Measuring group and individual relationship between patterns in sedentary behaviour and glucose in type 2 diabetes adults

Kathryn A. McMillan[1,2], Aye C. Paing[3], Alison F. Kirk[1], Allan Hewitt[1], Sandra MacRury[4], Andrew Collier[3], Sebastien F.M. Chastin[3,5]

Author affiliations: [1]Physical Activity for Health Group, School of Psychological Sciences and Health, University of Strathclyde, Glasgow, UK. [2]Digital Health and Wellness Group, Department of Computer and Information Science, University of Strathclyde, Glasgow, UK. [3]School of Health and Life Sciences, Glasgow Caledonian University, Glasgow, UK. [4]Highland Diabetes Institute, University of Highlands and Islands, Inverness, UK. [5]Department of Movement and Sports Science, Ghent University, Ghent, Belgium

Kathryn Anne McMillan, Ph.D Digital Health and Wellness Group LT14.14a Livingstone Tower University of Strathclyde Glasgow kathryn.mcmillan@strath.ac.uk 0141 548 4101	Aye Chan Paing School of Health and Life Sciences Room-257, Govan Mbeki Building Glasgow Caledonian University Glasgow AyeChan.Paing@gcu.ac.uk 0141 331 3357
Dr Alison Kirk, Ph.D Physical Activity for Health Group Room 532 Graham Hills Building University of Strathclyde Glasgow alison.kirk@strath.ac.uk 0141 548 4153	Dr Allan Hewitt, Ph.D Physical Activity for Health Group Room 538 Graham Hills Building University of Strathclyde Glasgow allan.hewitt@strath.ac.uk 0141 548 3255
Professor Sandra MacRury, MD Highland Diabetes Institute University of Highlands and Islands Inverness sandra.mcarury@uhi.ac.uk 01463 279 583	Professor Andrew Collier School of Health and Life Sciences Govan Mbeki Building Glasgow Caledonian University Glasgow Collier, andrew.collier@aaaht.scot.nhs.uk
Professor Sebastien Chastin School of Health and Life Sciences Govan Mbeki Building Glasgow Caledonian University Glasgow sebastien.chastin@gcu.ac.uk	

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Corresponding author: Kathryn Anne McMillan, Room LT1414a, Livingston Tower, 16 Richmond Street, Glasgow, G1 1XQ. E-mail address: kathryn.mcmillan@strath.ac.uk

Abbreviations: (FGM) Flash Glucose Monitoring, (UEC) University Ethics Committee, (COV) Coefficient of variation, (BMI) Body Mass Index

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Abstract

Aims: Explore the relationship between patterns in sedentary behaviour and glucose in adults with Type 2 diabetes.

Methods: 37 adults with Type 2 diabetes managed with diet and/or anti-diabetes medication (not insulin) were recruited. Participants wore an activPAL accelerometer and FreeStyle Libre flash glucose monitor for continuous measurement of activity and glucose for 24hours/day for 3-14days whilst documenting sleep, food and medication. The relationship between daily patterns of sedentary behaviour and sedentary breaks with glucose was investigated using correlation analysis. Regression analysis was used to investigate these relationships at an individual level.

Results: Participants (mean age 62.8±10.5yrs, BMI 29.6±6.8 kg/m^2) spent 64% of their day sedentary, 44.7% of sedentary bouts were 30-60 minutes in duration and mean bout duration was 47.2 minutes. No association between mean glucose and sedentary proportion (total sedentary time) was identified. Mean glucose and glucose standard deviation were positively correlated with sedentary bout duration (both $p<0.05$). Individual regression analysis showed increased sedentary time is associated with increased mean glucose in 25 (68%) of the participants, with a negative association being shown in 12 (32%) of the participants.

Conclusions: In analysis of the whole group, sedentary bout duration but not sedentary proportion was associated with mean glucose and glucose variability. Individual regression analysis identified a different relationship pattern for the majority of participants. This is the first study to identify an individualised response to activity behaviour and highlights the importance of conducting individual analysis when using continuous measurement methods.

