Title:
activPAL and ActiGraph Assessed Sedentary Behavior and Cardiometabolic Health Markers

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Abstract

Aim: To establish whether associations between total, prolonged and breaks in sedentary time and cardio-metabolic health differ when assessed by thigh-worn (activPAL) and waist-worn accelerometry (ActiGraph).

Methods: This study reports data from three studies which recruited participants at a high risk of type 2 diabetes from the East Midlands area, United Kingdom (2010-2014) and assessed sedentary behaviour using two devices: activPAL worn on the thigh continuously and ActiGraph worn on the waist during waking hours. Average total, prolonged (bouts lasting ≥30minutes) and breaks in sedentary time were calculated. Cardiometabolic health markers included adiposity, total, LDL and HDL cholesterol, triglycerides, blood pressure and glucose (fasting, 2hr and HbA1c). Clustered cardiometabolic risk was calculated. Linear regression analysis examined the associations with cardio-metabolic health, adjusted for basic confounders.

Results: 1457 participants (mean age: 59.38 ± 11.85; 51.7% male; mean BMI: 30.19 ± 5.59 kg/m^2) with at least four valid days of both activPAL and ActiGraph data were included. ActivPAL and ActiGraph sedentary variables were moderately correlated (.416 - .648, $p<0.01$), however all variables, except average sedentary time (activPAL: 9.13 ± 1.85 hrs/day vs ActiGraph: 9.22 ± 1.58, $p=0.063$), were significantly different from each other ($p>0.05$). For total and prolonged sedentary time there was consistency in the direction and magnitude of associations for adiposity, HDL, triglycerides and cardiometabolic risk across both devices and for breaks in sedentary time with adiposity and cardiometabolic risk. Differences were observed across devices for diastolic blood pressure for total and prolonged sedentary time, 2hr glucose for total sedentary time and HDL for breaks in sedentary time. No other associations were observed for any other health markers for either device.

Conclusions: Our results suggest that associations with cardiometabolic health are largely comparable across the two common assessments of sedentary behaviour but researchers should be aware that some differences may exist for certain markers of health.

Introduction

A wealth of epidemiological evidence now exists linking high levels of sedentary behaviour, defined as sitting, lying and reclining behaviours with low energy expenditure performed during waking hours, to morbidity (Wilmot, Biswas, Patterson) and mortality (Patterson et al 2018; Ku et al 2018). However, sedentary behaviour has mainly been assessed by self-report, surrogate measures of sitting (e.g., TV viewing), and waist-worn accelerometry. The latter infers sedentary behaviour from lack of movement rather than assessing the specific posture of sitting. Some studies (Healy et al 2008; Healy et al 2011; Henson et al 2013), but not all (Cooper et al 2012; Jefferis et al 2018), also suggest that the number of breaks in sedentary behaviour per day is an important factor for some aspects of health. These 'interruptions in sitting' have however been inferred from waist-worn accelerometer data in epidemiology research. Using data from waist-worn accelerometers, researchers commonly use a cut-off of <100 counts/minute to define sedentary time, which may overestimate time spent sedentary due to upright activity (e.g., standing) with limited movement being included within this threshold. Furthermore, a break in sedentary behaviour is determined when an individual moves above the 100 count/minute threshold, consequently changes from standing to ambulation may be classified as a 'break' leading to an overestimation in the number of breaks per day.

These issues with sedentary behaviour measurement were recently highlighted as a major limitation with the current epidemiology evidence base (Stamatakis et al 2018). A major step forward in this research area would be to measure sedentary time and breaks in sedentary time as accurately as possible by directly assessing the posture of sitting. One such device that can measure sitting is the activPAL accelerometer worn on the thigh. This device can accurately record time spent sitting/lying, standing and stepping as well as transitions from a seated to upright posture (Edwardson et al 2016). In order to aid the interpretation of previous epidemiological research and advance our understanding of sedentary behaviour as a risk factor for health, it is imperative we understand whether, despite not directly measuring sitting and breaks in sitting, the use of cut-points to determine sedentary behaviour from waist-worn accelerometer data produce similar associations with health as a direct assessment of posture, such as data collected from a thigh worn accelerometer. Indeed, research has shown when the activPAL and the waist-worn ActiGraph devices are worn simultaneously there can be a 2-hr difference in sedentary time between the two monitors (Koster et al 2016), accordingly this could potentially influence associations with health. To our knowledge no studies have been published directly comparing activPAL and ActIgraph measured sedentary behaviours and associations with health.

