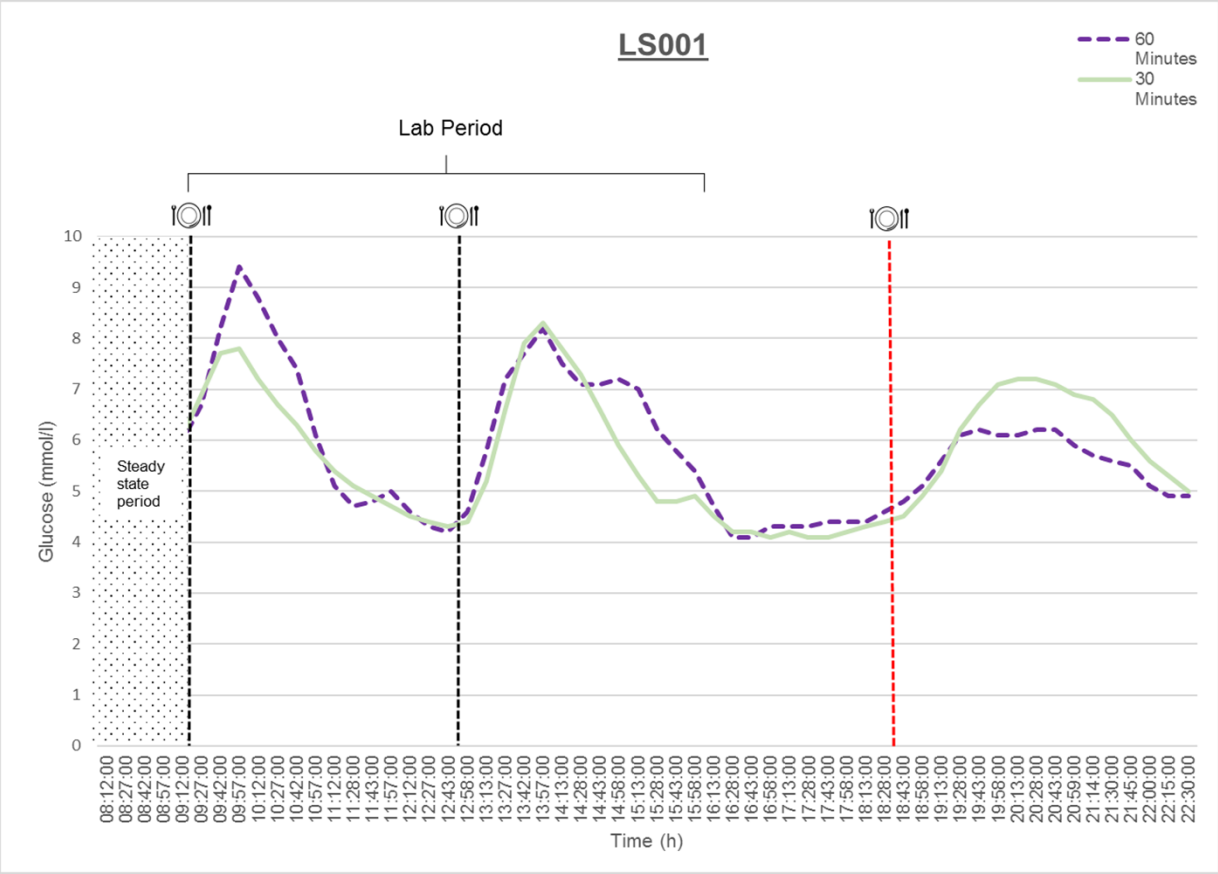
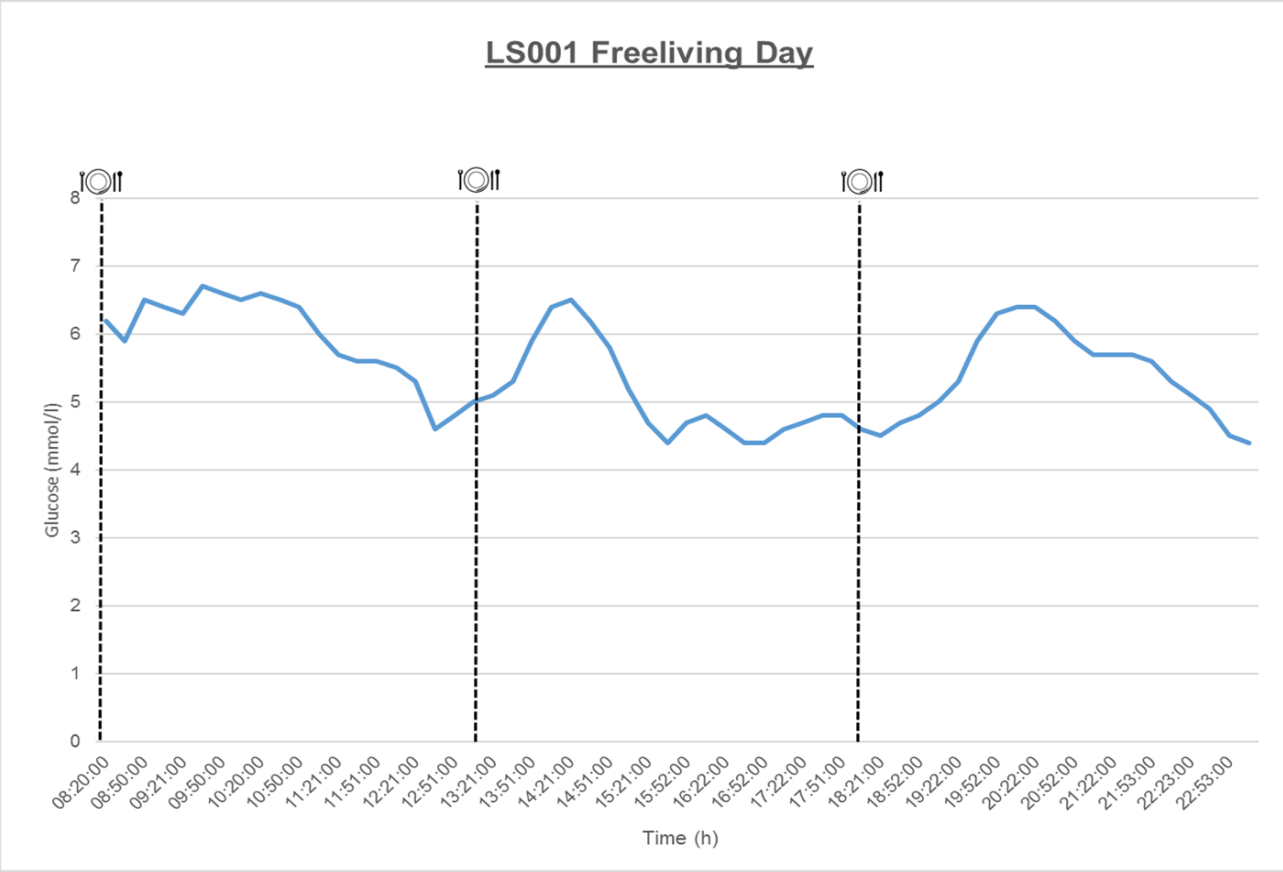


Figure 5.2: Participant A Glucose Profile for Free Living Day



3.2.2 Participant B

Participant B completed the 60 and 30-minute lab protocols. As mentioned above, the participant broke sitting 6 times and accumulated 6.7hours of sitting, or a proportion of 83.75%, and 18 minutes of walking during the 60-minute protocol. During the 30-minute protocol the participant broke sitting 12 times, walking for 36 minutes and sitting for 6.4hours, or 80% of the lab duration. During the same period on a free living day, the participant sat for 67.75% or just 5.42 hours and was stepping for 38.4minutes (Table 5.2). Mean sit to stand transitions per hour during this day were 2.88.

The glucose profiles for these days are highlighted in Figure 5.3. Mean glucose during the 60-minute lab period was 6.55mmol/l and 6.69mmol/l during the 30-minute protocol (Table 5.2). There was a high peak after breakfast during both conditions, but this was higher in the 60-minute condition. The decrease in glucose was steeper during the 60-minute condition compared to a steady decrease observed in the 30-minute profile. The peak following lunch was not as high as that following breakfast; however, glucose did increase steeply in both conditions and unlike the steady decline post breakfast, the decrease in glucose after this peak was variable.

Mean glucose during the same period of time on a free living day was 6.47mmol/l and a similar glucose profile was observed, with a high peak followed by a gradual decline after breakfast and a lower peak following lunch with a more variable decline (Figure 5.4). Participant B ate breakfast and lunch at similar times, within 45minutes, during the free living day compared to the lab days and although they reported to be prescribed Metformin, the timing and dose was not self-reported during participation.

Glucose standard deviation was 0.83mmol/l on the free living day compared to 1.31mmol/l during the 60minute lab and 1.10mmol/l during the 30-minute lab condition (Table 5.2).

Figure 5.3: Participant B Glucose Profile for 60-Minute and 30-Minute Lab Conditions

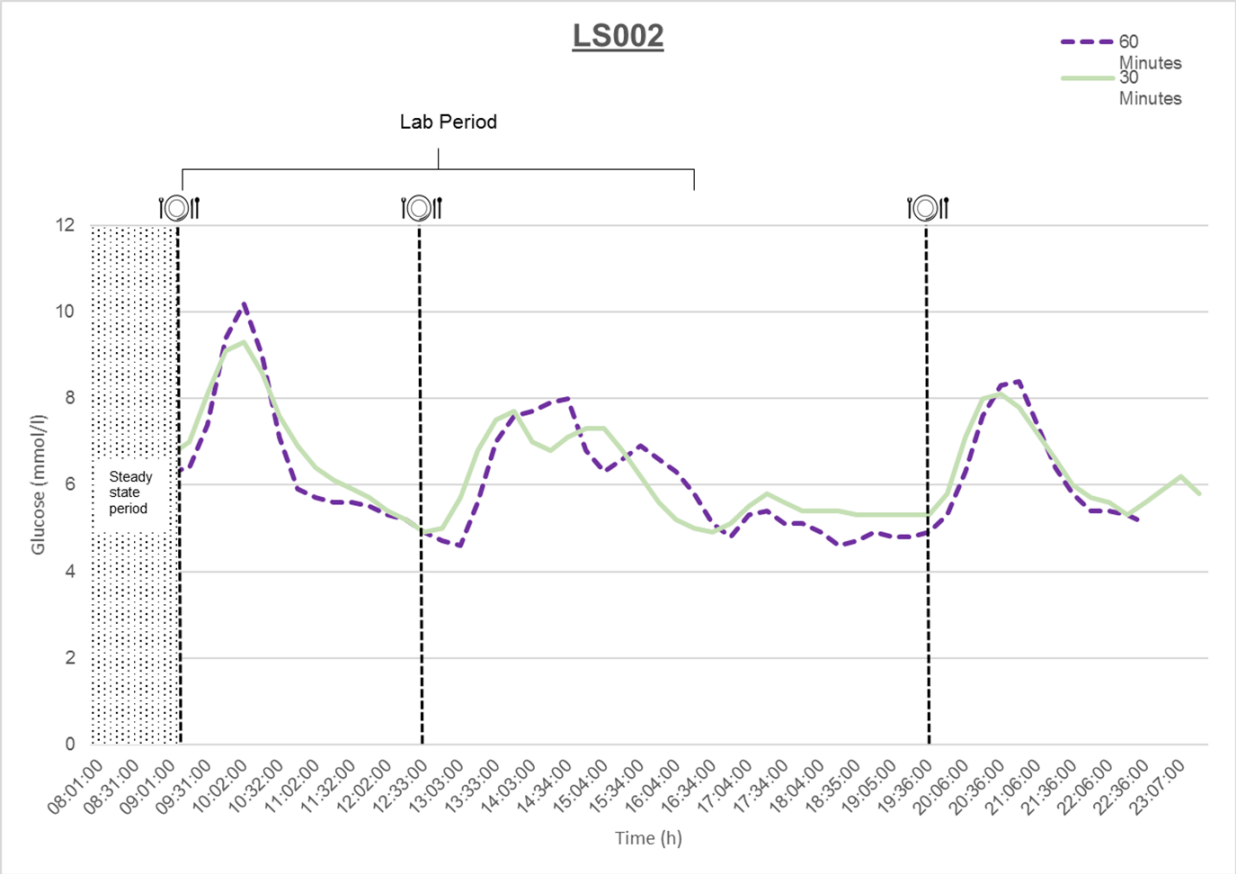
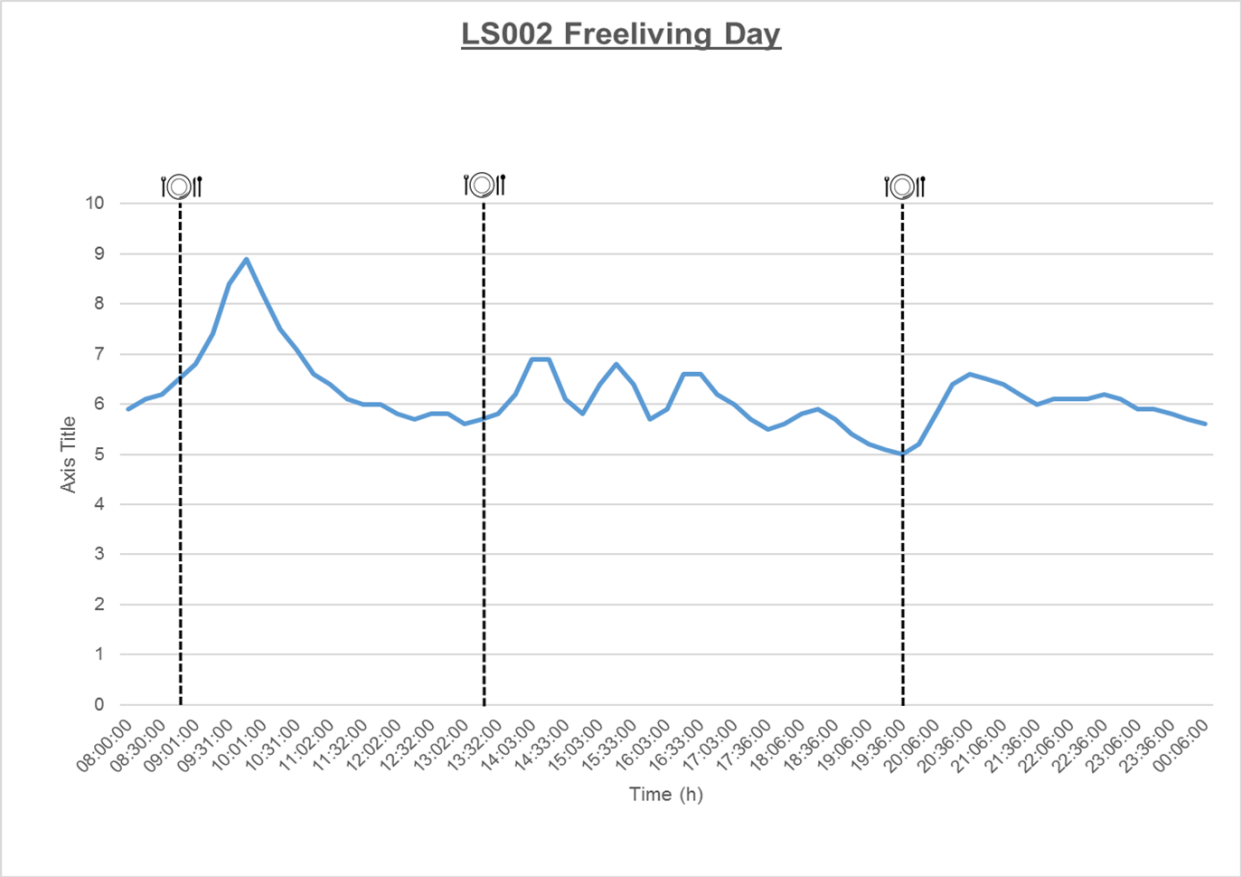


Figure 5.4: Participant B Glucose Profile for Free living Day



3.2.3 Participant C

Participant C completed the 60 and 15-minute protocol and the glucose profile for both conditions are shown in Figure 5.5. During the 60-minute protocol sitting was broken 6 times and 6.7 hours of sitting and 18 minutes of walking was accumulated. Sitting was broken 23 times, 69 minutes of walking and sitting for 5.85 (73.13% of lab duration) hours were accumulated during the 15-minute protocol. During Participant C's free living day, they spent 76.25% of their time, or 6.10hours, sitting and 36minutes stepping. Sedentary time was broken an average of 3 times per hour (Table 5.2).

Mean glucose for the 60-minute condition was 6.72mmol/l and for the 15-minute condition was 6.50mmol/l. Glucose rose higher and at a steeper rate during the 15-minute condition following breakfast and glucose remained higher than during the 60-minute condition throughout the rest of the morning until lunchtime. Glucose increased following lunch to around 8mmol/l in both conditions, however again this rise was notably steeper in the 15-minute protocol than the 60-minute and glucose reduced at a more gradual pace and not by so much in the 60-minute condition. Although the mean glucose for the lab conditions were similar, glucose during the 15-minute profile appears visually to be more variable than that of the 60-minute condition. Standard deviation during the 60-minute condition was 1.09mmol/l compared to 1.65mmol/l in the 15-minute condition. Participant C reported taking their medication in the evening after the lab period.

In comparison, the glucose profile from the free living day shows a similar level of variability with glucose going from 8mmol/l after breakfast down to under 4mmol/l before climbing steeply again after lunch to almost 12mmol/l (Figure 5.6). Glucose decreased at slower, more gradual pace following lunch than breakfast. Mean glucose was 6.47mmol/l and variability were higher with a standard deviation of 2.30mmol/l (Table 5.2). Participant C did not report the timing of their Metformin during the free living day.

Figure 5.5: Participant C Glucose Profile for 60-Minute and 15-Minute Lab Conditions

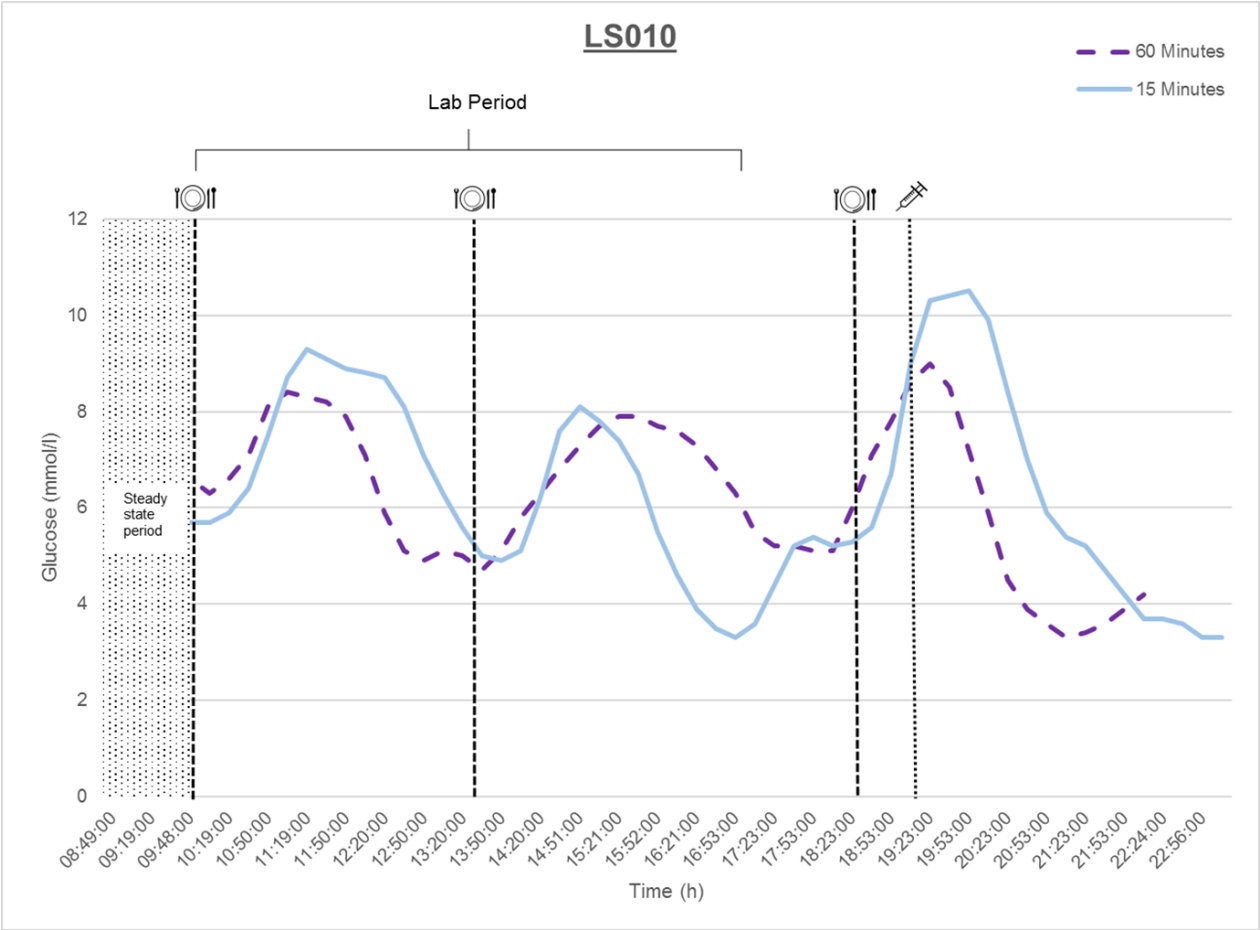
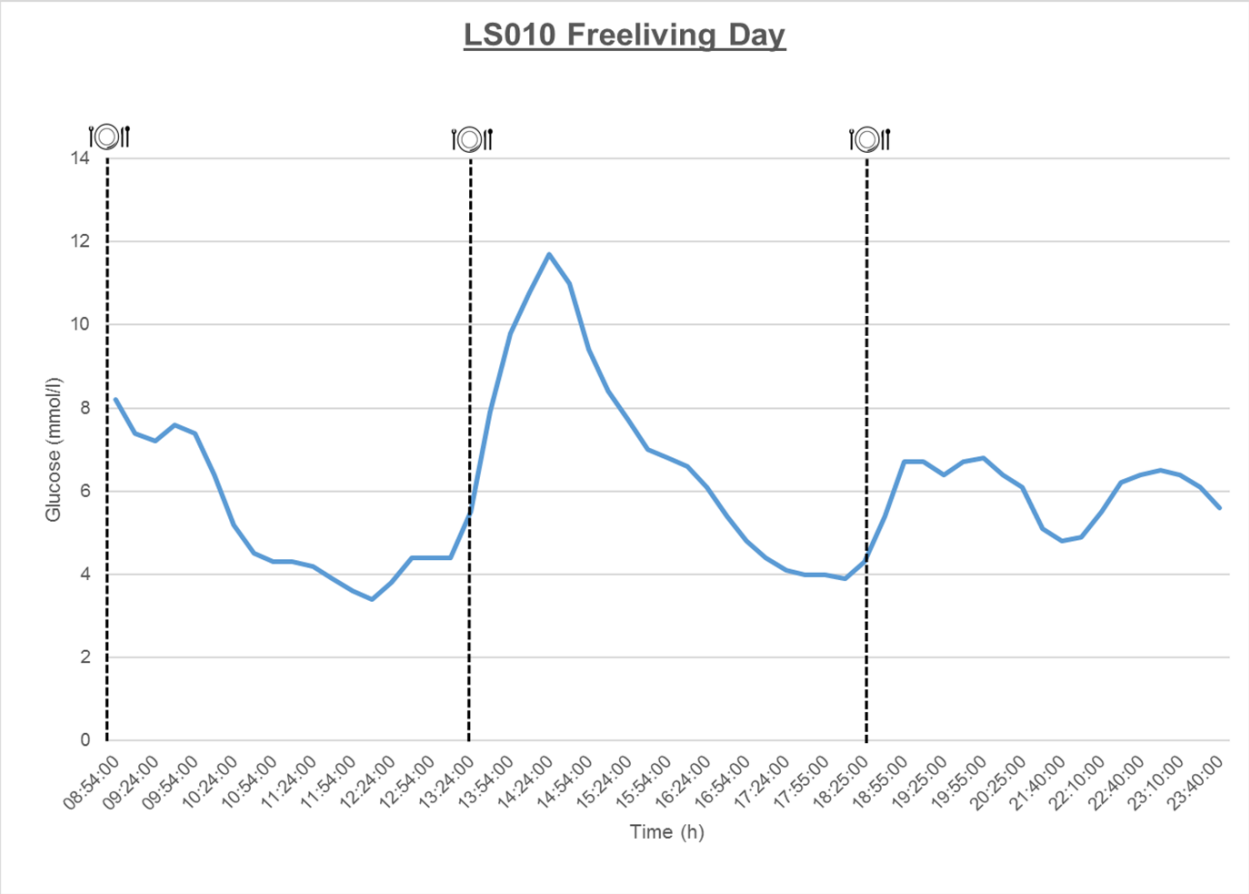