Key Points:

1. A reduction in prolonged bouts of sedentary behaviour are beneficial to good glycaemic control in people with Type 2 diabetes.
2. There is no relationship between proportion of time spent sedentary and mean glucose.
3. Longer bouts of sedentary behaviour is associated with increased glucose variability.
4. There is an individual nature in the relationship between sedentary behaviour and glucose.
5. Further research is required using digital wearable technologies to explore these individual relationships in more detail and to understand how the technology and information obtained can be used to support and tailor health care interventions.

Introduction

There is substantial evidence documenting the benefits of frequent physical activity for people with Type 2 diabetes [1, 2, 3] including improvements in glycaemic control and insulin sensitivity [2, 3]. Sedentary behaviour, characterised as any waking behaviour in a sitting or reclined posture with a resultant energy expenditure of $\leq$1.5 metabolic equivalents [4], has been associated with poorer glucose outcomes, independent of physical activity levels [5]. In adults with Type 2 diabetes, regular physical activity breaks in sedentary time of 3-minutes of light intensity walking or 3-minutes of simple resistance activities every 30 minutes significantly reduced glucose, compared to continuous prolonged sitting during an 8-hour lab period [6]. This pattern of reducing prolonged periods of sedentary behavior is recommended in current American Diabetes Association guidelines; however, the current guidelines surrounding sedentary behaviour are quite broad and do not suggest a specific dose, but rather just to minimise time spent sedentary [7]. Studies to date have objectively measured physical activity and sedentary behaviour in people with Type 2 diabetes in a free-living setting [8]. Others have examined the relationship between objectively measured physical activity and sedentary behaviour and continuously measured glucose in a lab setting [6, 9, 10], but identifying associations in a freeliving setting are important for transferability of future interventions and to enable more specific guidelines [11].

Advances in technology have led to the development of mobile technologies, which continuously monitor lifestyle behaviours and health outcomes. Flash Glucose Monitoring (FGM) is one of the newest methods of glucose monitoring, providing multiple continuous glucose readings compared with conventional ad hoc capillary blood glucose data or 3-month averaged glucose with HbA_{1c}. Further benefits of FGM include the lack of need for regular calibrations and the low cost compared to continuous glucose monitors, making these devices accessible and minimally invasive. FGM has been validated against capillary blood glucose

sampling [12] and have been used in previous research to continuously measure glucose [13,14]. Using mobile technologies that continuously measure behaviour and health outcomes within research opens opportunity to explore in detail group and individual patterns and associations between these outcomes.

The aim of this study was to examine relationship between patterns in sedentary behavior and glucose at group and individual levels when continuously measured using mobile technologies in people with Type 2 diabetes.

Methods

Participants

Eligible participants were adults (>18yrs) with Type 2 diabetes, receiving diet modifications and/or anti-diabetes medication (not insulin). Exclusion criteria were pregnancy, cancer, alcohol or substance misuse and hepatic or renal function impairment. Participants were recruited by distributing posters and emails around the University of Strathclyde and Glasgow Caledonian University, visiting local diabetes support groups and an advert appeared in Diabetes UK Balance magazine. The study was approved by the University Ethics Committee of the University of Strathclyde and conformed to the Declaration of Helsinki. Written informed consent was received from all participants.

Study procedures

This intensive longitudinal study was conducted between February 2016 and February 2017 and consisted of two visits. At the first, demographic data were recorded including: age, gender, height, weight, waist circumference, anti-diabetes medication, retirement status and duration of diabetes. Participants were fitted with a FreeStyle Libre flash glucose monitor (Abbott FreeStyle Libre, Abbott Diabetes Care, CA, USA) with a sensor inserted into the subcutaneous tissue at the back of the upper arm. Participants were also fitted with a