Therefore, the aim of this study was to establish whether associations between total, prolonged and breaks in sedentary time and cardio-metabolic health differ when sedentary behaviours are assessed by thigh-worn (activPAL) and waist-worn accelerometry (ActiGraph) in a population at high risk of T2DM.

Methods

Design and participants

This study used combined data from three diabetes prevention studies: Project STAND (Wilmot et al; Biddle et al), Walking Away from Diabetes (Yates et al; Yates et al 2017), and PROPELS (Yates et al); all of which has been described in detail elsewhere. Baseline data for Project STAND and PROPELS were used and collected in 2010 and 2013-2014 respectively. Data collected at 36 month follow up, during 2013-2014, were used for Walking Away, as this was the only time point where the activPAL was included. All studies recruited participants that were deemed to be at a high risk of developing type 2 diabetes (T2DM) although the method of identification and the inclusion criteria varied slightly between studies as follows:

Project STAND: Adults aged 18-40 years of age were recruited from General Practices (GP) within Leicestershire and Northamptonshire, central England, UK. GP databases were searched for individuals within our target age range and had a BMI in the obese range (≥30kg/m^2 with ≥27.5kg/m^2 for South Asians) or overweight range (≥25kg/m^2 with ≥23kg/m^2 for South Asians) and with one or more additional risk factor for diabetes i) family history of diabetes or cardiovascular disease in a first degree relative; ii) previous gestational diabetes; iii) polycystic ovarian syndrome; iv) HbA1c ≥5.8%; v). impaired glucose tolerance and/or impaired fasting glucose. The study was approved by the Nottingham National Health Service (NHS) Research Ethics Committee.

Walking Away from Diabetes: Adults aged 30-75 years of age were recruited from General Practices (GP) within Leicestershire, UK. A modified version of the automated Leicester Risk Score (Gray et al) was used on GP databases to rank individuals for diabetes risk using predefined weighted variables (age, gender, ethnicity, body mass index (BMI), family history of T2DM and use of antihypertensive medication). Individuals scoring in the 90th percentile within each GP were invited. The study was approved by the Nottingham National Health Service (NHS) Research Ethics Committee.

PROPELS: Adults aged 40–74 years of age for white European, or aged 25–74 years of age for South Asian were recruited from GP practices within Leicestershire and Cambridge, UK. In Cambridge existing research databases were also used to identify eligible individuals. Databases, both GP and existing, were searched for individuals within our target age range for ethnicity and who had a previous blood glucose or HbA1c result recorded in the prediabetes range (NICE, 2012) within the last 5 years. The study was approved by the NHS East Midlands Committee.

Individuals who met the inclusion criteria for the studies were sent a letter from the general practitioner or the Principal Investigator (for existing databases) inviting them to take part along with study information and a reply slip. Reply slips were returned directly to the research team and interested individuals were contacted and booked for their measurement visit. Written informed consent was taken at the baseline assessment.

Demographics and Anthropometric measures
A healthcare professional obtained information on age, sex, ethnicity, smoking status, medical history and medication via a short interview. Height (Leicester Height Measure), body weight (Tanita, West Drayton, UK), body fat (Tanita, West Drayton, UK) and waist circumference (midpoint between the lower costal margin and iliac crest) were measured to the nearest 0.5cm, 0.1 kg, 0.1%, and 0.5 cm, respectively. Body mass index was calculated as by the Tanita scales as kg/m^2.