Figure 5.6: Participant C Glucose Profile for Free Living Day



3.2.4 Participant D

Participant D completed the 60 and 30-minute lab conditions, the glucose profiles for these are shown in Figure 5.7. Similar to Participants A and B, sitting was broken 6 times, achieving 28 minutes of walking and accumulating 6.7 hours of sitting during the 60-minute protocol, and in the 30 minute protocol the participant broke sitting 12 times and walked for 36 minutes during the eight hour lab and sitting for 6.4hours. In comparison, Participant D was sitting for 75.63% of the time, or 6.05 hours and broke sitting on average 2.5 times per hour and spent 27.6 minutes stepping during the free living day.

Participant D had the highest dose of Metformin prescribed (2x1000mg per day) and reported taking these in the morning prior to the lab starting and in the evening after the lab condition was finished. Following breakfast, glucose rose steadily from around 6mmol/l to just above 10mmol/l but did not decline prior to lunch. Glucose was higher in the 30-minute condition until lunch where it became lower and remained this way until the end of the lab period. Following lunch, glucose did not rise further but instead started to decrease in both conditions. The decrease in the 30-minute condition was less gradual and slightly more variable than the 60-minute condition. Mean glucose during the 60-minute condition was 8.22mmol/l and 8.34mmol/l during the 30-minute condition. Glucose variability was slightly lower during the 30minute condition (1.21mmol/l) compared to the 60-minute condition (1.91mmol/l).

During the same period of a free living day, where meal content and timing were not controlled, the participant ate both their breakfast and lunch later than during the lab and took their medication at similar times before breakfast and late evening. The glucose profile for the free living day is quite different to those of both lab conditions. There is a steep increase following breakfast where glucose rises to almost 13mmol/l and then becomes quite variable, decreasing before increasing again prior to lunch. Glucose continues to decrease following lunch before increasing sharply around an hour after lunch was reported. Mean glucose during this period was

8.38mmol/l, so although the profile was different during the lab days compared to the free living day, the resulting mean glucose was similar. However, variability was noticeably higher during the free living day with a glucose standard deviation of 2.89mmol/l.

Figure 5.7: Participant D Glucose Profiles for 60-Minute and 30-Minute Lab Conditions

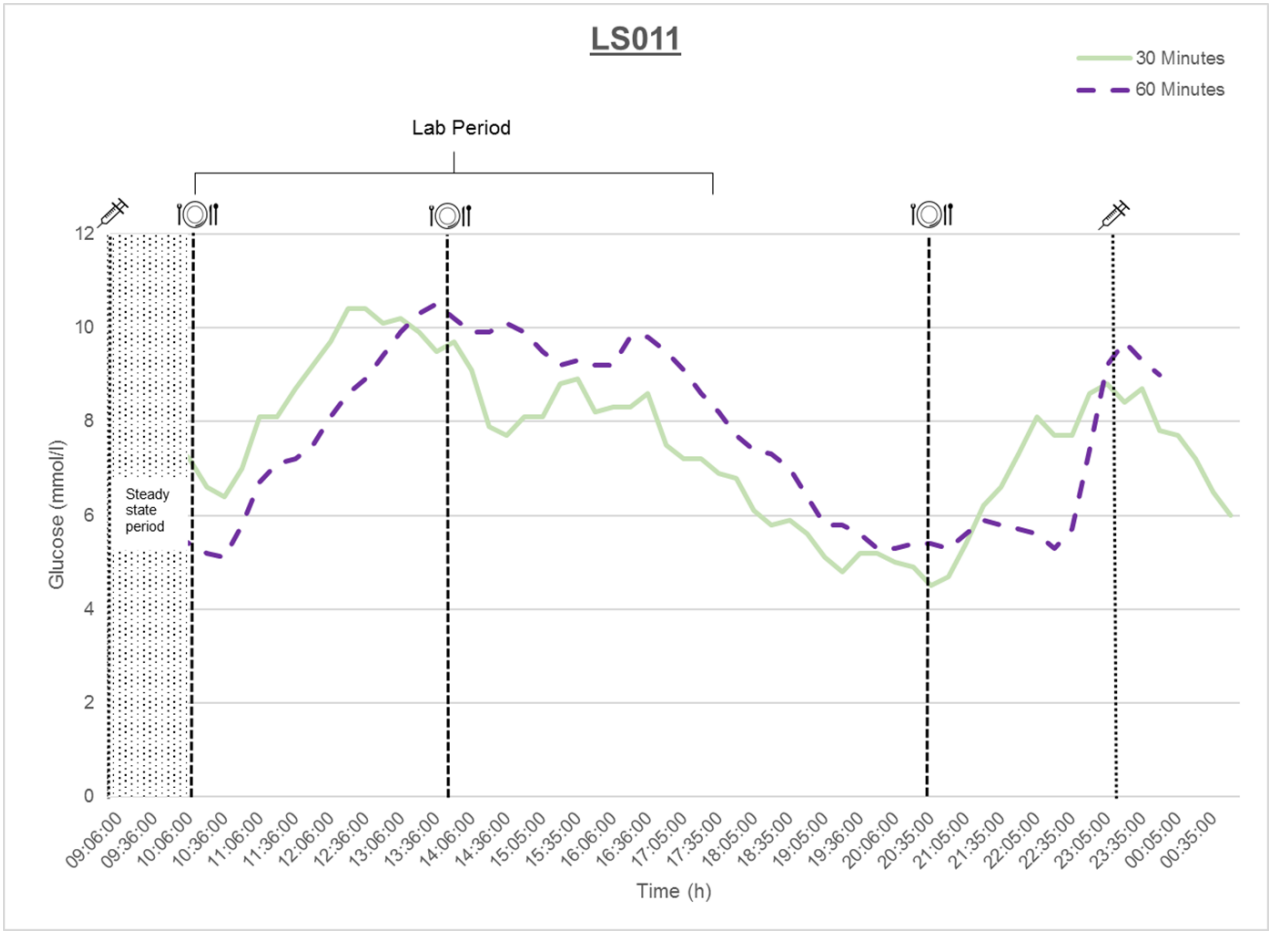
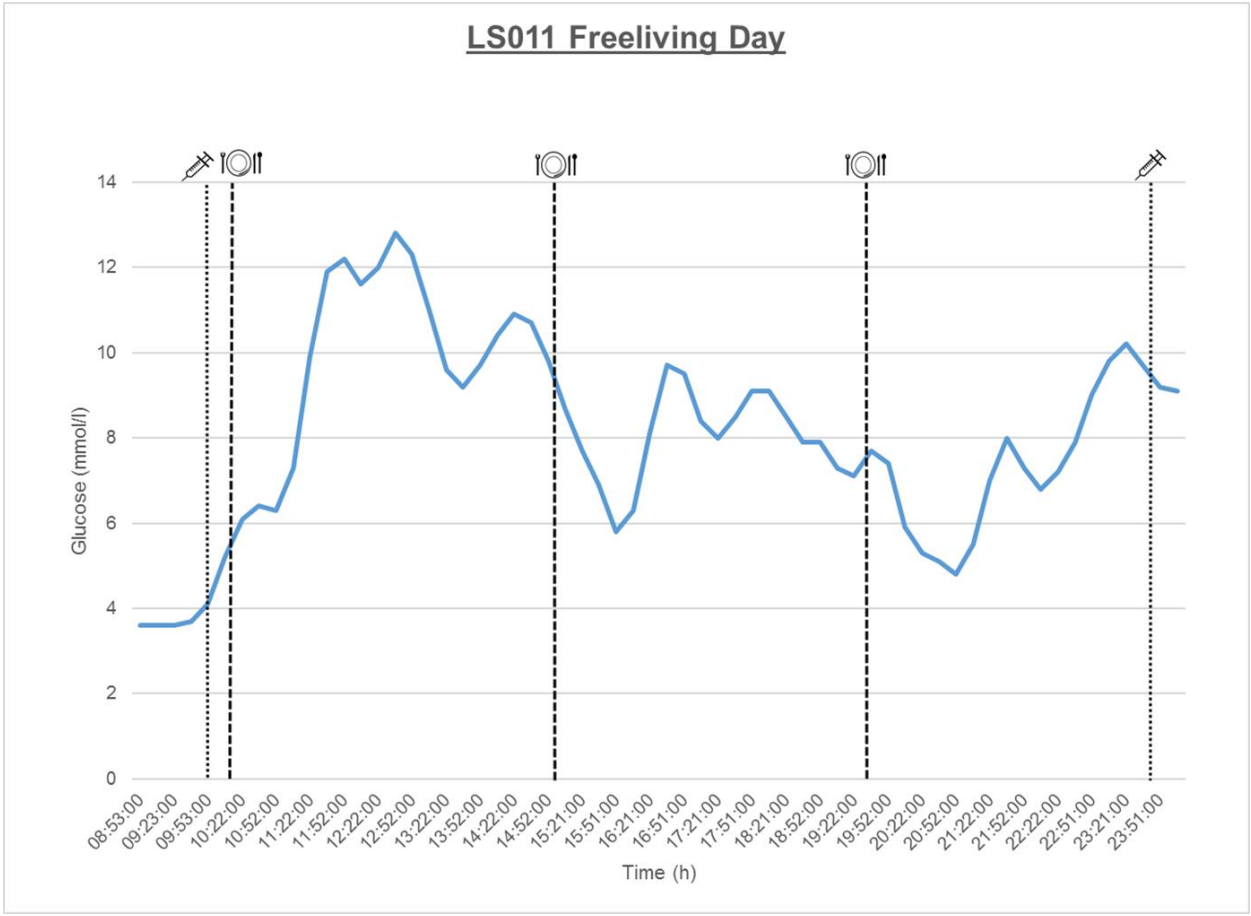


Figure 5.8: Participant D Glucose Profile for Free living Day



3.3 Glucose Response after Lab

For each participant the differences between lab day and free living day glucose profiles in the period following each lab until the participant reported going to bed are discussed below (Table 5.3). Similarly, the differences in activity and sedentary behaviour between days for this period are also discussed (Table 5.3). Following each lab condition, participants were given a standardised meal of their choice and asked to eat this between 6.30pm and 8.30pm, their physical activity and sedentary behaviour were no longer controlled. As participants reported going to sleep at varying times, sedentary time will be reported as a proportion of time rather than in hours.

3.3.1 Participant A

Participant A spent less time sitting (73.54% and 68.31%) and more time stepping (37.8minutes and 38.4minutes) after both lab conditions compared to the same time period during the free living day, where they spent 79.86% of their time sitting and just 23.4 minutes stepping (Table 5.3). Average sit to stand transitions per hour for this duration were 3.71 for the 60-minute condition, 3.29 for the 30-minute condition and 3.14 for the free living day.

Participant A's mean glucose for the period between the lab finishing and bedtime was 5.16mmol/l on the 60-minute protocol day and 5.54mmol/l on the 30-minute protocol day. For the same time during a free living day mean glucose was 5.21mmol/l (Table 5.3). Mean glucose for all three conditions was around 1mmol/l lower post lab than during the lab period. Participant A did not report the timing of dinner for the lab conditions so using the food diary for other days, the average time of dinner was calculated as 6.30pm. For both lab conditions glucose remained stable until the participant ate dinner where it began to rise to a peak, peaking higher following the 30-minute protocol than in the 60-minute protocol (Figure 5.1). The decline in glucose following this peak was more gradual in the 60-minute protocol. Standard deviation for the 60 and 30-minute conditions was 0.76mmol/l and

1.20mmol/l respectively (Table 5.3). The post lab period glucose profile for the free living day was very similar to that of the lab condition days where it was stable until dinner and then increased by around 2mmol/l before a gradual decline to pre-dinner glucose level prior to bed (Figure 5.2). Variability was lowest on the free living day with a standard deviation of 0.67mmol/l. Participant A did not provide any information regarding the timing of Metformin on any of the days reported.

3.3.2 Participant B

Participant B spent 74.15% of their time sedentary following the 60-minute lab and broke their sitting on average 3.43 times per hour. 67.45% of their time sedentary after the 30-minute lab and they broke their sitting an average of 4 times per hour (Table 5.3). Following both conditions, they spent 28.2minutes walking. On the free living day, Participant B accumulated 19.2minutes of stepping and was sedentary for 77.88% of the time, breaking their sedentary time on average 1.88 times per hour.

Mean glucose for the period between the lab finishing and bedtime for Participant B was 5.65mmol/l following the 60-minute lab and 5.91 following the 30-minute lab. On the free living day, mean glucose was 5.90mmol/l. This is around 1mmol/l lower than the mean glucose for the lab period for all three days. Following the lab period, glucose was stable with the 30-minute glucose slightly higher than the 60-minute glucose, until dinner where glucose sharply increased by around 2mmol/l followed by a sharp decrease in both conditions before levelling off (Figure 5.3). Standard deviation for the 60-minute lab was 1.10mmol/l and 0.90mmol/l following the 30-minute lab. This was similar to the profile for the same time period of the free living day, however the post-dinner spike was not as high and the decrease was more gradual (Figure 5.4). Standard deviation during this time was 0.44mmol/l.

3.3.3 Participant C

Participant C spent 64.4% of their evening sedentary, 30-minutes stepping and mean sit to stand transition per hour was 3.86 following the 60-minute lab. After the 15-minute lab, the participant spent 36.6minutes stepping, 69.44% of their time sedentary and broke their sedentariness on average, 3.14 times per hour. During this time on the free living day, the participant was sedentary 81.86% of the time, spent 15 minutes stepping and broke sedentariness 2.57 times per hour.

Glucose levelled off following both lab conditions for Participant C until dinner where there was a steep increase, particularly following the 15-minute protocol where it increased by almost 5mmol/l in the hour following dinner. Participant C reported taking Metformin at 7.20pm, just prior to the post-dinner glucose peak. Within an hour of taking Metformin and two hours of having dinner, glucose began to sharply decrease again prior to bedtime for both conditions, however there was a slight increase in the 60-minute glucose in the hour before Participant C reported going to bed. Although the profile appears similar in the free living day glucose, the rise in glucose is sharp but does not peak as high following dinner and glucose is more variable following this peak and does not return to pre-dinner levels before bed. Participant C did not report what time Metformin was taken during the free living day. Mean glucose for this period for the 60-minute condition was 5.55mmol/l, 6mmol/l for the 15 minute condition and 5.56mmol/l for the free living day. This is between 0.5 and 1mmol/l lower in all conditions than the lab period. Glucose variability was higher during this period following the 15-minute lab with a standard deviation of 2.39mmol/l compared to 1.83mmol/l and 1.02mmol/l following the 60-minute lab and on the free living day respectively.

3.3.4 Participant D

Participant D spent 65.21% of their time after the 60-minute lab sedentary, 43.2 minutes stepping and broke their sitting an average of 1.57

times per hour. After the 30-minute lab, the participant spent 94% of this time sedentary, mean sit to stand transitions per hour was 1.38 and they spent 31.8 minutes stepping (Table 5.4). On the free living day, 99.33% of this time was spent sedentary and just 13.2minutes was spent walking. Mean sit to stand transitions per hour for this time was 2.43.

Following the unusual glucose profile during the lab period, glucose continued to drop after the lab period finished for both conditions, until dinner. Following dinner, the 60-minute glucose remained steady for around two hours before rising sharply to a peak where Participant D took their Metformin and glucose immediately begins to drop prior to bedtime (Figure 5.7). The response to dinner in the 30-minute glucose is quite different, however, as it immediately rises following dinner before levelling off and then decreasing following medication before bed (Figure 5.7). The glucose profile on the free living day is different again, being more variable than the two lab day profiles. Glucose drops slightly before dinner and then continues to drop further until around one hour after dinner where it rises until just before reported medication and bedtime; however, this rise is not steady with glucose rising and dropping slightly before rising again.

Mean glucose for this time was 6.53mmol/l after the 60-minute lab, 6.69 following the 30-minute lab and 7.75mmol/l for this time period on the free living day. Glucose variability was similar for all three conditions, being 1.32mmol/l for the 60minute lab, 1.46mmol/l for the 30-minute lab and 1.44mmol/l for the free living day.

Table 5.3: Post Lab Activity and Glucose

		Activity				Glucose (mmol/l)			
Participant	Day	Time Sedentary (h)	Sedentary Proportion (%)	Time Stepping (mins)	Mean Sit to Stand Transitions/ Hour	Mean	SD	Min	Max
A	60 Minute Lab	4.78	73.54	37.8	3.71	5.16	0.76	4.10	6.20
	30 Minute Lab	4.44	68.31	38.4	3.29	5.54	1.20	4.10	6.20
	Free living Day	5.59	79.86	23.4	3.14	5.21	0.67	4.40	6.40
B	60 Minute Lab	4.82	74.15	28.2	3.43	5.65	1.10	4.60	8.40
	30 Minute Lab	4.89	67.45	28.2	4	5.91	0.90	4.90	8.10
	Free living Day	6.23	77.88	19.2	1.88	5.90	0.44	5.00	6.60
C	60 Minute Lab	4.19	64.4	30	3.86	5.55	1.83	3.30	9.00
	15 Minute Lab	4.34	69.44	36.6	3.14	6.00	2.39	3.30	10.50
	Free living Day	5.73	81.86	15	2.57	5.56	1.02	3.90	6.80

	60 Minute Lab	3.75	65.21	43.2	1.57	6.53	1.32	4.50	8.80
D	30 Minute Lab	6.35	94	31.8	1.38	6.69	1.46	5.30	9.70
	Free living Day	5.96	99.33	13.2	2.43	7.75	1.44	4.80	10.20

4. Discussion

The aim of this study was to use a series of n-of-1 studies to examine the individual glucose response in relation to sedentary time and breaks in sedentary behaviour in a controlled setting, compared to a free living setting. Two periods of observation were identified; the eight-hour intervention period where the participant was in the lab, and the period of time post intervention until the self-reported bedtime. Data from a free living day before the intervention period was used, in addition to the data from the two lab days, to allow comparisons to be drawn between the controlled behaviour and the free living behaviour.