waterproofed activPAL3 activity monitor (PAL Technologies, Glasgow, UK) on the front of the right thigh midway between the knee and the hip [15]. Participants were requested to wear both devices 24 hours/day for a minimum of 3 and up to 14 days of normal daily living. A minimum of three days was decided in order to comply with recommendations from previous activity monitoring research [16]. At the time of this study there were no published recommendations for glucose and therefore the same observational time frame was used. Measurement was limited to a maximum of 14days by the capacity of the FreeStyle Libre sensors. Participants were provided with dietary, medication and sleep recall forms. This allowed for average daily carbohydrate intake to be calculated for each participant using the Carbs & Cals Counter [17]. After 3-14 days, participants attended a second visit to remove the devices. If participants lived further away and were unable to attend the University, a postal method was used. In this instance, the devices were initialised and waterproofed, ready to be attached, and posted to participants with instructions on how to attach and remove the devices and complete the demographic questionnaire and the recall forms. Participants were also asked to self-report weight, height and waist circumference.

Outcome measures

Flash glucose monitor - Abbott FreeStyle Libre

The Abbott FreeStyle Libre records interstitial glucose every 15 min for up to 14 days. Glucose data are retrieved wirelessly by placing the glucose reader close to the sensor for a few seconds. Due to the limited memory in the sensor, the reader must be scanned at least every 8 hours. The raw glucose data were extracted using the FreeStyle Libre software (version 1.0). Glucose summary data extracted included: Wake time mean glucose (mmol/l) and commonly used measures of glucose variability; standard deviation (SD), range

(difference between minimum and maximum glucose value) and coefficient of variation (COV)[18].

Sedentary behaviour - PAL Technologies ActivPAL3

The activPAL3 accelerometer was used to measure sedentary behaviour. The activPAL3 records time spent sitting/lying, standing and stepping, in addition to step count and sit to stand transitions, for up to 14days. After 3-14 days of wear time, the data were downloaded using activPAL3^{TM} software (version 7.2.32). To determine the total daily sedentary time, the time spent in sitting/lying posture for each day (hours and % of day) was calculated, after excluding the sleep manually using a sleep diary. For each participant, the average time (h) and proportion (%) per day spent sitting and total sit to stand transitions over the monitored days were computed. A day was defined by self-reported wake time to self-reported sleep time. Using the activPAL events output file, individual sedentary bouts were identified and categorised by duration (≤30 minutes, 30-60 minutes and >60 minutes).

Data Alignment

Once the raw data had been extracted, the first and last days of recording were removed from the dataset. Sleep was removed and the datasets were combined using Matlab. Only data from participants with three days of matched data were included in the analysis. The process of data alignment and analysis has been published previously [19].

Statistical analysis

Sample size calculations were based on reported associations between breaks in sedentary time and high 2-h plasma glucose ($R^2 = 0.21$) [20]. Assuming a statistical power of 85%, an alpha of 0.05 and six predictors, we estimated that 37 participants would be required to detect significant associations between sedentary time and glucose measures.

Data processing was conducted using Matlab (MathWorks, USA) and Microsoft Excel (Microsoft, USA). Data analysis was conducted using R (R Foundation, USA). Descriptive data of participants were described as numbers and mean with standard deviation (SD). Pearson correlation analysis was used to examine the association between sedentary behaviour patterns and wake time glucose patterns at a group level. The models were adjusted for confounding factors (age, BMI, gender, waist circumference, duration of diabetes diagnosis, medication status, retirement status, mean daily carbohydrate intake, mean sleep, mean step count and mean glucose). Thresholds for correlation coefficient >0.7 and Variance Inflation Factor >10 were used to determine the presence of multi-collinearity between independent variables [21]. In this study, no evidence of multi-collinearity was detected between independent variables (Correlation coefficients <0.7, Variance Inflation Factors <5). Individual regression analysis was used to examine these relationships at an individual level by looking at day-to-day variation within an individual. This method addresses the multi-level nature of the data, where multiple days of data per participant were collected. Significance was identified at p <0.05.