Objectively measured sedentary behaviour and physical activity
activPAL: Participants were asked to wear the activPAL (PAL Technologies, Glasgow, UK) for 10 days in Project STAND and 7 days in Walking Away from Diabetes and PROPELS. In all three studies the activPAL was worn 24hr/day and was fully waterproofed using nitrile sleeves and Hypafix and attached to the thigh using Hypafix dressing. Devices were initialised using the default settings. Data were processed in STATA using a validated automated algorithm (Winkler et al). This algorithm separates waking wear data from everything else i.e., time in bed, prolonged non-wear and invalid data. Heatmaps of processed data were created (Edwardson et al) to visually check the processed data and any occasions where the algorithm appeared to incorrectly code data, sleep/wear diaries were checked against the heat maps and data were corrected if necessary. Data were considered valid if a day consisted of ≥10 hours of waking wear data, >500 steps and <95% spent in any one behaviour (e.g., sitting, standing, or stepping) (Winkler et al). Participants were required to have at least four valid days to be included in this analysis. Automated code in STATA was then used on the valid data to generate our outcome variables of interest.

ActIgraph: Participants were asked to wear the ActiGraph accelerometer (ActiGraph, Pensacola, FL, USA) for 10 days in Project STAND and 7 days in Walking Away from Diabetes and PROPELS. In all three studies the ActiGraph was worn on an elastic belt on the right midaxillary line of the hip during waking hours only and removed for any water-based activities. Devices were initialised with a sampling frequency of 5 seconds, 15 seconds and 100Hz in Project STAND, Walking Away and PROPELS respectively and then all data was reintegrated into 60 second epochs. Data were processed using a commercially available package (KineSoft version 3.3.76, Loughborough, UK). Non-wear periods, defined as ≥60 minutes of consecutive zero counts with no allowance for counts greater than zero (Orme et al 2014), were removed from the data, days with ≥10 hours of wear data were considered valid (Matthews et al 2012) and participants with at least four valid days were included in the analysis. Sedentary behaviour was determined using a threshold of <100 counts/min, and moderate to vigorous physical activity was derived using a threshold of ≥1952 counts/min (Freedson et al 1998).

Metabolic and cardiovascular markers
Arterial blood pressure was measured in the sitting position (Omron Healthcare, Henfield, UK); three measurements were obtained and the average of the last two measurements was used. HDL, LDL, total cholesterol, triglycerides, and HbA1c were measured in all three studies and in Project STAND and Walking Away fasting and 2-hour challenge glucose were also measured using an Oral Glucose Tolerance Test (OGTT). For Project STAND and Walking Away participants were asked to fast overnight. Cholesterol and triglycerides were measured using standard enzymatic techniques, glucose samples using a glucose oxidase method and HbA1c using the Bio-Rad Variant II HPLC system (Bio-Rad Clinical Diagnostics, Hemel Hempstead, UK). Analysis was conducted by individuals blinded to the patients' identity, using stable methodology standardised to external quality assurance reference values.

Statistical analysis
Statistical analyses were performed using IBM SPSS Statistics 24.

Correlation coefficients and paired t-tests were used to assess the strength of the relationship and the differences, respectively between the following: activPAL waking wear time and ActiGraph wear time, activPAL assessed sitting time and ActiGraph assessed sedentary time, activPAL assessed prolonged sitting time and ActiGraph assessed prolonged sedentary time and activPAL assessed sit-to-upright transitions and ActiGraph breaks in sedentary time.

HDL cholesterol and triglycerides were log transformed due to their skewed distribution. A clustered cardiometabolic risk score was generated using the following health markers: waist circumference, HDL cholesterol, triglycerides, systolic and diastolic blood pressure and HbA1c. For the risk score, each variable was log transformed, followed by conversion to z-scores, HDL z score was inverted, blood pressure variables were summed and averaged and finally all z score variables were summed and divided by the number of variables included (n=5). Linear regression was used to examine associations of total sedentary time, prolonged sedentary and breaks in sedentary time, measured by the ActiGraph and activPAL, with cardiometabolic health markers (adiposity, blood pressure, fasting and 2hour glucose, HbA1c, total cholesterol, HDL and LDL and triglycerides) and the cardiometabolic risk score. The model was adjusted for age (continuous), sex (male, female), ethnicity (white, non-white), smoking status (never and previous, current), family history of T2DM (yes, no), β-blocker (yes, no) and lipid lowering medication status (yes, no), activPAL/ActiGraph waking wear time. Given some dependent variables were log-transformed and to allow for direct comparison between measures and outcomes, results are reported as standardized regression coefficients ± SE.