One of the interesting findings from this study surrounds the patterns of sedentary behaviour rather than the glycaemic response to different patterns of sedentary behaviour. Other than participant C during the 15-minute intervention, the intervention protocols made the participants spend more of their time sedentary and break their sedentary behaviour less frequently, during the eight-hour lab period. Although the 15-minute lab condition did not make Participant C more sedentary, it did not make them noticeably less sedentary either. In the post lab period, participants spent less of their time sedentary and broke their sedentary behaviour more frequently following the intervention period. This suggests participants were compensating their behaviour in the post-lab period due to being made more sedentary during the lab. This is similar, to findings of a study by Mansoubi, Pearson, Biddle and Clemes (2016), which examined the impact of using sit-to-stand workstations in 40 office workers. Although during working hours, time spent sitting significantly decreased (75±13% versus 52±16 - 56±13%) and standing and light physical activity significantly increased (standing: 19±12% versus 32±12 - 37±15%, light physical activity: 14±4% versus 16±5%), the proportion of time spent sitting significantly increased (60±11% versus 66±12 - 68±12%) and light physical activity significantly decreased (21±5% versus 19±5%) during post working hours. Although the results from these two studies report findings in an opposite direction, it suggests that future interventions should focus on behaviour across the full day. Generally

sedentary proportion and mean hourly sedentary breaks remained the same or similar between the two periods on free living days. Suggesting participants were compensating their behaviour in the evening following the interventions and behaviour remained the same during the free living day as they were not restricted by the intervention protocols. This is something which would not have been identified had just the differences between lab conditions been examined. This questions how well previous intervention studies which have used a controlled lab setting with manipulation of sedentary behaviour represent normal behaviour in people with Type 2 diabetes and again highlights the importance of looking at changes in patterns across the day after an intervention.

The glycaemic response to the differing patterns of sedentary behaviour varied between participants. Interestingly, Participants A and B had the unusual relationship between sedentary behaviour and glucose in Chapter 4 where the increased sedentary proportion was associated with increased mean glucose, differing from the current study.

Participants A and B had similar glucose and similar glucose responses to both food and breaks in sedentary behaviour. Glucose was lower and less variable the less sedentary they were, meaning both mean glucose and glucose variability were lowest on the free living day. Both participants saw the highest spike in their glucose come after breakfast during all three days, which agrees with the second-meal phenomenon described by Jovanovic, Gerrard and Taylor (2009), which is the effect of a prior meal on decreasing the rise in blood glucose after a subsequent meal, such as the effect of breakfast on the rise in glucose after lunch.

Similar to Participants A and B, mean glucose for Participant C was lower as the participant was less sedentary, again at its lowest on the free living day. However, glucose variability increased as sedentary time decreased and frequency in breaks increased, most noticeably during the free living day where SD was 2.30mmol/l. The higher variability during the free living day could be explained by a high peak in glucose following lunch.

Diet content during the free living day was not considered but perhaps could explain this unusually high peak.

The glucose profile of Participant D during the lab period was quite different to the other three participants, with a delayed peak after breakfast on the intervention days and no clear peak following lunch, in fact, glucose decreased following lunch. On the free living day the glucose profile was again different, mean glucose was similar for all days but glucose variability was again higher during the free living day where standard deviation was 2.89mmol/l. Participant D was on the highest dose of metformin and took this prior to breakfast and in the evening during all three conditions, possibly explaining the delayed post-breakfast spike in glucose. Participant D ate breakfast later on the free living day which may go some way to explaining the different profile between breakfast and lunch on this day.

In the post lab period, mean glucose was lower in all participants following all three conditions. This could be explained on the intervention days by the reduction in sedentary behaviour and increased sedentary breaks during time on intervention days but does not explain the reduction on the free living days. The second meal phenomenon may also explain the lowered mean glucose as the response to dinner, which was standardised following the lab days, was lower than that of lunch and dinner (Jovanovic, Gerrard & Taylor, 2009). The second meal phenomenon refers to the fact that glucose usually peaks after the first meal of the day and although it rises after each meal thereafter, the peak is never higher than after the first meal (Jovanovic, Gerrard & Taylor, 2009). Glucose standard deviation was used to measure glucose variability and there was no consistency between or within participants in glucose variability during the post lab period.

It is interesting that similar differences in the patterns of sedentary behaviour were observed between intervention days and the free living days in all participants, but glucose response varies significantly between participants. This suggests that sedentary behaviour patterns may go some way to explain the daily patterns in glucose, but other variables also impact

glucose management in people with Type 2 diabetes. Research by Zeevi et al. (2015), using continuous glucose monitoring, examined the post prandial glucose response in an 800-person cohort and found high interpersonal variability in response to the standardised meals. Although this research was not conducted in people with Type 2 diabetes, it highlights the need for personalised approaches to glucose management in Type 2 diabetes where food intake is shown to have more of an effect on post prandial glucose than non-diabetic individuals (Noecker and Borenstein, 2016). As mentioned, on the intervention days, participants were provided with three standardised meals and a snack. These meals were standardised based on the recommended carbohydrate intake for people with Type 2 diabetes, but the findings by Zeevi et al (2015) and the current study would suggest that standardising across a cohort is not appropriate, but individualised meals standardised for the intervention period would be more appropriate. This may explain why mean glucose was lower during the free living days for three of the participants compared to the intervention days.

Recent discussion surrounding the concept of subtypes of Type 2 diabetes is also growing. Ahlqvist et al. (2017) propose that there are four distinct subtypes of Type 2 diabetes that can be classified using an individual's characteristics, such as BMI and age at diabetes diagnosis, and diabetes complications. This further emphasises the need for an individualised approach to Type 2 diabetes management, particularly if the response to medication, diet and/or activity may vary depending on the subtype people have and could explain the difference in glucose response to similar patterns in sedentary behaviour both between the participants and also within the participants in this study. Additionally, van Ommen et al. (2018) suggest a personalised systems approach is necessary in the management of Type 2 diabetes and focusing on a single dimension of Type 2 diabetes, such as diet or sedentary behaviour, is not enough for long term behaviour change. A systems approach would include all relevant aspects of management such as: diagnosis, diet, physical activity, medication, motication, stress management and engagement in mHealth.

5. Limitations

The study discussed in this Chapter has some limitations. Firstly, participants took part in two of a possible three lab conditions, meaning that not all participants completed the same conditions, making it difficult to compare results. In this instance, an N-of-1 approach was used to understand the relationship between sedentary breaks and glucose at an individual level and the aim was not to compare participants with each other (McDonald et al., 2017). Future studies of this nature could consider extending the participation period to include time for three conditions with a five-day washout. This was considered for the current study, however extending participation beyond 15 days would have involved changing devices as the activPAL and FreeStyle Libre sensor can only record for up to 14 days at a time and it was decided that extending participation to include all three conditions would place too much burden on the participant. Second, usual glucose control was not included as inclusion or exclusion criteria for potential participants. It is possible that those with poorer glucose control and higher insulin resistence could see greater benefits of regular light-intensity walking breaks in sedentary behaviour (Dempsey et al., 2018). Third, meals during lab days were standardised across the cohort and were not adjusted for daily energy requirements and no consideration was made to the current dietry intake for each participant. Future studies should standardise meals based on participant weight and daily energy requirements or based on their usual daily intake. Finally, during this study participants were asked to provide information surrounding their food intake and timing for the duration of their participation. Only the meal times were used observationally in this Chapter. Similarly, the impact of dose and timing of diabetes related medication was not examined in depth. Both medication and food will have an impact on glucose, particularly in people with Type 2 diabetes. Future research output will include the data collected in the food and medication diaries to account for this.

6. Conclusions

This study has investigated the individual glycaemic response in four people with Type 2 diabetes to breaking up prolonged sedentary behaviour in a controlled setting. The findings from this study support the need for an individualised and multidimensional approach to Type 2 diabetes management and for more research to explore the individualised response to sedentary behaviour patterns in more detail. The use of mobile-based technology to monitor behaviours such as, activity, diet and medication and provide feedback on the impact these variables are having on an individual's glucose would enable to the individual to tailor their own behaviour and gain some control over their diabetes management. Future research should focus on exploring the opportunity to use mobile based technology to support individual behaviour change including the feasibility, acceptability and effectiveness of taking this approach.

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Chapter 6: Exploring the experience of, and attitudes towards, mobile technology to support active lifestyles in adults with Type 2 diabetes

1.0 Preface

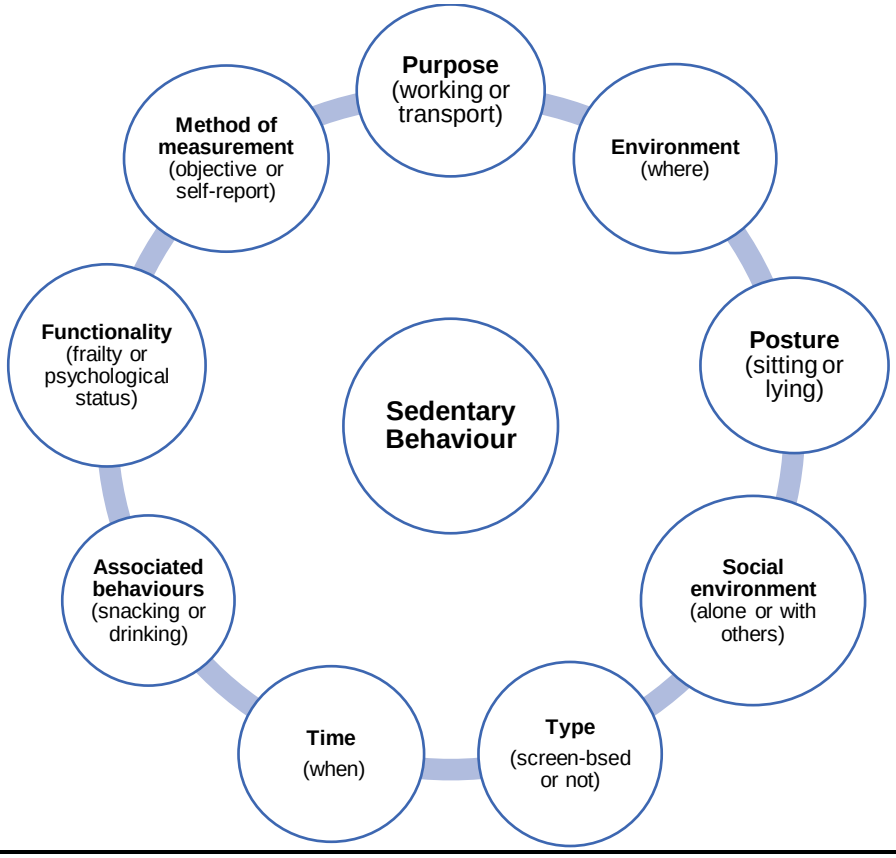
The Systematic and Integrated literature review (Chapter 2) identified a lack of research investigating the acceptability and feasibility of using mobile technology to promote active lifestyles in those with Type 2 diabetes. Other chapters in this thesis (Chapter 4 and Chapter 5) have examined the impact of physical activity and regular breaks in sedentary behaviour on glucose and have highlighted the importance of exploring the individual response to breaking sedentary behaviour. Technology offers the opportunity to develop and conduct lifestyle interventions on a large scale that can be personalised to individual participants. However, there is little understanding of how people feel about being more active and sitting less and how this may affect their glucose management, in addition to how they feel about using mobile technology to help them do so. In order to develop successful interventions, it is important to understand the effectiveness of behaviour change but equally, if not more importantly, to understand the feelings and attitudes of those who the intervention will be targeting. This chapter explores the experiences of, and attitudes towards, using mobile technology to support active lifestyles in people with Type 2 diabetes.

1. Introduction

The American Diabetes Association recommends an active lifestyle as part of good diabetes management (ADA, 2018). Although physical activity has been recommended in the prevention and treatment of Type 2 diabetes, sedentary behaviour has more become a target for behaviour change as a means of managing Type 2 diabetes more recently (ADA, 2018; Henson, Dunstan, Davies & Yates, 2016). It is recognised that people with Type 2 diabetes do not achieve the recommended levels of physical activity and are sitting too much without breaks (Van der Berg et al., 2016). A study examining the physical activity and sedentary behaviour levels in those with Type 2 diabetes found that they were spending over 10 hours per day or 64.5% of their time sedentary and as little as 10.7% of their day stepping (Van der Berg et al., 2016). The findings from Chapter 4 of this thesis, where participants' physical activity and sedentary behaviour was objectively measured in a free living context, show people with Type 2 diabetes were spending little over 10% (1.6hours) of their waking day moving, the rest of their time was spent sedentary or standing.

The Sedentary Behaviour International Taxonomy was developed to establish a classification of sedentary behaviour in order to improve understanding of context of behaviours (Chastin, Schwarz & Skelton, 2013). There was a consensus that there are nine categories of sedentary behaviour, they are illustrated as developed by Chastin, Shwarz & Skelton (2013) in Figure 6.1. The development of this taxonomy demonstrates the importance of understanding why someone was sedentary, where they were and who they were with if the behaviour is to be successfully changed (Chastin, Schwarz & Skelton, 2013). Most of these dimensions could also be related to, and considered for, physical activity behaviour.

Figure 6.1: Sedentary Behaviour Taxonomy



There are now a number of quantitative studies that have linked physical activity and sedentary behaviour with glucose management in overweight adults and adults with Type 2 diabetes (e.g. Dempsey et al., 2016; Dempsey et al., 2017; Dunstan et al., 2012; Duvivier et al., 2017). These studies have reported findings of sitting less, breaking up prolonged sitting and increasing physical activity all have positive effects on glucose in a lab setting (Dempsey et al., 2016; Dempsey et al., 2016b; Dunstan et al., 2012; Duvivier et al., 2017). Most intervention studies, however, have focused on increasing levels of physical activity in people with Type 2 diabetes with few achieving long term behaviour change (Avery et al., 2012; Thomas et al., 2006; Umpierre et al., 2011). Additionally, the individual nature of the relationship between sedentary behaviour, physical activity and glucose both between and within people with Type 2 diabetes that emerged from the quantitative studies in this thesis (Chapter 4 and Chapter 5) suggests there is more about this relationship that needs to be understood

and explored, particularly if an effective and sustainable active living intervention in this population is to be developed.

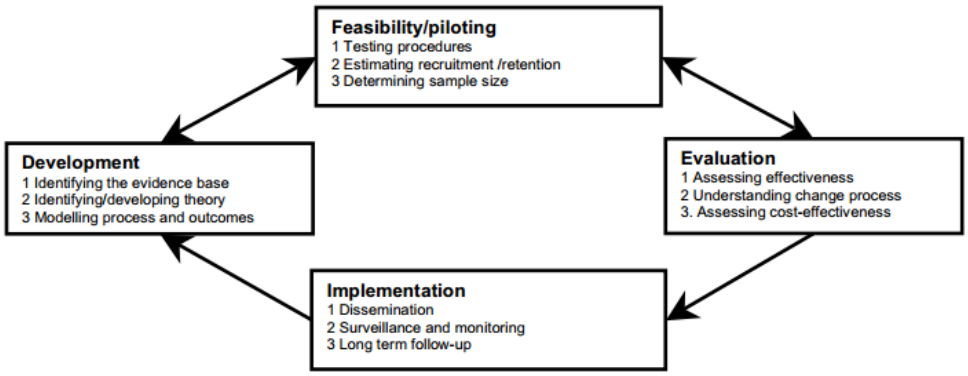
Emerging mobile-based technologies have recently been presented as a possible cost-effective means of delivering an intervention of this type and are being used more frequently as technology progresses (McMillan, Kirk, Hewitt & MacRury, 2016). These technologies can be used to facilitate self-management in those with chronic illness, such as Type 2 diabetes, and can be used to deliver behaviour interventions that promote habitual self-monitoring (Chomutare, Arsand & Hartvigsen, 2011; Heinrich, Shaper & De Vries, 2010). A recent integrated literature review examining the use of mobile-based technologies to promote an active lifestyle in those with Type 2 diabetes (Chapter 2) found that the acceptability and feasibility of using mobile-based technology to promote sustained behaviour change has not been examined (McMillan et al., 2016). These elements are crucial if long term adherence and motivation is going to be achieved amongst users (Bardus, Blake, Lloyd & Suggs, 2014; McMillan et al., 2016). To develop a successful intervention, it is important to understand the views of potential participants and have a patient-centred approach to development (Nundy & Oswald, 2014).

The sedentary behaviour taxonomy highlights the need to understand the context surrounding sedentary behaviour in order to best understand how to change the behaviour (Chastin, Shwarz & Skelton, 2013). Nundy and Oswald (2014) also highlight the importance of considering the experience and attitudes of a participant when trying to change their behaviour. A qualitative approach would allow for a deeper understanding of context of physical activity and sedentary behaviour and the individual experiences and attitudes towards active lifestyles. There are, however, few qualitative studies that have examined the experience and context of these behaviours in people with Type 2 diabetes.

It is intended that this thesis will provide the evidence base for future development of an intervention to promote active living in people with Type 2 diabetes using mobile technology. Development is one of the key stages

identified by the Medical Research Council in their framework for the development, evaluation and implementation of health interventions (Craig, Dieppe, MacIntyre, Michie, Nazareth & Petticrew, 2008). The MRC framework as described by Craig et al (2008) is illustrated in Figure 6.2. This study, and more broadly this thesis, is identifying and building an evidence base and theory for a future intervention. This research fits into the development stage of the MRC framework and it is hoped the findings will lead to the development of an intervention which utilises mobile technology to support active lifestyles for adults with Type 2 diabetes.

Figure 6.2: MRC Framework



The National Institutes for Health (NIH) (2011) has advocated the use of a mixed-methods approach, to allow the problem to be understood more comprehensively than could have been by using only qualitative or quantitative. It is suggested by the NIH (2018) that mixed-methods is most suitable for research where a solely quantitative or qualitative approach is inadequate to provide a complete understanding of the problem. The previous studies in this thesis have explored the relationship between sedentary behaviour, physical activity and glucose in both a free living and a controlled lab environment, using quantitative methods, but have no understanding of the context surrounding these behaviours or relationships. Therefore, the inclusion of this chapter, using a qualitative approach will provide more depth of understanding to the knowledge gained in Chapter 4

and Chapter 5 of this thesis and will further add to the evidence base for the development of an effective and sustainable intervention in the future.

The aim of this study was to explore the experience of, and attitudes towards, mobile based technology to support active lifestyles in adults with Type 2 diabetes in order to address the following research questions:

a) What are the experiences and attitudes of people with Type 2 diabetes towards using active living as a way of achieving good glucose management?
b) What are the experiences and attitudes of people with Type 2 diabetes towards using mobile technology to promote active living and good glucose management?

2. Methods

2.1 Participants

Participants in this study were recruited whilst participating in the previously discussed free living (Chapter 4) and lab (Chapter 5) studies, where they were recruited through social media or from Diabetes support groups in the Glasgow area. Participants were adults over 18 years old with diet and/or medication (not insulin) controlled Type 2 diabetes. Participants were excluded if they were receiving insulin therapy.

2.2 Ethics

Ethical approval was obtained from the University of Strathclyde. Participants were informed that participation was voluntary, and they could withdraw, without consequence, at any time. Participants were informed that collected data would be kept anonymous, confidential and would be destroyed after a five-year period. This process is in line with the Data Protection Act (1998). Participants provided informed, written consent prior to taking part in this study.

2.3 Interviews

To allow for open dialogue between the participant and the researcher whilst maintaining a focus, it was decided that semi-structured interviews would be the method of data collection used for this study. The interview topic guide as developed based on previous knowledge of research findings from Chapter 1 of this thesis in the area of active living promotion using mobile-based technology in people with Type 2 diabetes. The interview questions were discussed and refined by the research team. The topic guide (Appendix F) was piloted prior to study initiation to ensure any issues were identified and rectified prior to the study.

The interviews were conducted between January 2016 and March 2017, after participants had taken part in the free living study discussed in Chapter 4 and/or the lab-based study discussed in Chapter 5. The interview was conducted in a quiet location, convenient for the participant. The average duration of the interview was 23 minutes.

2.4 Data Management and Analysis

The interviews were audio recorded using a digital Dictaphone and interviews were transcribed verbatim. All identifiable information was removed from the transcripts and each participant was provided with a unique study code in order to anonymise the data. Interview transcripts were read and re-read before being coded into themes and then analysed for any emerging patterns within the themes. Interview transcripts were coded and analysed using NVivo qualitative software.

The data were analysed using a directed content analysis approach discussed by Hsieh and Shannon (2005), which has become a popular method of qualitative analysis in health research, particularly since the 1990s (Hsieh & Shannon, 2005). Content analysis is a flexible and pragmatic way to extend knowledge in a particular area of research, and focuses on the contextual meaning of the data, following a systematic process of coding (Elo & Kyngas, 2008). The flexible nature of content analysis tolerates the use of a combination of deductive and inductive creation of themes and patterns

from the data (El & Kyngas, 2008; Hsieh & Shannon, 2005). Deductive analysis was used to create the key themes and the second order themes. The key themes were derived from prior findings from this thesis and the research questions for this study, meaning codes were defined both prior to and during the analysis process (Hsieh & Shannon, 2005). Open-ended questions were used followed by more probing questions to further explore participants' experiences of, and attitudes towards the three key themes, physical activity, sedentary behaviour and using technology. Data was coded as an experience or an attitude within one of the three key themes. Inductive analysis was used identify first order themes that were not already accounted for (Hsieh & Shannon, 2005).