Results

Participant characteristics

Participants (n=37) had a mean age of 62.8±10.5 years, mean BMI (body mass index) of 29.6±6.8 kg/m^2 and mean diabetes duration of 6.61±5.2 years. Most participants were female (n=23, 62.2%), just over half (n=20, 54.1%) of participants were retired and most (n=25, 67.6%) were taking anti-diabetes medication (Table 1). Several participants reported their last known HbA_{1c} (n=22, mean=47.7±10.6 mmol/mol) and waist circumference (n=28, Mean=99.8±13.7 cm). $HbA_{1c,}$ as estimated by the FreeStyle Libre, was available for most participants (n=34, Mean=42.5±11.1 mmol/mol).

Habitual sedentary behaviour and glycaemic control

Mean concurrent wear time for the activPAL3 and FreeStyle Libre was 10±3.4 days, once the first and last days were removed. Participants spent, on average, 10.1±2.4 hours per day sitting/lying (64% of waking day). Mean sit to stand transitions were 49±16 per day. Waking mean glucose was 7.5±1.7 mmol/l (minimum 4.5 mmol/l (M=4.9mmol/l, S =1.4mmol/l), maximum 13.6 mmol/l (M =11.04, SD =2.3mmol/l)). Group wake time glucose variability patterns were calculated for several measures of variability including range, SD and COV (Table 2).

Mean duration of sedentary bout was 47.2±27.6 minutes (Table 3). In total 31.6% of bouts were less than 30 minutes, 44.7% bouts were between 30 to 60 minutes and 23.7% bouts were greater than 60 minutes.

Group association of sedentary behaviour with glycaemic control

Pearson product correlation analysis was conducted and adjusted for confounders, and the results are shown in Table 4. Sedentary proportion was not positively associated with mean glucose, glucose range and glucose standard deviation. Sedentary bout duration was positively associated with glucose range (r=0.47, p <0.05), glucose standard deviation (r=0.25, p <0.05) and glucose coefficient of variation (r=0.27, p <0.05). There was a very weak positive relationship between sedentary bout duration and mean glucose (r=0.06, p <0.05). Sit to stand transitions were negatively associated with glucose range (r=-0.41, p <0.05) and glucose coefficient of variation (r=-0.40, p <0.05).

Individual association of sedentary behaviour with glycaemic control

Figures 1 (a-b), Figure 2 (a-b) and Figure 3 (a-b) illustrate the associations of glucose with sedentary time (%), sedentary bout duration and daily sit to stand transitions, respectively. Each coloured line represents the regression line for an individual participant.

Mean glucose

In 25 participants, increased sedentary time was associated with increased mean glucose. In 22 participants, increased sedentary bout duration was associated with increased mean glucose. In 21 participants, increased daily sit to stand transitions were associated with increased mean glucose.

Glucose variability

The relationship between sedentary time and glucose variability measures were similar to that of sedentary time and mean glucose (standard deviation: 21 positive, 16 negative; range: 20 positive, 17 negative). This differs from the relationship between sedentary bout duration and glucose variability. In 33 of the 37 participants, there was a positive association between sedentary bout duration and glucose standard deviation. In all participants, there was a positive association between sedentary bout duration and glucose range. The relationship between daily sit to stand transitions and glucose variability measures was less consistent between participants than sedentary bout duration (standard deviation: 18 positive, 19 negative; range: 22 positive, 15 negative).

To identify any characteristics that may explain the two groups with differing relationships between glucose and sedentary behaviour, individual participant characteristics were examined. An example of the relationship between sedentary time (%) and mean glucose (mmol/l) is displayed in Table 5 (Supplementary File A). It appears that those with the expected positive relationship (increased sitting is associated with increased mean glucose)

have a lower carbohydrate intake, sleep less, have a higher daily step count and have a lower mean glucose.

Discussion

Analysis of the sedentary behaviour showed participants were spending almost two thirds of their waking day (64%), or just over 10 hours, sedentary, and breaking their sedentary time an average of 49 times/day. This is consistent with findings from the MAASTRICHT study [8], which involved adults (40-75 years) with Type 2 diabetes (*n*=714) wearing an activPAL accelerometer for 8 days and found that those with Type 2 diabetes spent 64.5% (10 hours) of their waking day sedentary and 53 sedentary breaks per day, with the average duration of a sedentary bout 12.62 minutes [8]. The current study found mean sedentary bout duration was 47.2(±27.6) minutes long. The mean wake time glucose was 7.48mmol/l, which is within the recommended <8.5mmol/l target for people with diabetes [22], suggesting glucose was relatively well controlled in this group. This could be reflected in the recruitment methods used in this study, which may have led to participants who are more motivated and committed to managing their glucose. Additionally, the sample did not include those on insulin therapy and mean diabetes duration was relatively short, both of which could have an impact on mean glucose.