Results

Out of the 2278 participants across the three studies, a total of 1457 (64%) participants (mean age: 59.38 ± 11.85; 51.7% male; mean BMI: 30.19 ± 5.59 kg/m^2) provided at least four days of valid activPAL and ActiGraph data and were included in this analysis. Participant characteristics of those included are displayed in Table 1. There were no differences in participant characteristics between those who provided valid data and those who did not, with the exception of weight where those included weighed slightly less than those who were not included (84.64 ± 18.23 vs 86.65 ± 19.24 kgs, p=.026).

Time spent in different behaviours (sedentary time, prolonged sedentary time and breaks in sedentary time) measured by the activPAL and ActiGraph are presented in Table 2. ActivPAL and ActiGraph sedentary variables were moderately correlated (.416 - .648, p<0.01), however all variables, except average sedentary time (activPAL: 9.13 ± 1.85 hrs/day vs ActiGraph: 9.22 ± 1.58, p=0.063), were different from each other (p<0.05).

Figures 1-3 present the associations between activPAL and ActiGraph assessed sedentary behaviour variables and cardiometabolic health. After adjustment for basic confounders, associations of both activPAL and ActiGraph assessed total and prolonged sedentary time with BMI, waist circumference, HDL, triglycerides and cardiometabolic risk were in the same direction (negative association for HDL and positive for all other markers) and of similar magnitude. Additional associations were observed for activPAL assessed total and prolonged sedentary time and diastolic blood pressure and ActiGraph assessed total sedentary time and 2 hr glucose. Associations between activPAL and ActiGraph assessed breaks in sedentary time with BMI, waist circumference and cardiometabolic risk were in the same direction and of similar magnitude, with additional associations seen for activPAL assessed breaks and HDL and ActiGraph assessed breaks and triglycerides. No other associations were observed.

Discussion

Despite a growth in studies using device-based assessments of sedentary behaviour to examine associations with health, the interpretation of these is still limited by the estimation of sedentary behaviour through lack of movement rather than the posture of sitting. We wanted to examine, in a cohort of individuals with two assessments of sedentary behaviour (one through lack of movement and one based on posture) whether associations with cardiometabolic health were consistent across both measurement methods. On the whole we demonstrated broad consistency in associations across the two devices. More specifically, we observed that the direction and magnitude of associations between total, prolonged and breaks in sedentary time and cardiometabolic risk and adiposity markers of health were consistent across measurement method. Consistency was also observed for associations between total and prolonged sedentary time and HDL and triglycerides across measurement method. Some differences in associations for the different devices were observed for diastolic blood pressure for total and prolonged sedentary time, 2hr glucose for total sedentary time and HDL for breaks in sedentary time. No other associations were observed for any other health markers for either device.

We have shown that results are broadly consistent across sedentary behaviour determined either by a waist-worn accelerometer or an accelerometer which identifies the specific posture of sitting/lying. However, researchers should be aware that some differences in results may exist for certain markers of health i.e., 2hr glucose, HDL cholesterol and triglycerides. A previous review (Brocklebank et al 2015) stated that results were inconclusive for an association between sedentary time and breaks in sedentary time, using waist-worn accelerometry, and 2 hour glucose and HDL cholesterol respectively, with some studies reporting positive associations and some no associations.

In the current analyses, ActiGraph assessed sedentary time was positively associated with 2 hour glucose whereas activPAL assessed sedentary time was not. In contrast, activPAL assessed breaks in sedentary time were positively associated with HDL cholesterol whereas ActiGraph breaks were not. Furthermore, in this previous review, ActiGraph assessed 'breaks' in sedentary time were reported to have a negative association with triglycerides which is consistent with the present findings but contrasts the results observed for activPAL assessed breaks.
Only one other large study has been published reporting associations between activPAL assessed sedentary accumulation patterns and cardiometabolic risk biomarkers (Bellettiere et al 2017). Our results (i.e., significant and non-significant associations) were consistent for nearly all sedentary behaviour variables and cardiometabolic markers with this previous study, with the exception of breaks in sitting time and HDL cholesterol and total and prolonged sitting and diastolic blood pressure. Further research using direct assessments of sitting behaviours are needed to confirm these findings.