2.5 Trustworthiness

Several methods were used to ensure quality and trustworthiness of the analysis (Lincoln and Guba, 1985). In the model of trustworthiness, Lincoln and Guba (1985) identify four components of trustworthiness: 1) Credibility, 2) Transferability, 3) Dependability and 4) Confirmability. Credibility was enhanced as each interview transcript was reviewed individually and checked for similarities between and within participants. Two interview transcripts were coded and then the key themes and first and second order themes were cross-checked by two researchers (AK, AH) as a measure of inter-rater reliability. Researchers met to discuss the coding language used and to refine the themes and sub-themes. Where disagreements occurred, discussions continued between researchers until full inter-rater agreement was reached. A coding framework was agreed upon and the remaining 8 interviews were coded using this framework. Additionally, quotations from the transcripts were used throughout the results to demonstrate the findings did come from the data collected. A detailed description of the methods and participant characteristics is provided to enable to methods to be transferred to another participant group. To enhance confirmability, the transcripts were referred back to at each stage of the analysis process to ensure the coding framework developed was appropriate.

3. Results

A total of 10 adults with Type 2 diabetes participated in the semi-structured interviews. Descriptive statistics for the participants are displayed in Table 6.1.

Table 6.1: Participant Characteristics

n = 10	Mean (SD)	*n* (%)
Age (Years)	60.7 (10.9)	
BMI (kg/m^2)	30.8 (4.9)	
Gender (Male)		5(50)
Waist Circumference (cm)	102.2 (13.3)	
Duration since diagnosis (Years)	6.4 (4.7)	
Smoking status (Non-smoker)		9 (90)
Retirement status (Retired)		6 (60)

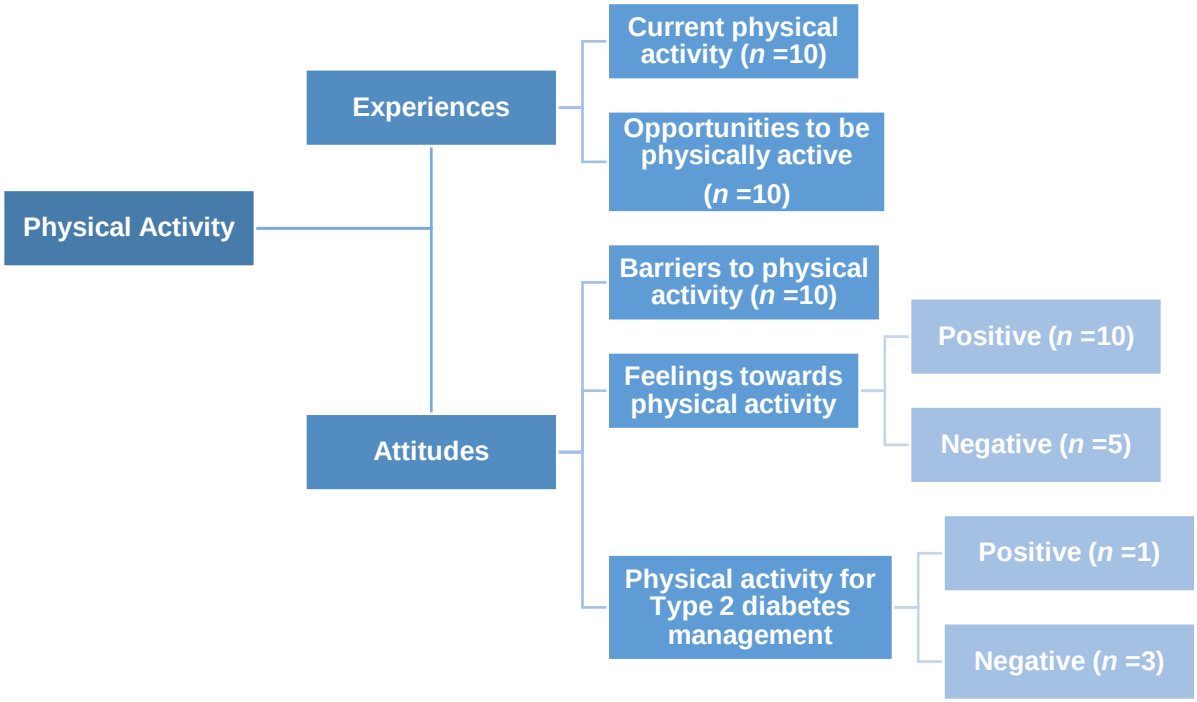
Note. BMI = Body Mass Index, SD = Standard deviation

Deductive and inductive content analysis revealed 14 first order themes, six second order themes and three key themes. The key themes were: 1) Physical activity, 2) Sedentary behaviour and 3) Using technology. Within the three key themes, data were categorised into two second order themes: a) Experiences and b) Attitudes.

Theme 1. Physical Activity

This theme explored participants' experiences of physical activity and opportunities to be physically active. Additionally, attitudes towards physical activity, physical activity for Type 2 diabetes management and barriers towards being physically active. Figure 6.3 illustrates the first and second order themes identified within the physical activity theme and provides context as to how many sources contributed to each.

Figure 6.3: Mind-Map Illustrating the Physical Activity Theme



a) Experiences

"Well walking, and I walk around the house, I do things, I do an awful lot of gardening…I try to walk once a day, sometimes more depending on the weather, but even if its bad weather I still go out"

(Retired female, 75 years old)

Current physical activity

When asked, participants had a mixed response to how physically active they felt they were. Some participants were very positive and described a regular routine of walking around the estate every night or walking everywhere during the day, rather than taking the car.

Participants were aware of how much activity they were recommended to be doing and often said they felt they were not doing enough. Most of those who showed a negative attitude towards their current level of activity acknowledged they felt guilty about it, they knew what they should be doing, and they had the means to be regularly active, but still struggled with it.

A variety of different ways in which they were physically active were described, including both structured and unstructured activities. Walking was the most common form of physical activity mentioned, whether it was a planned walk every evening around the estate and going to the beach with friends at the weekend or active commuting to work or the train station every day. Others described how they would rather walk to the post box and local shops than take their car, which was less regular or structured. Gardening was also frequently mentioned alongside other household tasks such as cooking, cleaning and DIY as ways in which they were active. Some of those who were more positive about their activity explained how they "never sit down" and were "constantly on the move", these were the participants who described activity that would be considered unstructured and part of everyday life. Those who described feeling as though they were not currently active enough described more structured activities, such as sports or attending the gym, as the types of activity that they do.

While some described themselves as wanting to be more active but being constrained by their work environment, others explained that they felt they were more active during the day than they were in the evening. This could be the difference between those who were working and those participants who were retired.

Opportunities to be physically active

The opportunity to be physically active was discussed and there were opportunities for the majority of people to be active. Active travel, such as walking or cycling to the train station, was consistently mentioned as a way of being active. However, the lack of consistency in trains or simply running late were reasons cited for having the intentions of active travelling but ultimately taking the car instead. Other opportunities included having access to a gym and gym classes or regularly playing sports, such as golf, with peers. There was a positive attitude around the opportunity and the intention was there,

but this was always met with a barrier, such as the exercise being cancelled or poor weather.

Most participants discussed the importance of a routine and making physical activity a habit, and how this makes it less likely that anything will become a barrier to this behaviour. Retirement status was often described as a significant factor in the opportunity to be physically active. Some felt that since retirement and losing the routine of working, their opportunity to be active had diminished. Others however, felt they were more active throughout the day now they were retired as they were not restricted to sitting at a desk most of the time.

Making active travel or playing sport with friends a habit was very important. If there is a routine of walking to the train every morning or playing badminton every week then people said they are less likely to let anything become a barrier to this.

Retirement was mentioned a lot and seem to be a significant factor in the opportunity for physical activity. Some felt that since retiring and losing the routine of working, their opportunity to be active has diminished, this contradicts what those who were retired said about often feeling they were more active throughout the day because they were not restricted to sitting at a desk most of the time. Some participants felt that they have more time and ability to be active now they are retired, but some felt that their change in routine means that they are less active as they have less to do.

b) Attitudes

"I like to walk. A walk would be a walk along the mile and a half to the garden centre and back again. I'd leave the car, I prefer to walk than drive"

(Retired female, 66 years old)

Attitudes towards physical activity

The majority of participants were aware of the importance of being physically active and had a positive attitude towards physical activity and being more physically active. Feeling better and "keeping your body going"

were often referred to as positive outcomes and motivations for being active. Negative effects of being inactive, such as feeling sluggish and weight gain, were also frequently mentioned as motivations for increasing activity levels. Some participants discussed how, although they were currently physically active, they could increase their level of activity.

For those who had a negative attitude towards physical activity, they either felt their current levels of physical activity were not enough, but had no motivation to change this, or they were not aware of what their current activity levels were. Those who described how they were already quite active however, said they would struggle to increase their physical activity as it would be an unrealistic goal. Participants often discussed physical activity in relation to walking, rather than any day to day activity that they may incur, and they were negatively associating walking with exercise.

Feelings towards physical activity as an aid to Type 2 diabetes management were mostly positive and it was felt if it would help with their management then increasing physical activity would be acceptable. One participant felt being physically active was not important for their glucose control but was important for other reasons, such as retaining muscle tone, for example.

Barriers towards physical activity

There were several barriers towards participating in regular physical activity and opportunities towards improving current activity levels. The most significant barrier towards being physically active was the poor weather. Needing to be in the house to look after a disabled spouse, not having a routine after retirement and simply not having the motivation to be active were also expressed as barriers towards physical activity.

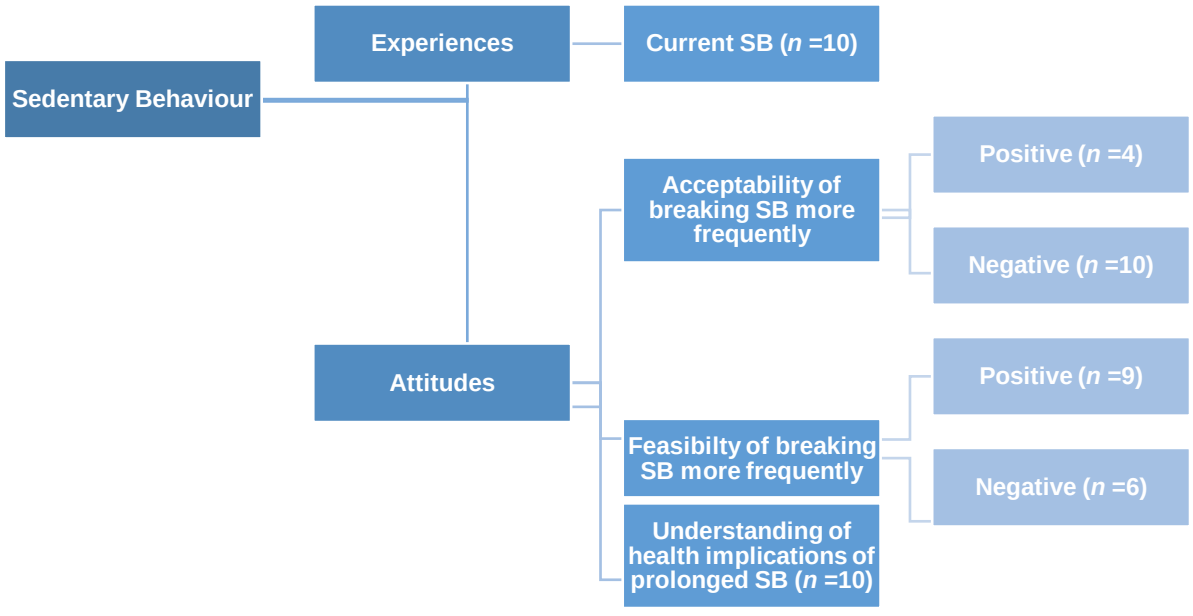
The most frequently mentioned reason for not increasing physical activity was the feeling that they did not want to just be doing activity for the sake of doing it, it would need have a purpose or value, for example, they did

not understand the point or benefit of going for a walk if they were not going anywhere specifically.

Theme 2. Sedentary Behaviour

This theme explores the participants' current experiences with sedentary behaviour and their attitude towards sedentary behaviour and breaking up their sedentary behaviour as a possible means of managing their Type 2 diabetes. First order themes identified include: current levels of sedentary behaviour, understanding of the health implications of prolonged sedentary behaviour and the acceptability and feasibility of breaking up sedentary behaviour more frequently. Figure 6.4 illustrates the sub-themes identified within the sedentary behaviour theme and the number of sources which contributed to each sub-theme.

Figure 6.4: Mind-Map Illustrating the Sedentary Behaviour Theme



a) Experiences

"I sit and watch the television and I'm a great reader as well. I'll sit for a couple of hours at night certainly and through the day for a bit. I don't do DIY or anything like that"

(Retired male, 73 years old)

Current sedentary behaviour

Most participants described their behaviour as very up and down rather than long bouts of sedentary behaviour or physical activity. They may sit for an hour at a time but would very rarely sit longer than an hour without moving. Many said they were more likely to sit longer in the evening than during the day. The majority of sedentary activities described involved screens, such as working at a computer, watching the television or sitting on social media on the computer or a tablet. Other sedentary activities mentioned included reading and socialising with their spouse in the evening.

Some participants found the work environment restrictive and made them less active than when they were not working, however, others felt their prolonged sitting was more likely to be broken at work due to toilet or tea breaks, for example.

b) Attitudes

"Well I would suspect that of course it's feasible, but it would probably take, I mean realistically, it would probably actually mean that I had to remind myself to do it."

(Retired male, 65 years old)

Understanding the health implications of prolonged sedentary behaviour

The most common form of understanding the implications of sitting for a prolonged period of time came from participants' own personal experiences, rather than a knowledge of the guidelines or information provided by their GP or diabetes specialist nurse. Some participants referred

to the negative clinical effects of sedentary behaviour, such as increased risk of cardiovascular problems, weight management and management of blood sugar.

"Ceasing up" and becoming "stiff" were most frequently referred to when participants spoke about the effect sitting had on their health. The majority acknowledged how sitting for a long period of time could cause them achy joints and a sore back and discussed the need to regularly break sitting, go for a walk and stretch to relieve this. Several participants, however, explained that they were aware that sitting was bad for their health, and their diabetes management, but this knowledge was not enough to motivate them to change their current behaviour.

Sitting for long periods of time led some participants to become lethargic and more likely to want to sit and less likely to want to get up and move. Getting in a rut appears to be more impactful on sedentary behaviour than having the knowledge that it was bad for your health. Making an individual aware of the poor health outcomes if they are regularly sitting for long periods of time is not enough to change their behaviour.

A small number of comments referred to already being very active and, on the go, and never sitting long enough for there to be any negative health implications. Overall, it does not appear to be the knowledge of poor health outcomes that encourages people to sit less, but the physiological need to move, for example, feeling that they are becoming stiff and uncomfortable, so they get up and make a cup of tea.

Acceptability of breaking up sedentary behaviour

Some participants had positive attitude towards breaking up sedentary behaviour more regularly and they seemed to think it would fit into their current lifestyle, particularly if it were going to help manage their diabetes. Largely it was felt that if they were told, or reminded, to stand up and move after a prolonged time then they would be happy to do this. Some

participants had a positive attitude towards breaking sitting and felt it was acceptable as they were not regularly sitting for long periods of time currently and sitting for over an hour at a time rarely happened, meaning it would not be necessary to change their current behaviour.

Some participants felt it would fit into their working routine more than their leisure time in the evening, reasons for this included; the structure of working in an office allowed them to have a break and make a coffee or go to the printer. In comparison, they felt it would be more difficult in their spare time as this is when they are likely to be watching a film or spending time with family.

More participants had a negative attitude towards the acceptability of more frequent breaks, of those who had a negative attitude, there was one consistent point made. They felt they already naturally broke their sitting regularly and they did not like the idea of making the behaviour regimented.

Feasibility of breaking up sedentary behaviour

Similar to the acceptability of sitting less, participants were asked if they felt breaking their sedentary behaviour more often would be feasible. Attitudes towards this were more mixed with some participants having a positive attitude and feeling that they could feasibly break their sitting more often and others having a more negative attitude towards this.

The time of year influenced the attitude slightly, with some commenting on the fact that they felt it would be more feasible to sit less in the summer months compared to the winter months, due to the poorer weather and shorter days. The frequency of the breaks was important for some, stating that getting up and moving every 15 minutes was not feasible as they would not get anything done, every 30 minutes appeared to be more feasible for some, whereas the majority felt that moving every 60 minutes could fit into their life.

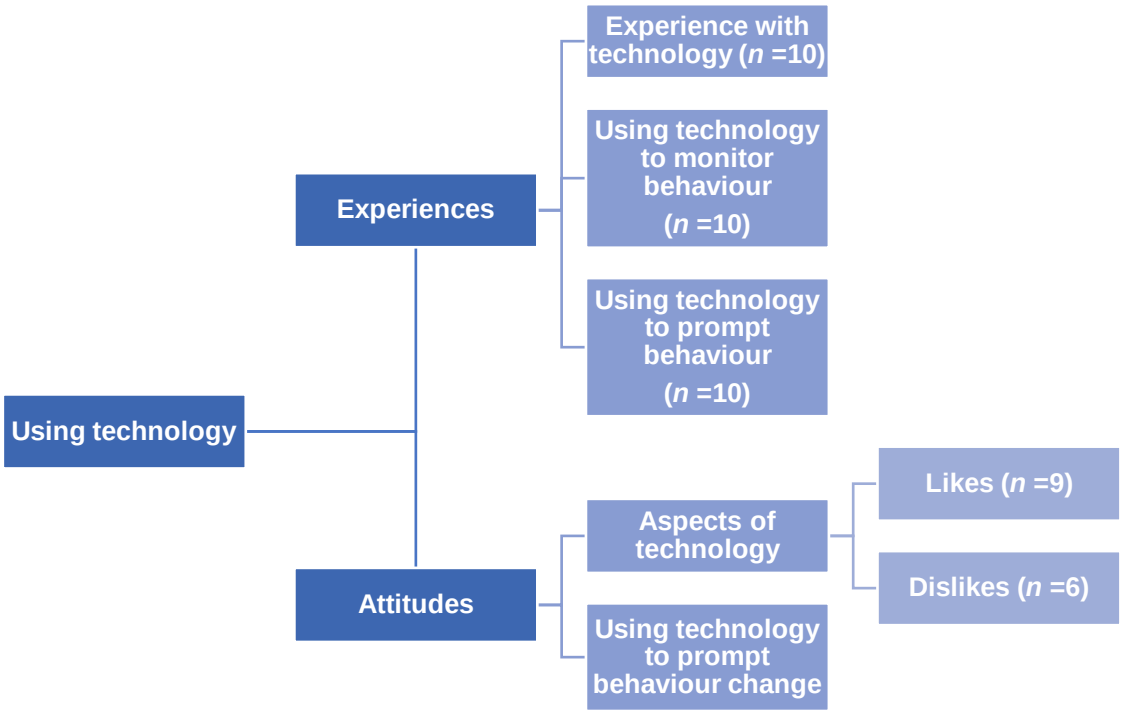
It was mentioned several times that in order to regularly break sitting, some form of prompt or reminder would need to be in place until the behaviour became a habit. Those who were positive about fitting more frequent breaks into their lifestyle either referred to breaks as short and regular, such as making a cup of tea and returning to work or longer, more structured and less regular breaks such as a 20 minute walk a couple of times throughout the day. Most participants were more positive about changing their daytime or working behaviour and less positive about changing their evening behaviour. They felt it would be more difficult in the evening and they would be less willing to sit less, particularly if they were watching a film.

Those participants who felt negatively towards fitting more frequent sedentary breaks into their day generally said they felt they would not be able to as they were already very active and always “up and down” as it was. They felt more breaks would have a negative impact on their productivity at work, particularly if they were to break their sitting as regularly as every 15 minutes. Others felt that to sit less than they currently were they would need to invest in other equipment such as, standing desks or treadmills. Some felt that they would need to be reminded to stand up and move if they were going to change their behaviour and this was something that they did not want.

Theme 3. Using Technology

Participants in this study took part in either the aforementioned free living (Chapter 4) or the lab based (Chapter 5) studies so have experience using the flash continuous glucose monitor, FreeStyle Libre, and the activity monitor, activPAL. They were able to see the summary output files from both of these devices as part of their participation in these studies. Additionally, participants were shown a range of health technologies that are currently available, including apps and wearable devices by the researcher prior to the interview.

Figure 6.5: Mind-Map Illustrating the Using Technology Theme



The participants' current experiences with different forms of technology, the aspects of technology they felt they liked or disliked and their attitudes towards using technology to prompt a change in behaviour are discussed here. Figure 6.5 provides context surrounding the themes identified within theme three and the number of sources contributing to each theme.

a) Experiences

"Just the app on my phone, which I stumbled across rather than somebody pointing it towards me. I didn't find it terribly useful, a little cumbersome. If you didn't have your phone in your pocket then you know, you're getting little gaps in the day"

(Retired male, 54 years old)

Current experience with technology

Experience with technology ranged from minimal use of a desktop computer to check e-mails and book holidays to regularly and confidently using smartphones and tablets. Some participants had experience with technologies designed to promote an active lifestyle. This included apps, such as the inbuilt health apps and others designed to record steps and cycles, improve your running and record your food intake. Other technologies such as interactive games, pedometers and wearable activity trackers were also mentioned.

Using technology to monitor behaviour

Participants described their experience using technology specifically designed to monitor behaviour, including their experience using the FreeStyle Libre and the activPAL as part of the other studies. Most of the participants were very positive about the FreeStyle Libre, mainly due to the instant feedback they were able to get from it. They enjoyed the control the device gave them over their diabetes management and felt it was much more informative than their three or six-monthly check-up with the GP or diabetes specialist nurse. The experience with the activPAL was less positive, mainly due to the fact that they only received any feedback on their activity at the end of their participation, which could have been up to 14 days. It should be noted that the activPAL is designed predominantly as a research tool and not a consumer device, unlike the FreeStyle Libre. The fact that the activPAL was just attached and required no input or attention was a positive to the majority of participants. Similarly, those with experience of wearable activity monitors enjoyed the feedback they could get on the accompanying app and the minimal effort that was required.