The correlation analysis was conducted to identify whether there was a generic relationship between sedentary behaviour and glucose. Increased proportion of time spent sedentary had no association with mean glucose when adjusted for confounders. In contrast, lab-based studies have found interrupting prolonged sitting time in those with Type 2 diabetes lead to significantly lower mean glucose, which persisted for up to 22 hours [6, 12, 13]. Similarly, a longitudinal, descriptive study found increased sedentary time was predictive of increased time spent in hyperglycaemia in people with Type 2 diabetes (*n*=86) [22]. Dunstan et al [24] found regular activity breaks in sedentary behaviour lead to significant (p <0.01) reductions

in glucose area under the curve. Kingsnorth et al. (2018) found that sedentary time was positively associated with higher mean glucose and glucose variability in nondiabetic adults over 13 days [11]. The difference in study design and participants involved could explain the differences in findings between the current study and those discussed [6, 9, 10, 11, 23, 24]. The previous studies were controlled lab-based studies in which sedentary behaviour was manipulated, what sedentary behaviour was broken up with was controlled for and participants were provided with standardised meals. The current study was conducted in a free-living setting.

Increased sedentary bout duration was associated with significantly increased mean glucose and glucose variability, implying that if sedentary time is accumulated in fewer, but longer bouts, it is associated with poorer glycaemic control. To examine these relationships further, and account for the multi-level data, individual regression analysis was conducted. This is the first time this relationship has been analysed in this way and has presented some novel and interesting findings. The individual analysis showed a different glucose response to sedentary behaviour. The individuality is quite clearly shown in figures 1, 2 and 3, as there is noticeable variability between participants who have the same direction of relationship. Participant characteristics were checked in an attempt to identify anything that may explain the different relationships. An example of this is presented in supplementary file A and interestingly, those participants in the group whose mean glucose increased the more time they spent sedentary were more active, slept less, had a lower daily carbohydrate intake and had a lower daily mean glucose. Further examination is required; however, differences in baseline fitness, other medical conditions, the glycaemic index of meals, the timing of meals and medication may be some individual factors influencing these relationships.

A similar individual glucose response was reported in a large cohort (n=800) study examining the effect of meal content on glucose [25]. Participants in this study did not have

Type 2 diabetes. The response to identical meals were assessed and high variability was shown between participants. Additionally, four sub-types of Type 2 diabetes have recently been identified and Ahlqvist et al [26] 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. This is the first study to identify an individualised response to activity behaviour as suggested by Ahlqvist and colleagues [26].

There is growing evidence to support a more personalised approach to diabetes care [25, 26] and incorporating mobile technology could provide a mechanism for this tailored approach. A recent pilot study examined the use of personalised glucose feedback to change activity behaviour in nondiabetic adults (n=33) and found that the feedback resulted in reduced sedentary time at follow-up. This is an example of how digital health may be used to promote behaviour change and self-management in the future [27]. More research is required using these technologies to further understand the relationships identified in the current study and explore how this information can be used to provide a personalised prescription [28, 29, 30].

Strengths

The key strength of this study is the free-living context combined with objective and continuous measurement of sedentary behaviour and glucose and the inclusion of self-reported food intake. This, along with a sample size of 37 and average wear time of 10 days per participant, enabled a large amount of data to be collected and thereby increasing the rigor of our findings. This also presented a significant challenge for data processing and analysis which has previously been discussed [19].