The majority of previous research has demonstrated an overestimation of daily sedentary time, sometimes up to 2 hours per day when assessed by the waist-worn ActiGraph using a cutpoint of <100 counts per minutes compared to the thigh worn activPAL (Koster et al 2016; Hart et al 2011; Judice et al 2015). However, findings from another recent study (Pfister et al 2017) as well as our present results showed little difference for average daily sedentary time. Although, similar to previous studies (Barreira et al 2015, Judice et al 2015) we observed a higher number of breaks in sedentary time per day recorded by the ActiGraph compared to the activPAL. These differences will be important for prevalence research but as demonstrated in the current analyses may not impact on associations with health.

Strengths of this study include a large dataset where sedentary behaviour has been assessed using two commonly used accelerometers. However, the sample was considerably smaller for fasting and 2hr glucose. Furthermore, although we restricted the analysis to only include those providing at least four valid days of data, different days of data may have been included for the activPAL and ActiGraph. Different processing methods were applied to the activPAL and ActiGraph data, which may have influenced the results however, these represent researcher practice and may be a better reflection of the literature rather than matching the data exactly. The associations should, however, be interpreted with caution due to the cross-sectional design of this study which limits the ability to make causal inferences. Finally, we only adjusted for basic confounders in order to demonstrate any similarities and differences in associations.

In summary, associations with cardiometabolic health are largely comparable across the two common device-based assessments of sedentary behaviour but researchers should be aware that some differences may exist for certain markers of health.

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Table 1. Participant characteristics

Characteristics	**N**	
Age (years)	1454	59.38 ± 11.85
Male (%)	1455	51.7
White European (%)	1456	75.9
Family history of diabetes (%)	1444	43.5
Current and past smokers (%)	1456	33.7%
Weight (kg)	1453	84.58 ± 18.13
Waist circumference (cm)	1449	100.36 ± 13.66
BMI (kg/m^2)	1453	30.19 ± 5.59
Diastolic Blood Pressure (mmHg)	1454	82.00 ± 10.84
Systolic Blood Pressure (mmHg)	1454	130.95 ± 17.56
HDL (mmol/l)	1441	1.44 ± 0.41
LDL (mmol/l)	1425	3.02 ± 0.91
Total Cholesterol (mmol/l)	1451	5.14 ± 1.10
Triglycerides (mmol/l)	1450	1.51 ± 0.89
HbA1c (%)	1452	5.77 ± 0.39
Fasting plasma glucose (mmol/l)	508	5.16 ± 0.74
2-hour plasma glucose (mmol/l)	497	5.86 ± 1.90

Continuous parametric results as mean±SD, number (column percentage) and continuous nonparametric results as median (interquartile range).

Table 2. Summary of the activPAL and ActiGraph output variables (n=1457)

Variables	**activPAL**	**ActiGraph**	**Correlation**	**Paired t-test**
Average waking wear hours/day (hours)	15.71 ± 1.13	14.67 ± 1.37	.543**	P<0.001
Average sitting/lying time/day (hours)	9.13 ± 1.85	9.22 ± 1.58	.648**	P=0.063
Average prolonged bouts (≥30mins) of sitting/lying time/day (hours)	4.82 ± 1.85	2.83 ± 1.49	.505**	P<0.001
Average number of breaks in sitting/day	48.03 ± 15.13	85.95 ± 16.99	.416**	P<0.001
Average standing/day (hours)	4.79 ± 1.59	N/A	N/A	N/A
Average stepping/day (hours)	1.79 ± 0.66	N/A	N/A	N/A
Average MVPA (minutes)	N/A	29.48 ± 33.34	N/A	N/A