The majority felt that in order to see the benefits from monitoring their behaviour, they would need to do it all the time or until their new behaviour became routine or a habit. This was not a problem, but most felt that using a

wearable device for a short period of time would not lead to sustained behaviour change.

Using technology to prompt behaviour change

People had minimal experience with using technology as prompt to get up and move around. There was general experience with using technology to remind them to do something or of an appointment they had but not as a prompt to change their behaviour.

b) Attitudes

"Oh I like them, the diabetes one…It can help you control it. Control is the thing isn't it, if you've already got it. If it helps my diabetes then I'll use it."

(Retired male, 73 years old)

Aspects of technology

The aspect of technology that was consistently mentioned and referred to throughout the interviews was the ability to see what your physical activity or sedentary behaviour profile looked like. The idea of having instant, real time feedback on their behaviour was something that most participants liked about mobile-based technology. Feedback was noted as a real positive, but real time, instant feedback is better. Feedback at the end of the week or after a few days of recording behaviour was something that participants did not like about some of the technology. One of the main reasons given for instant feedback, from several participants, was the control it gave, and it allowed them to adjust their behaviour depending on the feedback they received. This was particularly important when discussing technology in the diabetes management context, participants were very positive about using technology to make them feel like they have more control over their diabetes management. It was also felt that the feedback can be really rewarding, particularly when you achieve a goal.

Being intuitive and easy to use and being able to set reminders were all highlighted as important aspects of mobile-technology. Wearable devices combined with an app were preferable to mobile phone or tablet apps on their own due to participants feeling the apps could be inaccurate, as people do not always have their phone on them.

Negative comments surrounding the technology included the intrusive nature of the technology, demotivating, difficult to use and too many reminders. Some felt that they did not want something recording their behaviour all the time and said that it could sometimes feel like “Big Brother was watching them”. It was also mentioned that sometimes the feedback could be demotivating and make them feel guilty if they were not achieving the goals they or the device had set. If the device or app was too difficult to work or required too much time and effort it was felt that it became more of a distraction, leading to a loss of interest. Devices that automatically record behaviour and require minimal input from the user were much preferred by all participants. Similarly, too many reminders too often become annoying, leading to the user ignoring them.

Using technology to prompt behaviour change

Although there was little experience with it, the majority of participants had a positive attitude towards using an app or a wearable to remind them to get up and move or to check their glucose. It was to be the most important aspect of technology if they were going to sit less and be more active, they would need to be reminded to do so because their habitual behaviour was to sit. The type of prompt liked and disliked was very variable, highlighting the individual nature of technology. Those mentioned included: vibration, flashing light and some sort of alarm or tone.

4. Discussion

The findings compliment and add to those of the previous studies in this thesis and provide further insight into the participants' experiences of, and attitudes towards, physical activity and sedentary behaviour and the use of technology. Participants provided a more detailed understanding as to the contextual surrounding of their behaviour, including their motivations and barriers towards changing their current behaviour and how they felt about using technology to do so.

4.1 Theme 1: Physical Activity

A large proportion of participants felt they were not currently as active as they could be, for a number of different reasons. Although they showed a positive attitude towards physical activity and being physically active, their current experience with physical activity was more mixed. For the most part, it was felt that there was plenty of opportunities to be physically active; however, making regular activity a habit and making the most of the available opportunities seemed to be more difficult. Rhodes, de Buijn and Matheson (2010) explored the role of habit in predicting physical activity using the theory of planned behaviour. Authors reported that those participants with high habit also showed high intention to be physically active and those with low habit had a low intention of being physically active, supporting their notion that habit may be an important aspect of physical activity to consider, and is associated with the level of intention to be physically active. A habit is formed through repeated behaviour over a prolonged period of time (Lally & Gardner, 2013). Lally and Gardner (2013) discuss how habits can be changed when the environmental cues are identified and can be avoided, or processes can be put in place to ensure the response, in this case is making the most of opportunities to be active. The habit is specific to the context of the behaviour making it an important consideration when trying the change or break the habit.

Retirement status appears to have an impact on whether these opportunities are used or not, those who were retired seemed to participate in more unstructured, leisure time physical activity, which is consistent with previous longitudinal research (Barnett, van Sluijs, Ogilvie & Wareham, 2014; Touvier, Bertrais, Cherreire, Vergnaud, Hercberg & Oppert, 2010). Barnett et al. (2014) report a significant (p <0.001) reduction in transport and occupational physical but significant increases in recreational (p <0.02) and household (p <0.002) activity, however, overall activity was reduced in the retired group compared to those who were still working. Touvier et al. (2010) reported increases in leisure time physical activity in those who were retired of 2hours/ week, compared to no change in those who were not retired. There was also an increase in time spent watching television observed, particularly in the retired men (Touvier et al., 2010). Consideration should be made of retirement status when developing future interventions in this population, perhaps more focus should be given to different periods in the day and different types of activity depending on retirement status.

Most participants had a positive attitude towards increasing their current levels of physical activity and if it were to help improve their diabetes management then it was further motivation for some to do so. There were some clear barriers towards physical activity; the barriers that were mentioned by almost all participants were poor weather and the darker evenings in the winter. These feelings could have been influenced by the time of year the interviews took place, as most of the interviews were conducted in the Autumn/Winter months of 2016/2017. This is line with previous research exploring the views of those recently diagnosed with Type 2 diabetes on management, diet and physical activity (Booth, Lewis, Dean, Hunter & McKinley, 2013).

4.2 Theme 2: Sedentary Behaviour

It was highlighted throughout theme two that people were aware of the negative health effects of prolonged sitting, either from personal experience

of sitting for long periods at a time or from a limited knowledge of health guidelines from the GP or their diabetes specialist nurse. For some participants, this appeared to motivate them to sit less and make a conscious effort to move more throughout the day. With other participants this knowledge appeared to have no impact on their sedentary behaviour or their motivation to change it, the advice alone was not enough. In a systematic review conducted by Umpierre et al. (2011), physical activity advice was associated with lowered HbA_{1c} in people with Type 2 diabetes, when it was in conjunction with dietary advice, physical activity advice alone was not enough for positive changes in glucose. There was a common feeling amongst most participants that they naturally broke their sedentary behaviour for physiological reasons, such as a stiffening of joints, and this had more influence on their behaviour than the knowledge that sitting was having a poor effect on their health. This suggests that feedback on the impact of their sitting behaviour whether it is physiological, or perhaps feedback on their glucose, has the most impact on their behaviour and could be a more successful approach to influencing or changing behaviour.

When discussing their current sedentary behaviour, the most common activities described were screen-based activities, such as watching the television or using their tablet to look a social media. There were mixed feelings as to whether the workplace had a negative or positive impact on sedentary behaviour, as with physical activity, some felt it would be easier to change their sedentary behaviour in a working, office environment rather than trying to change their leisure time activity and sedentary behaviour.

Most participants who commented, felt they would be more likely, or would find it more acceptable, to break their sedentary behaviour during the day than they would during the evening. Reasons given for this surrounded the type of activity they were doing, for example they were more likely to be working during the day and watching a film or spending time with their family in the evening. This appears to be largely driven by the habit of sitting watching the television in the evening and is also consistent with results discussed in Theme 1 and earlier research conducted by Kirk, Gibson,

Laverty, Muggeridge, Kelly and Hughes (2016). Kirk et al. (2016) examined sedentary behaviour patterns in female office workers, who wore an activPAL continuously for 7 days. Kirk et al. (2016) reported that the most common prolonged periods of sitting (>60minute bouts) were between 7-10pm on weekdays and 8-10pm at the weekend. Although the population in this study is not the same as the current one being discussed, it does suggest that the most habitual sedentary behaviour is in the evening. and future interventions should focus on the full waking day. Lally and Gardner (2013) explain that habits are a behavioural response to an environmental cue, such as the televisions being in the living room, and highlight the importance of identifying behavioural habits and their environmental context, in order to promote behaviour change and new habit formation. Understanding that participants in this study feel that it would not be acceptable to be less sedentary during the evening and why, helps the development of more acceptable, and hopefully sustainable, interventions.

Those participants who were negative about changing their sedentary behaviour said this was because they felt they were already breaking their sedentary behaviour frequently and to do so more often would negatively impact on their life and productivity. Additionally, most participants felt that hourly breaks would be feasible but anything more frequent would not be feasible. This is interesting as findings from the study discussed in Chapter 5 show participants were breaking their sedentary behaviour an average two to three times per hour during a free living day, which is more frequently than participants report feeling would be feasible. It should be noted that these may not be the same participants who took part in the lab-based study and they may not be representative of those who took part in this study. However, it could be that participants are already naturally breaking up their sedentary behaviour regularly throughout the day and would explain why some felt strongly that they could not be more active and less sedentary than they already were.

4.3 Theme 3: Using Technology

There was mixed level of experience with technologies used to promote active living amongst participants, ranging from no experience at all to using a wearable activity monitor regularly. When participants were shown some of the apps and devices that were currently available prior to the interview, they all showed an interest towards using them, particularly the wearable devices. Although it was not the intention of the interview to talk about the FreeStyle Libre, it was difficult to avoid as all the participants had experience of the device from participating in the previous studies, and it was the only point of reference for some.

Feedback from the device or the app was the most important aspect of the technology to participants, they felt without feedback there was little point or benefit of the technology. Feedback that was instant and visual was the most discussed and preferred form amongst participants and was consistently highlighted as a positive of the FreeStyle Libre. Participants liked that they were able to check their glucose regularly, see their glucose profile and perhaps modify their behaviour based on this information. This is consistent with comments from participants on physical activity and sedentary behaviour that information alone was not enough (Umpierre et al., 2011), participants need to see the impact the behaviour is having on their health or their glucose for it to change their attitude. This links with the feeling of control that participants felt this technology could give them over their own Type 2 diabetes management, whether it was measuring their activity or their glucose. It was apparent throughout the interviews that many of the participants did not feel that they themselves were managing their condition, they went to their three or six-monthly check-up and did as the healthcare professional asked them, as best they could, but they did not fully understand what the numbers meant or why they were being asked to do certain things, such as increase their activity for example. The feedback could increase behavioural intention by improving the participants' attitude towards sitting less by highlighting the impact sitting or being active is having on their management. Additionally, the feedback could also improve their perceived

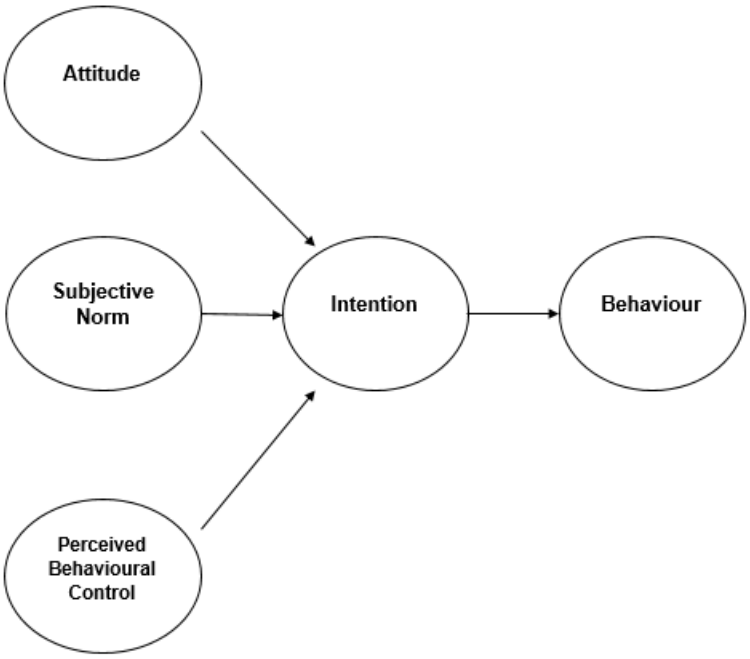
control over the behaviour, if they feel they are changing their behaviour to improve their own diabetes management.

Participants spoke about the need to use a prompt to remind them to break up their sitting and be more active. Some participants felt that in order to change their current behaviour, which was now a habit, they would need something like a prompt if they were going to successfully change their behaviour. Some felt they would need the prompt for a short time until their new behaviour became a habit, however most participants felt that they would need to use a device to prompt their behaviour continuously. That said however, many participants did not want to be reminded to stand up too often as they felt they would become annoying, and they did not like the idea of their behaviour becoming regimented. A possible solution to this would be for the prompts to be more random and less rigid in a way that was more acceptable and feasible for participants.

Given that attitude and perceived behavioural control are themes which have come from the interviews, a useful theory to base a future intervention promoting active living in people with Type 2 diabetes using mobile technology could be the Theory of Planned Behaviour (Azjen, 1985). The Theory of Planned Behaviour (Figure 6.6) proposes that a person's behavioural intention is predictive of their behaviour, and their behavioural intention can be predicted by their attitude towards the behaviour, the subjective norm and their perceived behavioural control (Azjen, 1985). The theory states that if a person has a positive attitude towards a behaviour and the perceived benefits of that behaviour, such as sitting less will improve their diabetes management, then they will have a higher intention of sitting less, making them more likely to sit less.

Additionally, the theory of planned behaviour has been applied in physical activity, and increasingly, sedentary behaviour research. The Medical Research Council (Craig et al., 2008) advise that a theoretical understanding of behaviour and behaviour change is needed in the developmental stages of an intervention.

Figure 6.6: The Theory of Planned Behaviour



5. Limitations

This study has two key limitations. The first limitation is the recruitment of participants from the studies discussed in Chapter 4 and Chapter 5. Interviews were conducted after participation in either or both of the previous studies took place, meaning participants had a prior experience of and possible biased opinion towards, the activPAL and the FreeStyle Libre devices. One of the main aims of the study was to understand participants' attitudes towards the use of mobile-technologies to improve glucose management and for some participants, the only real experience they had with such technologies was during the other studies. Additionally, all participants in this study took part in one or both of the previously discussed studies, meaning there was a common experience between all participants. In future, to avoid a possible bias, interviews could be conducted prior to data collection where such devices will be used. The second limitation is regarding the data analysis and the methods used to code the interviews. The interviews were analysed using a content analysis approach, a flexible approach which tolerates a combination of deductive and inductive coding (Hsieh & Shannon, 2005). However, as the interview schedule was

developed based on prior findings from this thesis and the interviews followed the schedule in a very structured rather than semi-structured manner, the key themes (physical activity, sedentary behaviour and using technology) could be considered categories determined by the interview schedule rather than themes identified through the analysis process.

6. Conclusions

This study provides valuable contributions to the current research surrounding active lifestyles in people with Type 2 diabetes. The interviews have provided important insights into the experiences of, and attitudes towards, physical activity, sedentary behaviour and using technology to promote active living in people with Type 2 diabetes. Participants had a positive attitude towards an active lifestyle, particularly if it would help them manage their diabetes. They felt that increasing the frequency of sedentary breaks would be both acceptable and feasible, however, making the change in behaviour habitual was seen as the biggest challenge. Mobile technology is an accepted method for promoting behaviour change and it was felt that using this technology to both monitor and prompt their behaviour would be most successful way to ensure sustained behaviour change. However, participants felt strongly about not having their behaviour regimented based on these prompts and felt if they were too consistent the prompt would become annoying and was likely to be ignored. Future research could investigate the effectiveness of random prompts as means of encouraging breaks in sedentary behaviour. The most important aspect of the technology that participants felt was most likely to help them was real-time visual feedback. Participants felt this gave them more control over their behaviour and engaged them more than the technology that did not provide any immediate feedback. Future research should focus on the use of technology that integrates activity and glucose monitoring, providing users with visual feedback and using random prompts as a way of encouraging a more active and less sedentary lifestyle.

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Chapter 7: Discussion of Thesis Findings

1. Chapter outline

The aim of this chapter is to collate and discuss the key findings from the thesis, discuss the strengths and limitations of the studies conducted and provide recommendations for future research. An overview of the findings from the thesis is provided, starting with the background and rationale identified in Chapter 1, followed by discussion surrounding the key findings from the studies conducted in Chapters 2 to 6. Next the implications for policy and practice and recommendations for future research will be made, followed by the strengths and limitations of the studies before final conclusions.

2. Background

In the review of the literature in Chapter 1, Type 2 diabetes was identified as a global problem, which is continuing to grow with almost 5 million people in the UK alone being diagnosed with Type 2 diabetes (IDF, 2017; Diabetes UK, 2018). This increase in prevalence has been partially attributed to the progressively changing and more sedentary lifestyle over the last 50 years, resulting in an increase in overweight and obesity and insufficient levels of physical activity (Colberg et al., 2016; IDF, 2017). The economic burden of treating and managing Type 2 diabetes is high, with the annual cost about 10% of the annual NHS budget (Hex et al., 2012).

Improved glucose control reduces the risk of developing diabetes related complications (Stratton et al., 2000; UKPDS, 1998). In addition to medication therapy, there is substantial, longitudinal, evidence that supports a healthy lifestyle for improved glucose control and diabetes management (Look AHEAD Research Group, 2010). However, recent research has suggested that a more personalised approach to diabetes care may be necessary and each individual may react differently to current methods of diabetes management (Ahlqvist et al., 2017; Zeevi et al., 2015).

Sufficient levels of physical activity and increased breaks in sedentary behaviour have been shown to improve glucose control in people with Type 2 diabetes (Avery et al., 2012; Dempsey et al., 2016; Duvivier et al., 2017; Thomas et al., 2006; Umpierre et al., 2011). The majority of people with Type 2 diabetes are not achieving the recommended levels of physical activity and are spending too much of their time being sedentary (ADA, 2018; Kennerly & Kirk, 2018; van Der Berg et al., 2016). This highlights the need for the development of effective and successful interventions to promote active lifestyles in people with Type 2 diabetes. Thus far, most interventions have focused on increasing physical activity levels and little focus has been given to the reduction of sedentary behaviour and few have shown sustained behaviour change (Avery et al., 2012; Thomas et al., 2006; Umpierre et al., 2011).

3. Summary of research findings

The aim of the thesis was to investigate the potential to use mobile technology to promote active lifestyles and improved glucose control in people with Type 2 diabetes. To achieve this aim, eight research questions were addressed across Chapters 2-6, a summary of key findings from each chapter can be found in Table 7.1.

The MRC framework identifies four stages of developing a complex health intervention (Craig et al., 2008). This thesis worked towards the first stage, the development stage, and provides the building blocks for a future pilot intervention. Chapter 2 identified gaps in the current literature, and the remaining Chapters built the evidence base for a future intervention. To do so, Chapter 4 and Chapter 5 examined the relationship between activity and glucose in people with Type 2 diabetes using continuous and objective measurement. Chapter 3 examined the challenges faced when combining and analysing the data from the activPAL and the FreeStyle Libre and presents the suggested solutions. Although this was not an initial focus of the Ph.D, it became apparent that spending time to understand how best to combine these rich data sets and then analyse them in a way that was

meaningful was an important and novel part of this Ph.D. And finally, Chapter 6 examined the experiences and attitutudes of people with Type 2 diabetes towards the use of technology to promote active lifestyles.

Chapter 2 was a systematic and integrated review of the literature of what mobile-based technology has been used previously to promote active lifestyles in people with Type 2 diabetes and the effectiveness, feasibility and acceptability of the technologies identified. Of over 7600 papers identified in the initial searches, only nine papers fit the inclusion criteria for review, highlighting the limited research that has been conducted in this area so far. With long term, sustained behaviour change being the ideal outcome, it was interesting that a key finding from this review was that none of the previous research had examined the feasibility or acceptability of using mobile technology to promote sustained behaviour change and none of the papers focused on using technology to change sedentary behaviour.

Table 7.1: Summary of Key Findings from Thesis

Chapter	Key findings
Chapter 2	Limited research published which explores use of mobile technology to support active lifestyles in Type 2 Diabetes The feasibility and acceptability of using mobile technology for sustained behaviour changes has not been examined No research has focused on reducing prolonged sedentary behaviour Visual feedback from the technology was motivational
Chapter 3	The development of a novel methodology for combining, processing and analysis continuously measured physical activity, sedentary behaviour and glucose data
Chapter 4	People with Type 2 diabetes have high levels of sedentary time and low levels of physical activity People with Type 2 diabetes who are retired spend less time sitting and more time standing and stepping compared to their non-retired counterparts As a group, there was a small but significant negative relationship between sedentary time and mean glucose and glucose variability Regression analysis at the level of the individual showed that 28 of the participants had a positive relationship between sedentary time and mean glucose and only 10 had a negative relationship
Chapter 5	The lab conditions (breaks every 60 and 30 minutes) were making participants more sedentary compared to their free living physical activity and sedentary behaviour Participants were compensating their behaviour by increasing the physical activity and decreasing their sedentary behaviour in the period after the interventions in the lab An individual glucose response to sedentary behaviour was identified

Chapter 6	Participants were positive towards living a more active lifestyle and using technology to do so, particularly if it would help their glucose management The real-time visual feedback the device could give was very important to the participants Participants felt a prompt would be necessary to change behaviour and make it a habit, but felt strongly that they did not want their behaviour to be regimented Participants felt mobile technology providing them with immediate visual feedback would give them more control over their own glucose management

This methodology developed in Chapter 3 was used for the data processing and analysis in Chapter 4 where the relationship between free living physical activity and sedentary behaviour and glucose was examined. Previous research examining these relationships had taken place in a lab setting, where participants' activity behaviour and their food and drink consumption was controlled for a relatively short period of time (Dunstan et al., 2012; Dempsey et al., 2016). There are benefits to looking at this relationship in a controlled setting, however, in order to understand how best to change behaviour, it is important to understand participants' current behaviour and the relationship with their glucose.