Limitations

The free-living design of the study allowed no control over participant meal content and timing or medication dose and timing; however, participant food and medication diaries were

collected and this data was controlled for in the analysis. Although average carbohydrate intake was calculated and controlled for in the analysis, the glycaemic index of meals, which indicates how quickly a carbohydrate is absorbed, was not. This should be considered in future research examining these relationships. Participant fitness levels and other health conditions were not collected, both of which have been shown to influence glycaemic control in previous research. Similarly, the focus of this paper was sedentary behaviour and breaks in sedentary behaviour so standing and stepping time were not included in the analysis. Future analysis focusing on the types of behaviour during a sedentary break would provide valuable insight into what behaviours would be most beneficial to break sedentary behaviour with. Participants were not blinded to the feedback provided by the FreeStyle Libre and therefore there is a possibility that they altered their behaviour based on this feedback.

Conclusions

Findings from this study highlight the individualised nature of the relationship between sedentary behaviour and glucose in adults with Type 2 diabetes emphasising that lifestyle modification will have different results in different individuals. This is an important finding given the current advances in technology. There are an increasing number of devices providing objective and continuous measurement of lifestyle behaviours and health outcomes. Further research is required to explore these individual relationships further and to understand how the technology and information obtained can be used to adopt individualised precision prescription of lifestyle modification.

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References

1. Thomas D, Elliott EJ, Naughton GA. Exercise for type 2 diabetes mellitus. Cochrane database of systematic reviews. 2006(3).

2. Avery L, Flynn D, Van Wersch A, Sniehotta FF, Trenell MI. Changing physical activity behavior in type 2 diabetes: a systematic review and meta-analysis of behavioral interventions. Diabetes care. 2012 Dec 1;35(12):2681-9.

3. Umpierre D, Ribeiro PA, Kramer CK, Leitão CB, Zucatti AT, Azevedo MJ, Gross JL, Ribeiro JP, Schaan BD. Physical Activity Advice Only or Structured Exercise Training and Association With Hba: A Systematic Review and Meta-analysis1c: A Systematic Review and Meta-analysis Levels in Type 2 Diabetes: A Systematic Review and Meta-analysis. Jama: The Journal of the American Medical Association. 2011 May 4;305(17):1790-9.

4. Tremblay MS, Aubert S, Barnes JD, Saunders TJ, Carson V, Latimer-Cheung AE, Chastin SF, Altenburg TM, Chinapaw MJ. Sedentary behavior research network (SBRN)–terminology consensus project process and outcome. International Journal of Behavioral Nutrition and Physical Activity. 2017 Dec;14(1):75.

5. Tremblay MS, Colley RC, Saunders TJ, Healy GN, Owen N. Physiological and health implications of a sedentary lifestyle. Applied physiology, nutrition, and metabolism. 2010 Nov 23;35(6):725-40.

6. Dempsey PC, Larsen RN, Sethi P, Sacre JW, Straznicky NE, Cohen ND, Cerin E, Lambert GW, Owen N, Kingwell BA, Dunstan DW. Benefits for type 2 diabetes of

interrupting prolonged sitting with brief bouts of light walking or simple resistance activities. Diabetes care. 2016 Apr 13:dc152336.

7. American Diabetes Association. 4. Lifestyle management: Standards of medical care in diabetes—2018. Diabetes Care. 2018 Jan 1;41(Supplement 1):S38-50.

8. van der Berg JD, Stehouwer CD, Bosma H, van der Velde JH, Willems PJ, Savelberg HH, Schram MT, Sep SJ, van der Kallen CJ, Henry RM, Dagnelie PC. Associations of total amount and patterns of sedentary behaviour with type 2 diabetes and the metabolic syndrome: The Maastricht Study. Diabetologia. 2016 Apr 1;59(4):709-18.

9. Dempsey PC, Blankenship JM, Larsen RN, Sacre JW, Sethi P, Straznicky NE, Cohen ND, Cerin E, Lambert GW, Owen N, Kingwell BA. Interrupting prolonged sitting in type 2 diabetes: nocturnal persistence of improved glycaemic control. Diabetologia. 2017 Mar 1;60(3):499-507.