**Correlation is significant at 0.01 level

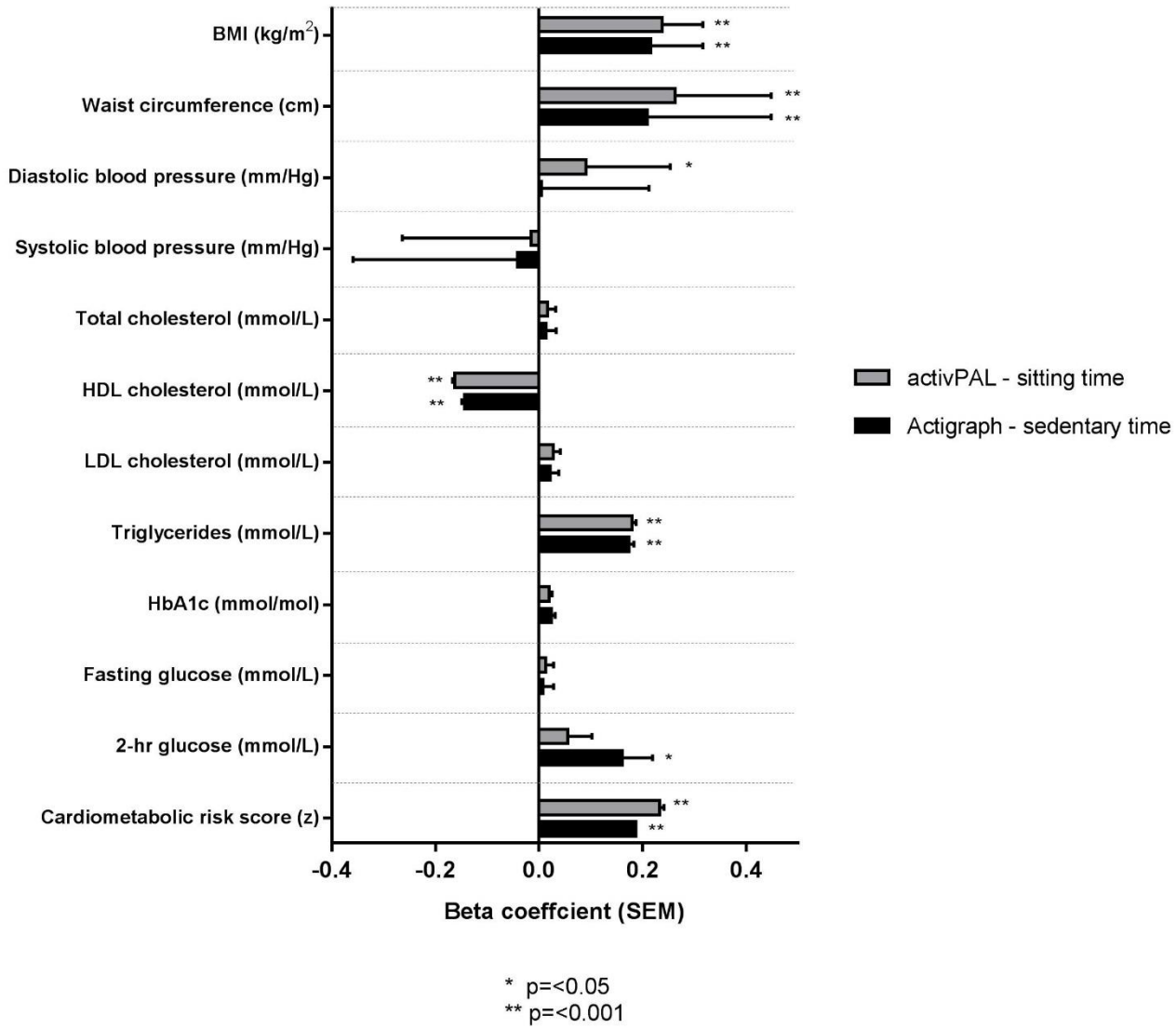

Figure 1. Associations between activPAL daily sitting time and ActiGraph daily sedentary time and cardio-metabolic health. Adjusted for age, sex, ethnicity, smoking status, family history of T2DM, β-blocker and lipid lowering medication status, activPAL/ActiGraph wear time.