In line with previous research, participants were spending over two thirds of their day sedentary and almost 70% of sedentary bouts were 30 minutes or longer. Mean Daily Glucose was 6.96±1.75mmol/l, suggesting that the participants had relatively good glucose control, which may have had an impact on the results from the study. Initial analysis examining the relationship between physical activity and sedentary behaviour, including sedentary bout duration, and mean glucose and glucose variability showed a statistically significant (p <0.05) but small negative association between time spent sedentary and mean glucose (r =-0.15) and glucose variability measures (glucose range (r = -0.13), glucose standard deviation (r = -0.13) and glucose CONGA (r = -0.24)). This suggests the longer a person sits

throughout the day, the lower and less variable their glucose becomes. This was an unusual but interesting finding as it is not consistent with previous research, which has suggested that there is an association between increased sitting time and increased mean glucose (Dempsey et al., 2016; Dempsey et al., 207; Duvivier et al., 2017). The study conducted by Dempsey et al. (2016) was conducted under controlled conditions in a lab where behaviour and food intake were controlled and results showed that sedentary time broken with frequent breaks of light intensity walking or light resistance activities resulted in improved glucose control compared to prolonged sitting. Duvivier et al. (2017) examined the effects of prolonged sitting or breaking sitting with light intensity walking or structured exercise on 24-hour glucose in free living conditions over a four-day period. It could be argued that this was not truly free living conditions as the participants behaviour was being dictated by the intervention during this time. The differences in study design between the previous research and the current study could explain the different findings.

There was no association between sedentary bout duration and mean glucose, however there was a significant (p <0.05) medium and positive association between sedentary bout duration and glucose range (r =0.43). Previous research has not examined the effect of different sedentary bout durations on mean glucose or glucose variability in people with Type 2 diabetes. However, the relationship between sedentary bout duration and metabolic syndrome markers in people with and without Type 2 diabetes has been investigated (van der Berg et al., 2016). Using data collected during the MAASTRICHT study, van der Berg et al. (2016) examined the relationship between the number or prolonged objectively measured sedentary bouts (> 30minutes) and metabolic syndrome markers in people with normal glucose metabolism (n =1395), impaired glucose metabolism (n =388) and Type 2 diabetes (n =714). Findings from the study were that an increased number of prolonged sedentary bouts was not significantly related to metabolic syndrome markers in any of the three groups (van der Berg et al., 2016).

Additionally, Thorp, Kingwell, Sethi, Hammond, Owen and Dunstan (2014) examined the effect of alternated 30 minute bouts of sitting and standing throughout an 8-hour working day on postprandial glucose in overweight and obese office workers (*n* =23). Participants took part in two conditions over five days. Condition one (control), seated work posture for the 8-hour period. Condition two, alternating between 30 minutes of sitting and 30 minutes of standing for the 8-hour period. Fasting glucose and postprandial glucose samples after a mixed test drink were taken every hour for four hours on day one and day five of the study (Thorp et al., 2014). Dietary intake and physical activity were standardised across intervention days. Adjusted mean glucose incremental area under the time curve was lowered by 11.1% after the intervention condition (6.38 mMIhj1 (confidence interval, 5.04–7.71)) relative to the control condition (7.18 mMIhj1 (confidence interval, 5.85–8.52)). Authors concluded that alternating standing and sitting in 30 minute bouts had a small beneficial effect on postprandial glucose in overweight office workers.

In an attempt to understand the results better, individual regression analysis was used to look at these relationships at an individual participant level. Interestingly, 28 of the participants had a positive relationship between sedentary time and their mean glucose, where the longer they sat throughout the day, the higher their glucose became. The remaining 10 participants had the negative association discussed. Even between participants who had the same direction of relationship, there was large variation in the strength of the relationship. In the glucose variability measures some participants had increased variability and others had decreased variability as sitting time increased, however these differences are not consistent across participants or variability measures. The findings from this study do strengthen the emerging notion that glucose management should be personalised to suit the individual's needs, and technology allowing for continuous measurement enables users and clinicians to identify and measure these individual response and tailor behaviour and care provided to improve management.

To explore this individualised response further, some participants who took part in the free living study also participated in a controlled lab-based study (*n* =4) (Chapter 5), where their sitting behaviour was manipulated and their food intake was standardised. Four case studies were used, rather than analysing the data for the group as a whole. This has not been done before and allowed much more depth in examination of the data. The data from two lab intervention days and one free living day were plotted visually and examined over two periods of time, the eight hour lab duration and the period of time after the lab until self-reported sleep time. Interestingly, the lab conditions (breaking every 60 and 30 minutes) made participants more sedentary compared to the free living day and there was a compensation effect in that participants increased their physical activity and reduced their sedentary behaviour in the evenings following the lab interventions, but not in the evenings of the free living days. This is a key finding as it highlights the importance of looking at changes in patterns across the day and not just during the lab duration and also questions the representativeness of findings from previous studies which have used a controlled lab setting (Dempsey et al., 2016; Dunstan et al., 2012). It also shows that perhaps interventions should focus on the behaviour during the whole day, which may make them more successful, particularly in the older and retired population. Additionally, glucose was lower and less variable in the post lab period compared to the lab period. This could be explained by the second-meal phenomenon, as this pattern was seen in the data from both the lab and the free living days (Jovanovic, Gerrard & Taylor, 2009). The differences between glucose profiles for all participants further solidifies the individuality of the relationship between patterns in sedentary behaviour and glucose in people with Type 2 diabetes, whether it's in an uncontrolled free living setting or a controlled lab setting.

This thesis used a mixed methods approach, with Chapters 4 and 5 using a quantitative approach and Chapter 6 used qualitative methods. Ten adults who had also participated in at least one of the free living or lab based studies took part in a semi-structured interview examining their experiences

of, and attitudes towards, physical activity, sedentary behaviour and using technology. One of the key findings from this study is participants' acceptance and positive attitude towards being more active and less sedentary, particularly if it would help them manage their glucose. Those participants who had a negative attitude towards leading a more active lifestyle felt that they were already breaking their sedentary frequently enough and to do so more frequently would have a negative impact on their productivity. This is interesting when the observations from Chapter 5 are considered, where the lab conditions were making participants more sedentary than they already were. It appears to be the case that people with Type 2 diabetes are spending a high proportion of their day sedentary but are frequently breaking this behaviour with short non-sedentary bouts. Kirk, Gibson, Laverty, Muggeridge, Kelly and Hughes (2016) examined the patterns of sedentary behaviour in female office workers using the activPAL to measure sedentary time and patterns in sedentary behaviour. Participants (*n* =27; Mean age 43.0 ± 11.5 yrs; BMI 25.8 ± 4.1 kg/m^2) wore the activPAL for 7 days and their average weekday and weekend day sitting, standing, stepping, stepcount and sit to stand transitions were calculated. Additionally, sedentary bouts were identified and categorised as 20-40, 40-60 and >60 minutes in duration (Kirk et al., 2016). During the weekday, participants accumulated an average of 5.1 20-40 minute sedentary bouts, two 40-60 minute sedentary bouts and 1.8 sedentary bouts of >60 minutes duration. These results are consistent with the findings from the current study. No research has looked at this before in people with Type 2 diabetes, so the studies in this thesis have brought new insight into the free living patterns of sedentary behaviour in this population, and the context of why this may be.

Participants felt technology like the FreeStyle Libre gave them back control of their diabetes management and would allow them to change their behaviour/ food intake/ medication based on the information they were getting at the time, rather than the information they got at their 6-monthly or yearly appointment with the healthcare professional. This was very important to them. The most favoured aspect of the technology was the visual feedback

it could give them, again this made them feel more in control of their diabetes, and if the device did not give them immediate visual feedback then they did not see the point in using it. One of the key findings from the systematic and integrated review was that participants found the visual feedback from the technology to be motivating. This is something that should be considered when future devices and interventions are developed. An app that provided the user with combined information about their activity and glucose activity could be a successful approach to promoting active living for improved glucose management. This is interesting as currently in the UK, people with well controlled Type 2 diabetes are not required to monitor their glucose regularly and often the only time this is measured is during their diabetes check-up. One of the things participants were negative about was the idea of having a device prompt them to change their behaviour in a regimented way, however the majority felt that in order to sustain the behaviour change they would need to make the new behaviour a habit and felt the best way to do so was to have something prompting them. Suggesting random prompts which take into account previous behaviour may be more suitable.

In summary, the findings from the studies described in this thesis have contributed new knowledge to the area of utilising mobile technology to support active lifestyles and good glucose management in Type 2 diabetes.

3. Implications for policy and practice

In 2010, the Scottish Government produced the Diabetes Action Plan 2010, a follow-up to the Scottish Diabetes Framework Action Plan produced in 2006. The 2010 action plan focuses on the prevention and screening of diabetes and improving the quality of care for people with diabetes and the support that is available to them (Scottish Government, 2010). The action plan highlighted the importance of engaging people with diabetes in the development and improvement of diabetes care services and the findings

from this thesis confirm that people with Type 2 diabetes want to be more involved in their diabetes care and management and they felt mobile technology could help them achieve this. The Diabetes Improvement Plan (Scottish Government, 2014) emphasises the need to accelerate the development and diffusion of innovative solutions to improve treatment, care and quality of life of people living with diabetes. Services like MyDiabetesMyWay is an example of an innovative solution which promotes engagement amongst users, with the aim of improving care, by enabling patients to view data from multiple sources including results for clinics. The Diabetes Action Plan emphasises the need for optimal use of technology in both a clinical setting directly related to an individual's care, but also in the collection of good epidemiological data to improve the understanding of an individual's care needs (Scottish Government, 2010). SCI-Diabetes and MyDiabetesMyWay are pulling in and integrating data from multiple sources including mobile devices, such as continuous glucose monitors and wearable activity monitors, but currently little is known about howto understand and present this data in a meaningful way, which was a key aim of the studies in this thesis. The findings and insights presented in this thesis show that mobile technology can be used to collect and present data that is meaningful to both the clinician and the patient and could provide a significant contribution to the current developments surrounding diabetes care and technology in Scotland.

4. Recommendations for future research

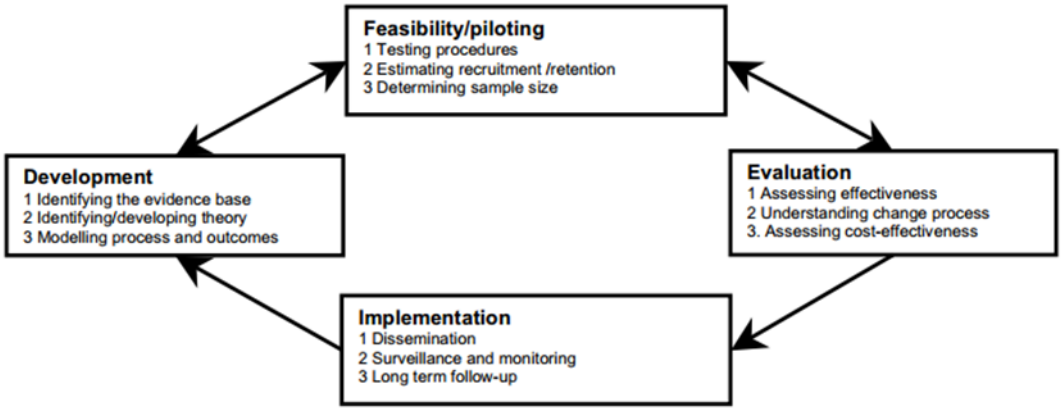
The aim of this thesis was to investigate the potential to use mobile technology to promote active lifestyles and improved glucose control in people with Type 2 diabetes. In relation to the MRC framework for the development, evaluation and implementation of complex health interventions (Figure 7.1), the aim of the studies in this thesis fit into the development stage of the framework (Craig et al., 2008). The findings provide a strong evidence base for using mobile technology to promote active living and good glucose management in people with Type 2 diabetes, and the building blocks for future pilot work in this area. The use of a mixed-methods approach really strengthens the evidence and adds to the current research in this area by providing a more complete understanding. The Integrated and Systematic literature review was successful in identifying clear gaps in the research conducted thus far, helping to shape the aim of the other studies. The findings from the free living and controlled lab study complement each other and both identified the need and the evidence to support an individual focused approach to be used in a future intervention, something the mobile technology would enable. This was emphasised further in the qualitative study, which showed that the use of this technology is not only acceptable but is seen to increase individual control over their Type 2 diabetes management. The findings from the studies described in this thesis have helped refine the research aims and questions for a future pilot intervention.

Future research should focus on using a co-design approach, involving Academics, Healthcare Professionals and people who have Type 2 diabetes to design a user-centred and pragmatic intervention to improve glucose management through the promotion of active lifestyles in people with Type 2 diabetes. This could involve the design of a mobile app which would combine and integrate data to enable the user to monitor and change their behaviour with the aim to improving their glucose management. The app could integrate activity and food data, continuous glucose measurements and other health data, such as heart rate, blood pressure and medication information, and would provide users with real-time visual feedback when

they wanted it. This app would also incorporate random prompts, to break sitting for example, and continuously capture data, to allow for both daytime and evening data to be measured.

Currently in Scotland there are ongoing developments in the use of integrated data to improve management of diabetes for both patients (MyDiabetesMyWay) and clinicians (SCI-Diabetes). These services, particularly MyDiabetesMyWay, could enable the feasibility and acceptability of the intervention to be explored, followed by implementation and evaluation on a larger scale throughout Scotland (Craig et al., 2008).

Figure 7.1: MRC Framework



4. Strengths and limitations of the thesis

4.1 Strengths

This thesis has several strengths. The use of a mixed-methods approach to health research has been advocated as way of gaining a fuller insight into a research area (NIH, 2018). The integrated and systematic review (Chapter 1) provided valuable insight into the previous research conducted in this area, and although the number of papers included for review was small, the strict inclusion criteria allowed for very specific gaps in the literature to be identified.

For the free living and lab studies in Chapters 4 and 5, both activity and glucose were validated devices, which allowed for objective and continuous measurement of physical activity, sedentary behaviour and

glucose. This is not something that has been done previously in a free living setting and means the data collected is more representative of the normal behaviour of those who participated. Spending time focusing on how best to process and analyse such a rich data set became a strength of this thesis. The methodology developed means the results were meaningful to both clinicians and those with Type 2 diabetes. Using case studies to examine the data in Chapter 5 was a novel approach to examining glucose data and provides further depth to the knowledge gained in Chapter 4. The individualised glucose response to physical activity and sedentary behaviour was emphasised and using the free living day as the control enabled the relationship between sedentary behaviour and glucose in the lab to be directly compared to the participants' current behaviour.

As mentioned, the mixed-methods approach and the inclusion of the interviews with participants is a strength of this thesis. The findings from the interviews were invaluable when considering the development of an intervention in the future. They provided important insights surrounding the participants' behaviour and their attitudes towards active living and their glucose management that the other studies could not.

4.2 Limitations

Those recruited for the free living and the lab studies, and subsequently the qualitative interview, were recruited from social media and diabetes support groups, they were proactive and motivated in their management of their Type 2 diabetes and this shows in the relatively low mean glucose levels. This may have had an impact on the results of the studies, with physical activity and sedentary behaviour possibly having less of an impact on those with well managed glucose. Future recruitment should focus on recruiting people with Type 2 diabetes who have less control of their glucose and are less motivated to improve their glucose management.

5. Conclusions

The aim of this thesis was to examine the potential to use mobile technology to promote active lifestyles and improved glucose management in people with Type 2 diabetes. The studies in this thesis successfully achieved this and have provided new contributions to the current literature, developing a robust evidence base to build on and develop future interventions. Additionally, the findings from the five studies presented in this thesis have demonstrated how data can be collated, analysed and presented in a way that is meaningful to both the clinician and the individual with Type 2 diabetes. This concept has potential to be transferred to other health data to support self management of other chronic disease.

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Appendices

Appendix A: Chapter 4 Physical Activity and Sedentary Behaviour Regression Tables

Table 4.7: Summary of Models Exploring the Relationship Between Proportion of Time Spent Sitting and Age, BMI, Gender, Waist Circumference, Retirement Status, Medication Status, Duration of Type 2 Diabetes and FreeStyle Libre HbA_{1c}

	Model							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Mean Intercept	87.16	96.36	98.49	107.97	102.26	84.92	72.74	73.03
Age Coefficient	-0.37*	-0.42*	-0.44*	-0.47*	-0.38*	-0.37*	-0.41*	-0.16
Age SE	0.06	0.07	0.07	0.07	0.12	0.12	0.12	0.12
BMI Coefficient	---	-0.20	-0.16	0.31	0.37	0.06	-0.57	-0.76*
BMI SE	---	0.11	0.11	0.27	0.28	0.28	0.30	0.30
Gender Coefficient	---	---	-3.67*	-6.28*	-6.68*	-7.30*	-7.39*	-7.90*
Gender SE	---	---	1.32	1.47	1.53	1.50	1.44	1.43
Waist Circumference Coefficient	---	---	---	-0.18	-0.20	0.04	0.31*	0.26*
Waist Circumference SE	---	---	---	0.11	0.11	0.13	0.13	0.12
Retirement Coefficient	---	---	---	---	2.31	0.90	4.11	6.87*
Retirement SE	---	---	---	---	2.54	2.50	2.51	2.44

Medication Coefficient	---	---	---	---	---	7.33*	7.22*	7.88*
Medication SE	---	---	---	---	---	1.81	1.75	1.67
Duration of T2D Coefficient	---	---	---	---	---	---	0.78*	0.90*
Duration of T2D SE	---	---	---	---	---	---	0.16	0.16
FreeStyle HbA1c Coefficient	---	---	---	---	---	---	---	-0.22*
FreeStyle HbA1c SE	---	---	---	---	---	---	---	0.08
R^2	0.08	0.09	0.10	0.17	0.17	0.22	0.27	0.31
AIC	3161.87	3160.47	3154.70	2400.16	2401.32	2386.95	2366.55	2206.19
BIC	3173.84	3176.42	3174.64	2422.48	2427.36	2416.71	2400.03	2242.82

Note. *= p <0.05; SE = Standard Error; AIC = Akaike information criterion; BIC = Bayesian information criterion.

Table 4.8: Summary of models exploring the relationship between proportion of time spent standing and age, BMI, gender, waist circumference, retirement status, medication status, duration of Type 2 diabetes and FreeStyle Libre HbA_{1c}

	Model							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Mean Intercept	7.68	-7.98	-11.10	-23.20	-21.54	-5.15	7.66	7.28
Age Coefficient	0.28*	0.38*	0.40*	0.44*	0.41*	0.41*	0.45*	0.28*
Age SE	0.05	0.06	0.05	0.06	0.10	0.10	0.09	0.10
BMI Coefficient	---	0.33*	0.28*	-0.20	-0.21	0.08	0.74*	0.98*
BMI SE	---	0.09	0.09	0.23	0.23	0.23	0.24	0.24

Gender Coefficient	---	---	5.38*	7.39*	7.50*	8.09*	8.18*	8.98*
Gender SE	---	---	1.07	1.21	1.27	1.23	1.16	1.14
Waist Circumference Coefficient	---	---	---	0.21*	0.22*	-0.01	-0.29*	-0.27*
Waist Circumference SE	---	---	---	0.09	0.09	0.10	0.11	0.10
Retirement Coefficient	---	---	---	---	-0.67	0.66	-2.72	-4.76
Retirement SE	---	---	---	---	2.10	2.05	2.01	1.94
Medication Coefficient	---	---	---	---	---	-6.92*	-6.81*	-7.32*
Medication SE	---	---	---	---	---	1.48	1.40	1.33
Duration of T2D Coefficient	---	---	---	---	---	---	-0.82*	-0.92*
Duration of T2D SE	---	---	---	---	---	---	0.13	0.13
FreeStyle HbA1c Coefficient	---	---	---	---	---	---	---	0.08
FreeStyle HbA1c SE	---	---	---	---	---	---	---	0.06
R^2	0.07	0.10	0.15	0.24	0.23	0.28	0.37	0.43
AIC	3023.61	3011.51	2988.67	2284.21	2286.11	2266.62	2230.87	2074.63
BIC	3035.58	3027.47	3008.62	2306.54	2312.15	2296.38	2264.36	2111.26

Note. *= p <0.05; SE = Standard Error; AIC = Akaike information criterion; BIC = Bayesian information criterion.

Table 4.9: Summary of models exploring the relationship between proportion of time spent stepping and age, BMI, gender, waist circumference, retirement status, medication status, duration of Type 2 diabetes and FreeStyle Libre HbA_{1c}

	Model							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Mean Intercept	5.16	11.61	12.61	15.22	19.27	20.23	19.59	19.69
Age Coefficient	0.08*	0.04	0.04	0.03	-0.03	-0.03	-0.04	-0.12*
Age SE	0.02	0.02	0.02	0.02	0.04	0.04	0.04	0.04
BMI Coefficient	---	-0.14*	-0.12*	-0.12	-0.15	-0.13	-0.17	-0.22*
BMI SE	---	0.04	0.04	0.09	0.09	0.10	0.11	0.11
Gender Coefficient	---	---	-1.72*	-1.10*	-0.82	-0.78	-0.79	-1.08*
Gender SE	---	---	0.47	0.49	0.51	0.51	0.51	0.52
Waist Circumference Coefficient	---	---	---	-0.03	-0.02	-0.03	-0.02	0.01
Waist Circumference SE	---	---	---	0.04	0.04	0.04	0.05	0.05
Retirement Coefficient	---	---	---	---	-1.64	-1.56	-1.39	-2.11*
Retirement SE	---	---	---	---	0.84	0.85	0.88	0.89
Medication Coefficient	---	---	---	---	---	-0.41	-0.41	-0.55
Medication SE	---	---	---	---	---	0.61	0.61	0.61

Duration of T2D Coefficient	---	---	---	---	---	---	0.04	0.01
Duration of T2D SE	---	---	---	---	---	---	0.06	0.06
FreeStyle HbA1c Coefficient	---	---	---	---	---	---	---	0.14*
FreeStyle HbA1c SE	---	---	---	---	---	---	---	0.03
R^2	0.03	0.06	0.09	0.09	0.10	0.10	0.10	0.11
AIC	2355.71	2344.97	2333.74	1728.72	1726.87	1728.43	1729.91	1625.13
BIC	2367.68	2360.93	2353.69	1751.04	1752.92	1758.19	1763.39	1661.76

Note. *= p <0.05; SE = Standard Error; AIC = Akaike information criterion; BIC = Bayesian information criterion.