10. Duvivier BM, Schaper NC, Hesselink MK, van Kan L, Stienen N, Winkens B, Koster A, Savelberg HH. Breaking sitting with light activities vs structured exercise: a randomised crossover study demonstrating benefits for glycaemic control and insulin sensitivity in type 2 diabetes. Diabetologia. 2017 Mar 1;60(3):490-8.

11. Kingsnorth AP, Whelan ME, Sanders JP, Sherar LB, Esliger DW. Using digital health technologies to understand the association between movement behaviors and interstitial glucose: exploratory analysis. JMIR mHealth and uHealth. 2018;6(5):e114.

12. Bailey T, Bode BW, Christiansen MP, Klaff LJ, Alva S. The performance and usability of a factory-calibrated flash glucose monitoring system. Diabetes technology & therapeutics. 2015 Nov 1;17(11):787-94.

13. Haak T, Hanaire H, Ajjan R, Hermanns N, Riveline JP, Rayman G. Use of flash glucose-sensing technology for 12 months as a replacement for blood glucose monitoring in insulin-treated type 2 diabetes. Diabetes Therapy. 2017 Jun 1;8(3):573-86.

14. Paing AC, McMillan KA, Kirk AF, Collier A, Hewitt A, Chastin SF. The associations of sedentary time and breaks in sedentary time with 24-hour glycaemic control in type 2 diabetes. Preventive medicine reports. 2018 Dec 1;12:94-100.

15. Dall PM, Skelton DA, Dontje ML, Coulter EH, Stewart S, Cox SR, Shaw RJ, Čukić I,… Chastin SFM. Characteristics of a Protocol to Collect Objective Physical Activity/Sedentary Behavior Data in a Large Study: Seniors USP (Understanding Sedentary Patterns). Journal for the measurement of physical behaviour. 2018 Apr 30;1(1):26-31.

16. Rich, C., Geraci, M., Griffiths, L., Sera, F., Dezateux, C., & Cortina-Borja, M. (2013). Quality control methods in accelerometer data processing: defining minimum wear time. PloS One, 8, DOI:10.1371/journal.pone.0067206.

17. Cheyette C, Balolia Y. Carbs & Cals: Count Your Carbs & Calories with Over 1,700 Food & Drink Photos!. Chello Publishing Limited; 2013.

18. Rawlings RA, Shi H, Yuan LH, Brehm W, Pop-Busui R, Nelson PW. Translating Glucose Variability Metrics into the Clinic via Continuous Glucose Monitoring: AG

raphical User Interface for Diabetes Evaluation (CGM-GUIDE©). Diabetes technology & therapeutics. 2011 Dec 1;13(12):1241-8.

19. McMillan KA, Kirk A, Hewitt A, MacRury S, Lennon M. 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. 2018 Jun;5:2055668318782805.

20. Healy, G. N., Dunstan, D. W., Salmon, J., Cerin, E., Shaw, J. E., Zimmet, P. Z., & Owen, N. (2008). Breaks in sedentary time: beneficial associations with metabolic risk. Diabetes Care, 31(4), pp661-666.

21. Dormann CF, Elith J, Bacher S, Buchmann C, Carl G, Carré G, Marquéz JR, Gruber B, Lafourcade B, Leitão PJ, Münkemüller T. Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. Ecography. 2013 Jan;36(1):27-46.

22. Nathan DM, Kuenen J, Borg R, Zheng H, Schoenfeld D, Heine RJ. Translating the A1C assay into estimated average glucose values. Diabetes care. 2008;31(8):1473-8.

23. Fritschi C, Park H, Richardson A, Park C, Collins EG, Mermelstein R, Riesche L, Quinn L. Association between daily time spent in sedentary behavior and duration of hyperglycemia in type 2 diabetes. Biological research for nursing. 2016 Mar;18(2):160-6.

24. Dunstan DW, Kingwell BA, Larsen R, Healy GN, Cerin E, Hamilton MT, Shaw JE, Bertovic DA, Zimmet PZ, Salmon J, Owen N. Breaking up prolonged sitting

reduces postprandial glucose and insulin responses. Diabetes care. 2012 Feb 27:DC_111931.