Table 4.10: Summary of models exploring the relationship between daily step count and age, BMI, gender, waist circumference, retirement status, medication status, duration of Type 2 diabetes and FreeStyle Libre HbA_{1c}

	Model							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Mean Intercept	2437.75	9763.02	12975.01	17933.01	18429.70	18116.22	16705.61	18258.79
Age Coefficient	78.20	29.58	19.44	7.37	0.97	0.88	-9.94	-69.97
Age SE	48.58	55.10	53.96	51.44	92.65	94.91	97.22	116.05
BMI Coefficient	---	-142.61	-137.23	-30.25	-34.26	-38.98	-120.91	-173.61
BMI SE	---	83.00	80.84	184.10	194.34	205.21	236.46	247.74
Gender Coefficient	---	---	-1691.06	-1664.98	-1630.15	-1639.67	-1557.58	-1564.48

Gender SE	---	---	994.63	941.54	1048.89	1079.23	1098.12	1232.95
Waist Circumference Coefficient	---	---	---	-75.30	-73.32	-69.75	-34.28	-22.05
Waist Circumference SE	---	---	---	76.77	-161.60	92.10	105.26	108.89
Retirement Coefficient	---	---	---	---	1922.98	-188.51	-34.80	-635.96
Retirement SE	---	---	---	---	---	1990.35	2025.52	2253.56
Medication Coefficient	---	---	---	---	---	158.33	158.39	193.14
Medication SE	---	---	---	---	---	1221.40	1237.55	1300.54
Duration of T2D Coefficient	---	---	---	---	---	---	82.44	45.90
Duration of T2D SE	---	---	---	---	---	---	113.74	124.01
FreeStyle HbA1c Coefficient	---	---	---	---	---	---	---	88.57
FreeStyle HbA1c SE	---	---	---	---	---	---	---	62.12
R^2	0.04	0.09	0.19	0.16	0.16	0.11	0.09	0.05
AIC	702.87	701.80	502.50	504.49	504.49	506.47	507.74	472.36
BIC	707.70	708.24	510.27	513.56	513.56	516.84	519.40	484.55

Note. *= p <0.05; SE = Standard Error; AIC = Akaike information criterion; BIC = Bayesian information criterion.

Table 4.11: Summary of models exploring the relationship between daily sit to stand transitions and age, BMI, gender, waist circumference, retirement status, medication status, duration of Type 2 diabetes and FreeStyle Libre HbA_{1c}

	Model							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Mean Intercept	39.05	74.01	66.91	44.62	51.27	48.65	35.87	24.40
Age Coefficient	0.16	-0.07	-0.05	0.10	0.01	0.01	-0.08	-0.001
Age SE	0.21	0.24	0.24	0.24	0.44	0.45	0.44	0.52
BMI Coefficient	---	-0.68	-0.69	-1.44	-1.49	-1.53	-2.27*	-2.33
BMI SE	---	0.35	0.36	0.88	0.92	0.98	1.08	1.11
Gender Coefficient	---	---	3.74	6.32	6.99	6.91	7.65	4.53
Gender SE	---	---	4.38	4.48	4.99	5.13	5.02	5.53
Waist Circumference Coefficient	---	---	---	0.28	0.31	0.34	0.66	0.62
Waist Circumference SE	---	---	---	0.37	0.39	0.44	0.48	0.49
Retirement Coefficient	---	---	---	---	-2.16	-2.39	-0.99	1.95
Retirement SE	---	---	---	---	9.14	9.46	9.27	10.11
Medication Coefficient	---	---	---	---	---	0.97	1.36	3.20
Medication SE	---	---	---	---	---	5.80	5.66	5.83
Duration of T2D Coefficient	---	---	---	---	---	---	0.75	0.47

Duration of T2D SE	---	---	---	---	---	---	0.75	0.56
FreeStyle HbA1c Coefficient	---	---	---	---	---	---	---	0.25
FreeStyle HbA1c SE	---	---	---	---	---	---	---	0.28
R^2	-0.01	0.06	0.05	0.18	0.14	0.10	0.14	0.12
AIC	299.88	298.07	299.26	213.73	215.66	217.62	216.84	202.04
BIC	304.71	304.51	307.32	221.50	224.73	227.98	228.50	214.23

Note. *= p <0.05; SE = Standard Error; AIC = Akaike information criterion; BIC = Bayesian information criterion.

Table 4.12: Summary of models exploring the relationship between sedentary bout duration and age, BMI, gender, waist circumference, retirement status, medication status, duration of Type 2 diabetes and FreeStyle Libre HbA_{1c}

	Model							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Mean Intercept	3930.64	3724.91	3852.68	4270.59	3710.47	2913.93	3093.57	3141.54
Age Coefficient	-17.40*	-16.13*	-17.24*	-19.49*	-10.51	-11.56	-11.00	-12.25
Age SE	3.11	3.50	3.52	3.77	6.16	6.15	6.18	6.54
BMI Coefficient	---	4.26	6.32	28.72*	36.81*	17.40	24.82	28.63
BMI SE	---	5.63	5.40	13.36	14.01	14.94	16.73	17.04
Gender Coefficient	---	---	-202.30*	-210.39*	-250.46*	-282.814*	-278.24*	-235.51*
Gender SE	---	---	66.62	72.92	76.05	76.34	76.48	79.96

Waist Circumference Coefficient	---	---	---	-9.41	-12.62*	1.34	-2.20	-1.56
Waist Circumference SE	---	---	---	5.58	5.84	6.95	7.82	7.88
Retirement Coefficient	---	---	---	---	233.37	120.85	88.34	49.00
Retirement SE	---	---	---	---	126.54	129.84	133.96	136.46
Medication Coefficient	---	---	---	---	---	355.88*	336.25*	331.16*
Medication SE	---	---	---	---	---	96.72	98.75	101.37
Duration of T2D Coefficient	---	---	---	---	---	---	-9.22	-7.96
Duration of T2D SE	---	---	---	---	---	---	9.36	9.65
FreeStyle HbA1c Coefficient	---	---	---	---	---	---	---	-3.41
FreeStyle HbA1c SE	---	---	---	---	---	---	---	4.23
R^2	0.01	0.01	0.01	0.02	0.02	0.03	0.03	0.03
AIC	49353	49354.37	49347.15	39622.67	39621.27	39609.73	39610.75	37437.07
BIC	49370.80	49378.10	49376.82	39656.96	39661.27	39655.44	39662.19	37493.65

Note. *= p <0.05; SE = Standard Error; AIC = Akaike information criterion; BIC = Bayesian information criterion.

Appendix B: Chapter 4 Retired vs Non-Retired Physical Activity and Sedentary Behaviour Regression Tables

Retired

Table 4.15: Summary of models exploring the relationship between proportion of time spent sitting in retired participants and age, BMI, gender, waist circumference, medication status, duration of Type 2 diabetes and FreeStyle Libre HbA_{1c}

	Model						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Mean Intercept	111.84	127.69	126.98	127.29	119.49	111.90	114.32
Age Coefficient	-0.71*	-0.77*	-0.74*	-0.53*	-0.68*	-0.59*	-0.46
Age SE	0.23	0.23	0.23	0.23	0.21	0.26	0.27
BMI Coefficient	---	-0.43	-0.43	0.44	0.98*	0.71	0.52
BMI SE	---	0.31	0.31	0.52	0.48	0.70	0.70
Gender Coefficient	---	---	-1.64	-8.00*	-11.41*	-10.93*	-9.59*
Gender SE	---	---	1.62	1.93	1.85	2.06	2.13
Waist Circumference Coefficient	---	---	---	-0.37*	-0.34*	-00.26	-0.25

Waist Circumference SE	---	---	---	0.15	0.14	0.20	0.20
Medication Coefficient	---	---	---	---	11.75*	11.07*	11.00*
Medication SE	---	---	---	---	2.02	2.39	2.40
Duration of T2D Coefficient	---	---	---	---	---	0.15	0.24
Duration of T2D SE	---	---	---	---	---	0.27	0.27
FreeStyle HbA1c Coefficient	---	---	---	---	---	---	-0.23*
FreeStyle HbA1c SE	---	---	---	---	---	---	0.09
R^2	0.04	0.04	0.04	0.13	0.28	0.27	0.30
AIC	1633.62	1633.76	1634.73	1286.57	1256.78	1258.49	1233.86
BIC	1643.66	1647.15	1651.46	1305.28	1278.61	1283.43	1261.76

Note. *= p <0.05; SE = Standard Error; AIC = Akaike information criterion; BIC = Bayesian information criterion.

Table 4.16: Summary of models exploring the relationship between proportion of time spent standing in retired participants and age, BMI, gender, waist circumference, medication status, duration of Type 2 diabetes and FreeStyle Libre HbA_{1c}

	Model						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Mean Intercept	-36.49	-55.33	-53.76	-66.99	-59.05	-46.57	-48.06
Age Coefficient	0.90*	0.97*	0.91*	0.78*	0.93*	0.78*	0.75*
Age SE	0.19	0.19	0.19	0.19	0.17	0.22	0.22
BMI Coefficient	---	0.51	0.52*	0.10	-0.43	0.01	0.11
BMI SE	---	0.26	0.26	0.45	0.40	0.57	0.58
Gender Coefficient	---	---	3.62*	7.71*	11.15*	10.36*	9.61*
Gender SE	---	---	1.32	1.65	1.53	1.69	1.77
Waist Circumference Coefficient	---	---	---	0.33*	0.31*	0.18	0.16

Waist Circumference SE	---	---	---	0.13	0.11	1.64	0.17
Medication Coefficient	---	---	---	---	-11.82*	-10.70*	-10.44*
Medication SE	---	---	---	---	1.67	1.99	2.00
Duration of T2D Coefficient	---	---	---	---	---	-0.24	-0.29
Duration of T2D SE	---	---	---	---	---	0.22	0.23
FreeStyle HbA1c Coefficient	---	---	---	---	---	---	0.08
FreeStyle HbA1c SE	---	---	---	---	---	---	0.07
R^2	0.09	0.11	0.13	0.22	0.40	0.40	0.40
AIC	1557.70	1555.90	1550.48	1235.44	1192.01	1192.82	1174.07
BIC	1567.74	1569.29	1567.22	1254.15	1213.84	1217.77	1201.97

Note. *= p <0.05; SE = Standard Error; AIC = Akaike information criterion; BIC = Bayesian information criterion.

Table 4.17: Summary of models exploring the relationship between proportion of time spent stepping in retired participants and age, BMI, gender, waist circumference, medication status, duration of Type 2 diabetes and FreeStyle Libre HbA_{1c}

	Model						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Mean Intercept	24.64	27.63	26.78	39.60	39.56	34.67	33.74
Age Coefficient	-0.19*	-0.20*	-0.17	-0.25*	-0.25*	-0.19	-0.29*
Age SE	0.09	0.09	0.09	0.08	0.08	0.10	0.10
BMI Coefficient	---	-0.08	-0.09	-0.55*	-0.54*	-0.72*	-0.63*
BMI SE	---	0.12	0.12	0.18	0.19	0.27	0.26
Gender Coefficient	---	---	-1.98*	0.28	0.26	0.57	-0.02
Gender SE	---	---	0.61	0.67	0.71	0.79	0.78
Waist Circumference Coefficient	---	---	---	0.03	0.03	0.08	0.09

Waist Circumference SE	---	---	---	0.05	0.05	0.08	0.07
Medication Coefficient	---	---	---	---	0.07	-0.37	-0.56
Medication SE	---	---	---	---	0.78	0.92	0.88
Duration of T2D Coefficient	---	---	---	---	---	0.09	0.05
Duration of T2D SE	---	---	---	---	---	0.11	0.11
FreeStyle HbA1c Coefficient	---	---	---	---	---	---	0.15*
FreeStyle HbA1c SE	---	---	---	---	---	---	0.03
R^2	0.02	0.02	0.06	0.08	0.07	0.07	0.18
AIC	1227.69	1229.23	1220.61	936.43	938.42	939.59	906.44
BIC	1237.73	1242.62	1237.34	955.14	960.25	964.54	934.33

Note. *= p <0.05; SE = Standard Error; AIC = Akaike information criterion; BIC = Bayesian information criterion.

Table 4.18: Summary of models exploring the relationship between daily step count in retired participants and age, BMI, gender, waist circumference, medication status, duration of Type 2 diabetes and FreeStyle Libre HbA_{1c}

	Model						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Mean Intercept	16993.60	23298.75	22299.49	33091.63	32671.00	24594.78	23727.37
Age Coefficient	-123.80	-146.26	-111.71	-138.49*	-146.32*	-53.09	-131.00
Age SE	74.60	75.55	72.68	68.04	68.56	86.92	85.46
BMI Coefficient	---	-170.03	-180.54	-245.34	-216.48	-503.05*	-428.30
BMI SE	---	103.79	99.30	157.53	160.50	230.12	221.74
Gender Coefficient	---	---	-2306.22*	-1210.18*	-1394.48*	-882.58	-1409.49*
Gender SE	---	---	512.52	581.71	613.61	678.01	675.04
Waist Circumference Coefficient	---	---	---	-85.21	-83.89	-1.83	-.29

Waist Circumference SE	---	---	---	45.83	45.86	65.83	63.28
Medication Coefficient	---	---	---	---	634.11	-89.41	-192.55
Medication SE	---	---	---	---	669.96	786.59	760.77
Duration of T2D Coefficient	---	---	---	---	---	154.92	119.53
Duration of T2D SE	---	---	---	---	---	89.66	86.85
FreeStyle HbA1c Coefficient	---	---	---	---	---	---	119.06
FreeStyle HbA1c SE	---	---	---	---	---	---	28.33
R^2	0.01	0.02	0.10	0.10	0.10	0.11	0.20
AIC	4069.85	4069.15	4051.46	3194.00	3195.08	3193.99	3123.34
BIC	4079.89	4082.53	4068.19	3212.71	3216.90	3218.93	3151.24

Note. *= p <0.05; SE = Standard Error; AIC = Akaike information criterion; BIC = Bayesian information criterion.

Table 4.19: Summary of models exploring the relationship between daily sit to stand transitions in retired participants and age, BMI, gender, waist circumference, medication status, duration of Type 2 diabetes and FreeStyle Libre HbA_{1c}

	Model						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Mean Intercept	93.08	89.21	88.27	142.04	137.70	178.09	172.02
Age Coefficient	-0.61*	-0.60*	-0.57	-0.70*	-0.78*	-1.24*	-1.42*
Age SE	0.29	0.29	0.29	0.28	0.28	0.35	0.35
BMI Coefficient	---	0.10	0.09	-1.67*	-1.37*	0.06	0.49
BMI SE	---	0.40	0.40	0.65	0.66	0.94	0.90
Gender Coefficient	---	---	-2.17	1.36	-0.54	-3.10	-6.22*
Gender SE	---	---	2.08	2.41	2.51	2.76	2.74
Waist Circumference Coefficient	---	---	---	0.01	0.03	-0.38	-0.45

Waist Circumference SE	---	---	---	0.19	0.19	0.27	0.26
Medication Coefficient	---	---	---	---	6.55*	10.17*	11.00*
Medication SE	---	---	---	---	2.74	3.20	3.09
Duration of T2D Coefficient	---	---	---	---	---	-0.77*	-1.00*
Duration of T2D SE	---	---	---	---	---	0.37	0.35
FreeStyle HbA1c Coefficient	---	---	---	---	---	---	0.38*
FreeStyle HbA1c SE	---	---	---	---	---	---	0.11
R^2	0.02	0.01	0.01	0.06	0.08	0.10	0.17
AIC	1735.52	1737.46	1738.35	1362.16	1358.34	1355.71	1316.96
BIC	1745.56	1750.84	1755.08	1380.87	1380.17	1380.65	1344.86

Note. *= p <0.05; SE = Standard Error; AIC = Akaike information criterion; BIC = Bayesian information criterion.

Non-Retired

Table 4.20: Summary of models exploring the relationship between proportion of time spent sitting in non-retired participants and age, BMI, gender, waist circumference, medication status, duration of Type 2 diabetes and FreeStyle Libre HbA_{1c}

	Model						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Mean Intercept	93.08	95.11	92.25	96.81	50.70	51.13	42.95
Age Coefficient	-0.61*	-0.42*	-0.32*	-0.36*	-0.35*	-0.78*	-0.44*
Age SE	0.29	0.14	0.14	0.16	0.16	0.17	0.17
BMI Coefficient	---	-0.16	-0.07	0.14	-1.13	-2.36*	-2.81*
BMI SE	---	0.12	0.12	0.41	0.67	0.67	0.73
Gender Coefficient	---	---	-6.95*	-6.33*	-7.72*	-10.73*	-13.89*
Gender SE	---	---	2.34	2.76	2.78	2.64	2.59
Waist Circumference Coefficient	---	---	---	-0.08	0.70	1.23*	1.34*

Waist Circumference SE	---	---	---	0.18	0.37	0.36	0.38
Medication Coefficient	---	---	---	---	12.64*	12.68*	15.79*
Medication SE	---	---	---	---	5.28	4.88	5.28
Duration of T2D Coefficient	---	---	---	---	---	2.09*	2.29*
Duration of T2D SE	---	---	---	---	---	0.43	0.43
FreeStyle HbA1c Coefficient	---	---	---	---	---	---	-0.24
FreeStyle HbA1c SE	---	---	---	---	---	---	0.21
R^2	0.02	0.04	0.07	0.09	0.12	0.25	0.38
AIC	1735.52	1527.75	1520.96	1116.58	1112.71	1091.90	957.33
BIC	1745.56	1540.72	1537.17	1134.15	1133.20	1115.32	982.71

Note. *= p <0.05; SE = Standard Error; AIC = Akaike information criterion; BIC = Bayesian information criterion.

Table 4.21: Summary of models exploring the relationship between proportion of time spent standing in non-retired participants and age, BMI, gender, waist circumference, medication status, duration of Type 2 diabetes and FreeStyle Libre HbA_{1c}

	Model						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Mean Intercept	4.90	-11.41	-8.43	-9.09	23.28	22.88	28.58
Age Coefficient	0.35*	0.47*	0.37*	0.30*	0.30*	0.70*	0.41*
Age SE	0.11	0.12	0.12	0.13	0.12	0.13	0.12
BMI Coefficient	---	0.31*	0.21*	-0.07	0.82	1.98*	2.32*
BMI SE	---	0.10	0.10	0.33	0.53	0.51	0.52
Gender Coefficient	---	---	7.25*	8.51*	9.48*	12.33*	14.99*
Gender SE	---	---	1.87	2.18	2.20	2.01	1.85
Waist Circumference Coefficient	---	---	---	0.10	-0.45	-0.95*	-1.02*

Waist Circumference SE	---	---	---	0.14	0.30	0.28	0.27
Medication Coefficient	---	---	---	---	-8.88*	-8.91*	-11.26*
Medication SE	---	---	---	---	4.18	3.71	3.77
Duration of T2D Coefficient	---	---	---	---	---	-1.97*	-2.18*
Duration of T2D SE	---	---	---	---	---	0.33	0.30
FreeStyle HbA1c Coefficient	---	---	---	---	---	---	0.24
FreeStyle HbA1c SE	---	---	---	---	---	---	0.15
R^2	0.04	0.09	0.15	0.19	0.21	0.38	0.56
AIC	1456.68	1448.91	1436.13	1050.86	1048.21	1016.46	873.79
BIC	1466.41	1461.87	1452.34	1068.42	1068.71	1039.87	899.18

Note. *= p <0.05; SE = Standard Error; AIC = Akaike information criterion; BIC = Bayesian information criterion.

Table 4.22: Summary of models exploring the relationship between proportion of time spent stepping in non-retired participants and age, BMI, gender, waist circumference, medication status, duration of Type 2 diabetes and FreeStyle Libre HbA_{1c}

	Model						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Mean Intercept	8.60	16.30	16.18	12.28	26.02	25.99	28.47
Age Coefficient	0.01	-0.05	-0.04	0.05	0.05	0.07	0.04
Age SE	0.05	0.05	0.05	0.05	0.05	0.06	0.06
BMI Coefficient	---	-0.15*	-0.14*	-0.07	0.31	0.38	0.49
BMI SE	---	0.04	0.04	0.12	0.21	0.22	0.27
Gender Coefficient	---	---	-0.31	-2.18*	-1.77*	-1.60	-1.10
Gender SE	---	---	0.79	0.83	0.83	0.86	0.96
Waist Circumference Coefficient	---	---	---	-0.02	-0.26*	-0.29*	-0.32*

Waist Circumference SE	---	---	---	0.06	0.11	0.12	0.14
Medication Coefficient	---	---	---	---	-3.76*	-3.77*	-4.53*
Medication SE	---	---	---	---	1.58	1.59	1.97
Duration of T2D Coefficient	---	---	---	---	---	-0.12	-0.12
Duration of T2D SE	---	---	---	---	---	0.14	0.16
FreeStyle HbA1c Coefficient	---	---	---	---	---	---	0.002
FreeStyle HbA1c SE	---	---	---	---	---	---	0.08
R^2	-0.01	0.06	0.05	0.09	0.12	0.12	0.07
AIC	1118.38	1107.21	1109.05	784.67	780.90	782.19	712.53
BIC	1128.10	1120.17	1125.26	802.23	801.39	805.60	737.91

Note. *= p <0.05; SE = Standard Error; AIC = Akaike information criterion; BIC = Bayesian information criterion.