25. Zeevi D, Korem T, Zmora N, Israeli D, Rothschild D, Weinberger A, Ben-Yacov O, Lador D, Avnit-Sagi T, Lotan-Pompan M, Suez J. Personalized nutrition by prediction of glycemic responses. Cell. 2015 Nov 19;163(5):1079-94.

26. Ahlqvist E, Storm P, Karajamaki A, Martinell M, Dorkhan M, Carlsson A, Vikman P, Prasad RB, Aly DM, Almgren P, Wessman Y. Clustering of adult-onset diabetes into novel subgroups guides therapy and improves prediction of outcome. bioRxiv. 2017 Jan 1:186387.

27. Whelan ME, Morgan PS, Sherar LB, Kingsnorth AP, Magistro D, Esliger DW. Brain activation in response to personalized behavioral and physiological feedback from self-monitoring technology: pilot study. Journal of medical Internet research. 2017;19(11):e384.

28. Connelly J, Kirk A, Masthoff J, MacRury S. A Website to Promote Physical Activity in People With Type 2 Diabetes Living in Remote or Rural Locations: Feasibility Pilot Randomized Controlled Trial. JMIR diabetes. 2017 Jul;2(2).

29. Duggal R, Brindle I, Bagenal J. Digital healthcare: regulating the revolution. BMJ: British Medical Journal (Online). 2018 Jan 15;360.

30. McMillan KA, Kirk A, Hewitt A, MacRury S. 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. 2017 Mar;11(2):299-307.

Table 1: Participant Descriptive Statistics

***n* = 37**	**Mean (SD)**	***n* (%)**
Age (Years)	62.8 (±10.5)	
BMI (kg/m^2)	29.6 (±6.8)	
Male sex		14 (37.8)
Waist circumference (cm)	99.8 (±13.7)*	
Duration since diagnosis (Years)	6.61 (±5.2)	
Work hours per week (hours)	11.6 (±15.4)	
Self-Reported HbA_{1c} (mmol/mol (%))	47.7 (±10.6) (6.5%)**	
FreeStyle Libre HbA_{1c} (mmol/mol (%))	42.5 (±11.1) (6%)***	
Retired		20 (54.1)
Carbohydrate intake (g/day)	125.3(±21.1)	
Anti-Diabetes Medication		
No medication/ diet controlled		12
Metformin		18
Metformin + sulfonylurea		5
Metformin + gliptin		1
Metformin + sulfonylurea + gliptin		1

Note. *n = 28, **n = 22, ***n = 34

Table 2: Daily sedentary behaviour and glucose during waking time

	Mean (SD)
Sedentary Behaviour	
Sitting/lying (h)	10.1 (±2.4)
Sitting/lying (%)	64.0 (±13.2)
Sit to Stand Transitions	48.6 (±16.4)
Sedentary Bout Duration (mins)	47.2 (±27.6)
Stepping (h)	1.6 (±0.6)
Sleeping (h)	8.3 (±1.4)
Glucose	
Mean (mmol/l)	7.5 (±1.7)
Min (mmol/l)	4.9 (±1.4)
Max (mmol/l)	11.04 (±2.3)
SD	1.6 (±0.5)
Range	6.2 (±1.9)
COV	0.2 (±0.1)

Table 3: Sedentary bout patterns

***n*= 2434**	**Total number of bouts**	**Proportion of bouts (%)**
≤30 minutes	770	31.6
>30 minutes ≤60 minutes	1088	44.7
>60 minutes	576	23.7

Table 4: Association of physical activity and sedentary behaviour with glucose

	Mean Glucose	**Glucose SD**	**Glucose Range**	**Glucose COV**	**Glucose CONGA*n***
Sedentary Time (%)	0.06	0.12	0.04	0.31	0.03
Sedentary Time (h)	0.05	0.12	0.04	0.32	0.03
Sit to Stand	-0.07	-0.24	-0.41*	-0.40*	-0.26
Sedentary Bout Duration	0.06*	0.25*	0.47*	0.27*	--

Note. * = p <0.05