Table 4.23: Summary of models exploring the relationship between daily step count in non-retired participants and age, BMI, gender, waist circumference, medication status, duration of Type 2 diabetes and FreeStyle Libre HbA_{1c}

	Model						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Mean Intercept	6971.27	15561.49	15383.12	12430.52	21633.86	21621.25	27068.08
Age Coefficient	-5.00	-68.08	-62.02	36.78	5.34	47.92	55.35
Age SE	39.04	38.97	40.08	39.36	38.98	45.74	53.29
BMI Coefficient	---	-162.73*	-157.06*	19.84	274.70	310.69	519.16*
BMI SE	---	33.00	34.13	101.88	166.36	180.13	227.22
Gender Coefficient	---	---	-433.88	-2138.96*	-1862.07*	-1773.52*	-1197.54
Gender SE	---	---	651.86	680.80	689.12	710.96	801.40
Waist Circumference Coefficient	---	---	---	-65.19	-221.38*	-236.93*	-325.65*

Waist Circumference SE	---	---	---	45.20	92.61	97.40	116.40
Medication Coefficient	---	---	---	---	-2523.37	-2524.36	-3982.26*
Medication SE	---	---	---	---	1309.90	1313.49	1635.92
Duration of T2D Coefficient	---	---	---	---	---	-61.39	4.34
Duration of T2D SE	---	---	---	---	---	115.98	132.34
FreeStyle HbA1c Coefficient	---	---	---	---	---	---	-78.45
FreeStyle HbA1c SE	---	---	---	---	---	---	65.51
R^2	-0.01	0.11	0.10	0.15	0.16	0.16	0.11
AIC	3668.51	3647.29	3648.84	2636.57	2634.74	2636.45	2380.00
BIC	3678.23	3660.26	3665.05	2654.13	2655.24	2659.87	2405.38

Note. *= p <0.05; SE = Standard Error; AIC = Akaike information criterion; BIC = Bayesian information criterion.

Table 4.24: Summary of models exploring the relationship between daily sit to stand transitions standing in non-retired participants and age, BMI, gender, waist circumference, medication status, duration of Type 2 diabetes and FreeStyle Libre HbA_{1c}

	Model						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Mean Intercept	16.51	51.47	57.69	37.73	50.45	50.71	11.80
Age Coefficient	0.58*	0.32	0.11	0.15	0.15	-0.11	-0.28
Age SE	0.18	0.18	0.18	0.16	0.16	0.18	0.20
BMI Coefficient	---	-0.66*	-0.86*	-1.35*	-0.99	-1.74*	-3.19*
BMI SE	---	0.16	0.15	0.41	0.67	0.71	0.86
Gender Coefficient	---	---	15.13*	16.66*	17.04*	15.20*	11.86*
Gender SE	---	---	2.88	2.71	2.78	2.79	3.02
Waist Circumference Coefficient	---	---	---	0.28	0.06	0.38	1.03*

Waist Circumference SE	---	---	---	0.18	0.37	0.38	0.44
Medication Coefficient	---	---	---	---	-3.49	-3.47	6.64
Medication SE	---	---	---	---	5.28	5.15	6.16
Duration of T2D Coefficient	---	---	---	---	---	1.28*	0.70
Duration of T2D SE	---	---	---	---	---	0.45	0.50
FreeStyle HbA1c Coefficient	---	---	---	---	---	---	0.68*
FreeStyle HbA1c SE	---	---	---	---	---	---	0.25
R^2	0.05	0.13	0.24	0.35	0.34	0.37	0.42
AIC	1638.63	1623.13	1598.77	1111.38	1112.92	1106.86	995.52
BIC	1648.36	1636.01	1614.98	1128.94	1133.41	1130.28	1020.90

Note. *= p <0.05; SE = Standard Error; AIC = Akaike information criterion; BIC = Bayesian information criterion.

Appendix C: Chapter 4 Mean Glucose and Glucose Variability Multiple Regression Tables

Table 4.29: Summary of Models Exploring the Relationship Between Mean Glucose and Age, BMI, Gender, Waist Circumference, Retirement Status, Medication Status and Duration of Type 2 Diabetes and Self-Reported HbA_{1c}

	Model							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Mean Intercept	6.34	0.93	0.42	0.01	0.10	0.72	0.43	-0.72
Age Coefficient	0.02*	0.05*	0.05*	0.07*	0.06*	0.07*	0.07*	0.001
Age SE	0.008	0.01	0.01	0.01	0.01	0.01	0.01	0.01
BMI Coefficient	---	0.11*	0.11*	0.16*	0.15*	0.17*	0.16*	-0.13*
BMI SE	---	0.01	0.01	0.03	0.03	0.03	0.04	0.05
Gender Coefficient	---	---	0.83*	0.60*	0.61*	0.62*	0.61*	-0.30
Gender SE	---	---	0.16	0.17	0.17	0.17	0.17	0.18
Waist Circumference Coefficient	---	---	---	-0.02	-0.02	-0.03	-0.02	0.05
Waist Circumference SE	---	---	---	0.01	0.01	0.01	0.02	0.02
Retirement Coefficient	---	---	---	---	-0.04	0.04	0.12	0.32
Retirement SE	---	---	---	---		0.27	0.28	0.35
Medication Coefficient	---	---	---	---	---	-0.28	-0.28	0.52
Medication SE	---	---	---	---	---	0.21	0.21	0.28

0.12Duration of T2D Coefficient	---	---	---	---	---	---	0.02	0.12
Duration of T2D SE	---	---	---	---	---	---	0.02	0.03
Self-Reported HbA1c Coefficient	---	---	---	---	---	---	---	0.13
Self-Reported HbA1c SE	---	---	---	---	---	---	---	0.02
R^2	0.01	0.17	0.22	0.23	0.23	0.23	0.23	0.58
AIC	1591.33	1522.31	1496.79	1110.40	1112.38	1112.60	1113.94	463.82
BIC	1603.35	1538.34	1516.84	1132.87	1138.60	1142.56	1147.65	494.70

Note. *= p <0.05; SE = Standard Error; AIC = Akaike information criterion; BIC = Bayesian information criterion.

Table 4.30: Summary of Models Exploring the Relationship Between Glucose Range and Age, BMI, Gender, Waist Circumference, Retirement Status, Medication Status and Duration of Type 2 Diabetes and Self-Reported HbA_{1c}

	Model							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Mean Intercept	4.28	4.09	3.63	4.34	4.24	7.47	7.01	4.07
Age Coefficient	0.03*	0.03*	0.04*	0.03*	0.03	0.04*	0.04*	0.02
Age SE	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02
BMI Coefficient	---	0.003	-0.004	-0.05	-0.05	0.02	-0.003	-0.22*
BMI SE	---	0.02	0.02	0.04	0.04	0.04	0.05	0.08

Gender Coefficient	---	---	0.76*	0.51*	0.51*	0.58*	0.57*	-0.72*
Gender SE	---	---	0.20	0.22	0.22	0.21	0.21	0.30
Waist Circumference Coefficient	---	---	---	0.01	0.01	-0.04*	-0.03	0.02
Waist Circumference SE	---	---	---	0.02	0.02	0.02	0.02	0.04
Retirement Coefficient	---	---	---	---	0.04	0.45	0.58	1.65*
Retirement SE	---	---	---	---	0.34	0.34	0.36	0.58
Medication Coefficient	---	---	---	---	---	-1.47*	-1.47*	-0.66
Medication SE	---	---	---	---	---	0.27	0.27	0.46
Duration of T2D Coefficient	---	---	---	---	---	---	0.03	0.20*
Duration of T2D SE	---	---	---	---	---	---	0.03	0.05
Self-Reported HbA1c Coefficient	---	---	---	---	---	---	---	0.07*
Self-Reported HbA1c SE	---	---	---	---	---	---	---	0.03
R^2	0.02	0.02	0.05	0.05	0.05	0.13	0.13	0.28
AIC	1721.80	1723.75	1711.99	1285.10	1287.09	1259.61	1260.59	630.11
BIC	1733.83	1739.78	1732.03	1307.58	1313.31	1289.58	1294.30	660.99

Note. *= p <0.05; SE = Standard Error; AIC = Akaike information criterion; BIC = Bayesian information criterion.

Table 4.31: Summary of Models Exploring the Relationship Between Glucose Standard Deviation and Age, BMI, Gender, Waist Circumference, Retirement Status, Medication Status and Duration of Type 2 Diabetes

	Model							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Mean Intercept	1.13	0.95	0.83	1.00	1.03	1.85	1.72	0.97
Age Coefficient	0.01*	0.01*	0.01*	0.01*	0.01	0.01*	0.01*	0.004
Age SE	0.002	0.002	0.002	0.002	0.01	0.004	0.004	0.01
BMI Coefficient	---	0.004	0.002	-0.01	-0.01	0.01	0.01	-0.07*
BMI SE	---	0.004	0.004	0.01	0.01	0.01	0.01	0.02
Gender Coefficient	---	---	0.20*	0.13*	0.13*	0.15*	0.15*	-0.27*
Gender SE	---	---	0.05	0.06	0.06	0.06	0.06	0.08
Waist Circumference Coefficient	---	---	---	0.001	0.001	-0.01*	-0.01	0.02
Waist Circumference SE	---	---	---	0.004	0.004	0.01	0.01	0.01
Retirement Coefficient	---	---	---	---	-0.01	0.10	0.13	0.24
Retirement SE	---	---	---	---	0.09	0.09	0.10	0.15
Medication Coefficient	---	---	---	---	---	0.38*	-0.38*	-0.06
Medication SE	---	---	---	---	---	0.07	0.07	0.12

Duration of T2D Coefficient	---	---	---	---	---	---	0.01	0.05*
Duration of T2D SE	---	---	---	---	---	---	0.01	0.01
Self-Reported HbA1c Coefficient	---	---	---	---	---	---	---	0.02*
Self-Reported HbA1c SE	---	---	---	---	---	---	---	0.01
R^2	0.02	0.02	0.05	0.04	0.04	0.12	0.12	0.28
AIC	636.88	638.09	625.92	451.34	453.34	427.62	428.35	197.51
BIC	648.91	654.13	645.97	473.82	479.56	457.59	462.07	228.39

Note. *= p <0.05; SE = Standard Error; AIC = Akaike information criterion; BIC = Bayesian information criterion.

Table 4.32: Summary of Models Exploring the Relationship Between Glucose Coefficient of Variance and Age, BMI, Gender, Waist Circumference, Retirement Status, Medication Status and Duration of Type 2 Diabetes and Self-Reported HbA1c

	Model							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Mean Intercept	0.19	0.31	0.31	0.37	0.36	0.47	0.45	0.37
Age Coefficient	0.003	-0.0003	-0.003	-0.001*	-0.001	-0.001	-0.001	-0.0002
Age SE	0.003	0.0003	0.0003	0.0003	0.001	0.001	0.001	0.001
BMI Coefficient	---	-0.002*	-0.002*	-0.01*	-0.01*	-0.003*	-0.004*	-0.01*
BMI SE	---	0.001	0.001	0.001	0.001	0.001	0.002	0.003
Gender Coefficient	---	---	0.004	0.001	-0.001	0.001	0.001	-0.03*

Gender SE	---	---	0.01	0.01	0.01	0.01	0.01	0.01
Waist Circumference Coefficient	---	---	---	0.001	0.001	-0.001	-0.001	0.001
Waist Circumference SE	---	---	---	0.001	0.001	0.001	0.001	0.002
Retirement Coefficient	---	---	---	---	0.001	0.01	0.02	0.03
Retirement SE	---	---	---	---	0.01	0.01	0.01	0.02
Medication Coefficient	---	---	---	---	---	-0.05*	-0.05*	-0.02
Medication SE	---	---	---	---	---	0.01	0.01	0.02
Duration of T2D Coefficient	---	---	---	---	---	---	0.001	0.003
Duration of T2D SE	---	---	---	---	---	---	0.001	0.002
Self-Reported HbA1c Coefficient	---	---	---	---	---	---	---	-0.001
Self-Reported HbA1c SE	---	---	---	---	---	---	---	0.001
R^2	0.002	0.05	0.05	0.08	0.08	0.16	0.16	0.17
AIC	-1072.36	-1092.39	-1090.80	-850.63	-848.63	-877.40	-877.23	-427.83
BIC	-1060.33	-1076.35	-1070.75	-828.15	-822.41	-847.43	-843.51	-396.95

Note. *= p <0.05; SE = Standard Error; AIC = Akaike information criterion; BIC = Bayesian information criterion.

Table 4.33: Summary of Models Exploring the Relationship Between Glucose CONGA*n* and Age, BMI, Gender, Waist Circumference, Retirement Status, Medication Status and Duration of Type 2 Diabetes

	Model							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Mean Intercept	0.58	0.79	0.72	0.99	1.04	1.37	1.28	0.68
Age Coefficient	0.01*	0.01*	0.01*	0.01*	0.01	0.01*	0.01	-0.001
Age SE	0.001	0.02	0.002	0.002	0.003	0.03	0.003	0.004
BMI Coefficient	---	-0.01	-0.01	-0.02*	-0.02*	-0.01	-0.02	-0.07*
BMI SE	---	0.003	0.003	0.01	0.01	0.01	0.01	0.01
Gender Coefficient	---	---	0.12*	0.09*	0.09*	0.10*	0.10*	-0.11*
Gender SE	---	---	0.04	0.04	0.04	0.04	0.04	0.05
Waist Circumference Coefficient	---	---	---	0.002	0.002	-0.003	-0.001	0.02*
Waist Circumference SE	---	---	---	0.003	0.003	0.004	0.004	0.01
Retirement Coefficient	---	---	---	---	-0.02	0.02	0.05	0.01
Retirement SE	---	---	---	---	0.06	0.06	0.07	0.10
Medication Coefficient	---	---	---	---	---	-0.15*	-0.15	0.13
Medication SE	---	---	---	---	---	0.05	0.05	0.08

Duration of T2D Coefficient	---	---	---	---	---	---	0.05	0.03*
Duration of T2D SE	---	---	---	---	---	---	0.05	0.01
Self-Reported HbA1c Coefficient	---	---	---	---	---	---	---	0.003
Self-Reported HbA1c SE	---	---	---	---	---	---	---	0.01
R^2	0.06	0.06	0.08	0.11	0.11	0.13	0.13	0.29
AIC	344.63	344.48	336.39	222.67	224.57	217.96	218.84	73.49
BIC	356.66	360.51	356.43	245.15	250.79	247.93	252.56	104.36

Note. *= p <0.05; SE = Standard Error; AIC = Akaike information criterion; BIC = Bayesian information criterion.

Appendix D: Chapter 4 Individual regression analysis examining the relationship between sitting time and glucose

Table 4.35: Table Summarising the Individual Regression Analysis Examining the Relationship Between Sitting Time and Glucose

Participant ID	Mean Glucose	Glucose Range	Glucose SD	Glucose CoV	Glucose CONGA*n*
1	-2.61	1.73	11.29	89.58	4.87
2	8.16	-0.47	-0.05	-23.62	-7.82
3	-8.73	3.17	12.84	91.49	17.60
4	0.51	0.45	1.29	7.84	1.42
5	2.38	1.53	9.04	64.20	6.74
6	-0.30	-1.13	0.90	5.39	-67.53
7	3.50	-0.52	-1.90	-26.02	-2.63
8	-1.66	-1.90	-7.68	-110.05	-7.02
9	2.36	-0.86	-4.05	-31.99	-2.38
10	14.67	0.10	8.64	29.44	11.90
11	4.48	-1.99	-3.35	-29.65	-12.51
12	5.58	0.80	1.54	-19.34	14.81
13	1.56	1.87	15.18	120.94	-2.44
14	4.15	-4.55	-14.58	-76.58	-10.62
15	5.80	1.44	6.99	22.40	11.14
16	-2.82	-0.41	-2.07	-2.94	-7.97
17	24.44	-5.91	-12.13	-118.56	-27.55
18	4.23	1.85	7.17	57.67	11.79
19	2.22	-4.00	-2.45	-27.51	-7.97
20	0.77	-0.18	2.51	18.85	-27.55
21	9.55	2.04	14.82	105.25	11.79
22	8.24	-9.93	-22.19	-140.92	-15.64
23	19.27	-14.47	-5.14	-46.14	-14.16
24	14.41	1.57	4.16	-0.53	2.45
25	11.14	2.97	9.32	45.43	166.02

26	-3.63	2.30	16.95	239.59	-13.14
27	12.89	0.49	6.18	22.49	-6.62
28	-3.46	-2.23	-9.59	-67.73	9.99
29	0.32	0.42	2.55	15.81	17.11
30	2.84	-1.02	-0.46	-29.29	1.72
31	1.18	0.52	3.20	34.22	-9.91
32	-2.65	-1.47	-1.11	1.89	4.25
33	-7.38	0.86	4.56	43.87	3.52
34	-9.99	-1.53	-6.69	-42.54	-1.64
35	3.62	-0.84	-3.86	-45.20	5.34
36	1.00	-0.43	-0.55	-10.95	8.80
37	6.97	0.34	-8.08	-52.90	-1.72
38	5.86	0.13	0.09	-13.67	1.50

Note. SD = Standard Deviation, CoV = Coefficient of Variation, CONGA = continuous overlapping net glycemic action (n hours)

Appendix E: Chapter 5 Diet Choice of Each Participant

During visit 1, the participants will be asked what they would like for breakfast, lunch, dinner and bedtime snack. This will be recorded. Breakfast and lunch will be standardised. The participants will be able to choose one of four different types of dinner and given a bedtime snack. The participants will be advised to have the same dinner and bedtime snacks at the exact time on each intervention day.

Breakfast

- (1) Weetabix 52 grams plus 250ml full fat milk = 50grams of carbohydrates
- (2) Cornflakes 45.4 grams plus 250ml full fat milk = 50 grams of carbohydrates.
- (3) 2 slides of Warburtons Thick White Bread with Butter (44 g CHO) plus 200 ml of full fat milk (9.32 g of CHO) = 53.32 g of carbohydrates.
- (4) 1 New York Bakery Co. Bagels, Blueberry with Butter (44.4 g CHO) plus 200 ml of full fat milk (9.32 g of CHO) = 53.72 g CHO
- (5) Sandwich x 2 slices thick bread 36 g of CHO and crisps 25 gram of multipack bag (51 g of CHO)

Lunch

- (1) Sandwich x 2 slices thick bread 40 grams of carbohydrates, yogurt 14-16 grams of carbohydrates, crisps 25 gram of multipack bag 13-15 grams of carbohydrates

Dinner

- (1) Sainsbury's spinach & ricotta cannelloni (400 g) (50.9 g CHO)
- (2) Sainsbury's beef lasagne (390 g) (45.5 g CHO)
- (3) Sainsbury's fish pie (450 g) (41.7 g CHO)
- (4) Sainsbury's chicken tikka masala & rice (380 g) (55.6 g CHO)

With side dish Sainsbury's classic salad bowl (205 g) (5.8 g CHO)

Bedtime snack

- (1) a slide of bread (22g) (10 g CHO)
- (2) a small apple (85 g) (10 g CHO)
- (3) a plum (110 g) (10 g CHO)

Appendix F: Chapter 6 Interview Topic Guide

Question	Prompt
How physically active do you feel you are?	Why do you feel that is? Can you tell me more about your activity?
Do you feel you could be more physically active?	Why do you feel that? How do you think you could be…? What makes it difficult for you? How do you feel it could be made easier?
What do you understand about the implications of sitting for long periods of time?	Why do you think that?
Are there times where you feel you sit for longer than 60minutes at a time?	Can you tell me more about that? How do you feel about sitting for that long?
How feasible do you think it would be for you to sit for less time during the day?	Why do you think that? How could it be made easier for you to sit less? Do you think standing up every 15/30/60 minutes would be acceptable if you knew it was helping you manage your diabetes?
Have you ever thought of using technology as a way of helping you to sit less or be more active?	What do you think about technology? Do you think you would find this type of technology useful? How do you feel about using this type of technology to monitor your activity and sitting behaviour? Do you think monitoring your behaviour for a period of time would be enough to encourage you to change your behaviour? Do you think this type of technology could be used to help you change your sitting behaviour over a long period of time? What do you/ don't you like about the idea of using technology in this way?
What types of technology have you used before?	Can you tell me more about that? What in particular did you like/ dislike about it? Do you think you would use it again? Why do you think that is?

Before we started I showed you some examples of the technology that is available, what did you think about them?	Why do you think that is? What in particular did you like/ dislike about it? What was your preferred type of technology that I showed you? What other features do you feel could be integrated into the technology that would be useful?
Have you ever used technology as a prompt or reminder?	What did you think about it? If not, would you consider it? Would you consider using a prompt to remind you to monitor your behaviour? Would you consider using a prompt to remind you to break your sitting time? What type of prompt do you think you would be most likely to use? And how long do you think you would use it for, for example, a couple of weeks/ months?