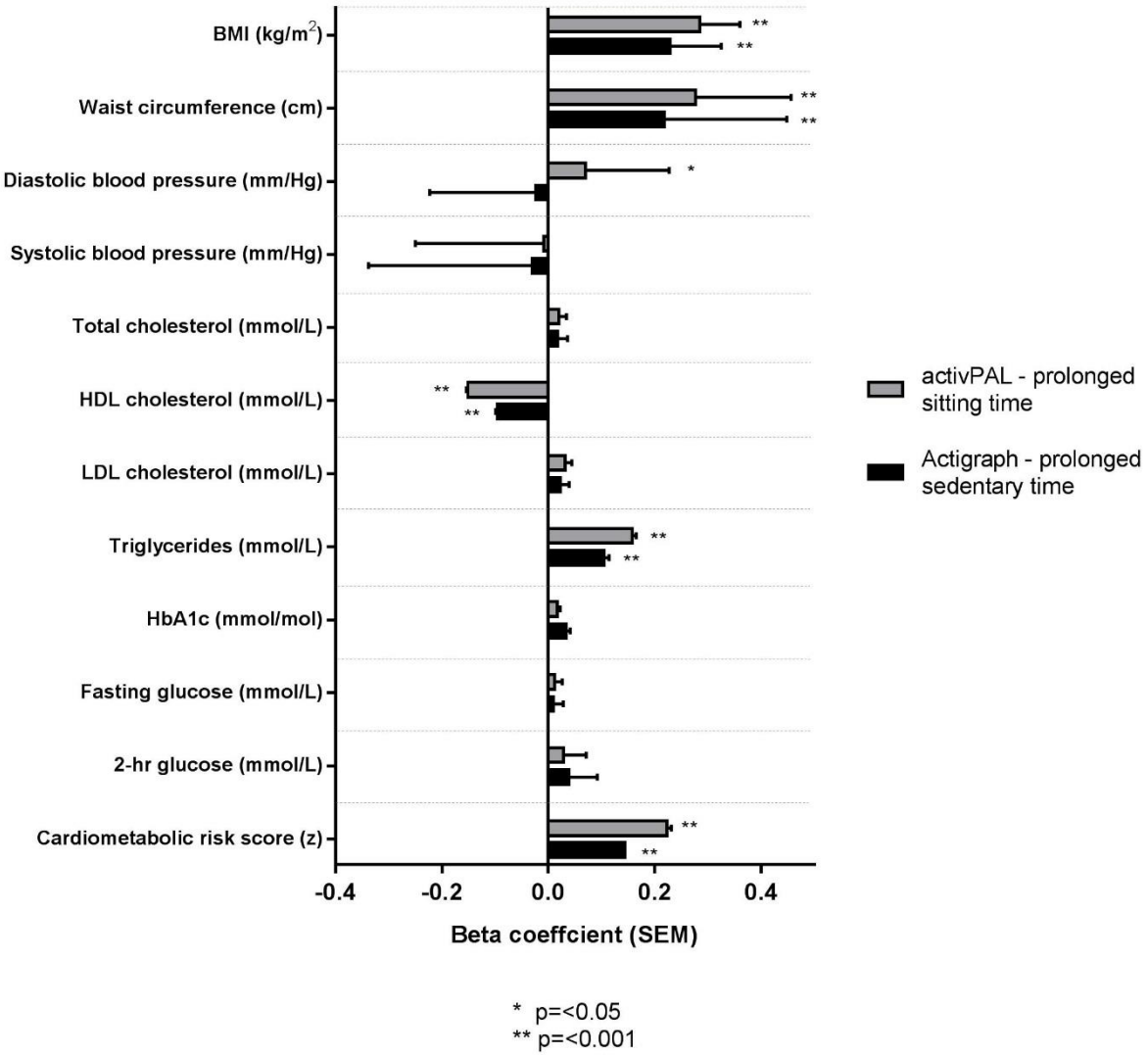

Figure 2. Associations between activPAL daily prolonged sitting time and ActiGraph daily prolonged sedentary time and cardio-metabolic health. Adjusted for age, sex, ethnicity, smoking status, family history of T2DM, β-blocker and lipid lowering medication status, activPAL/ActiGraph wear time.

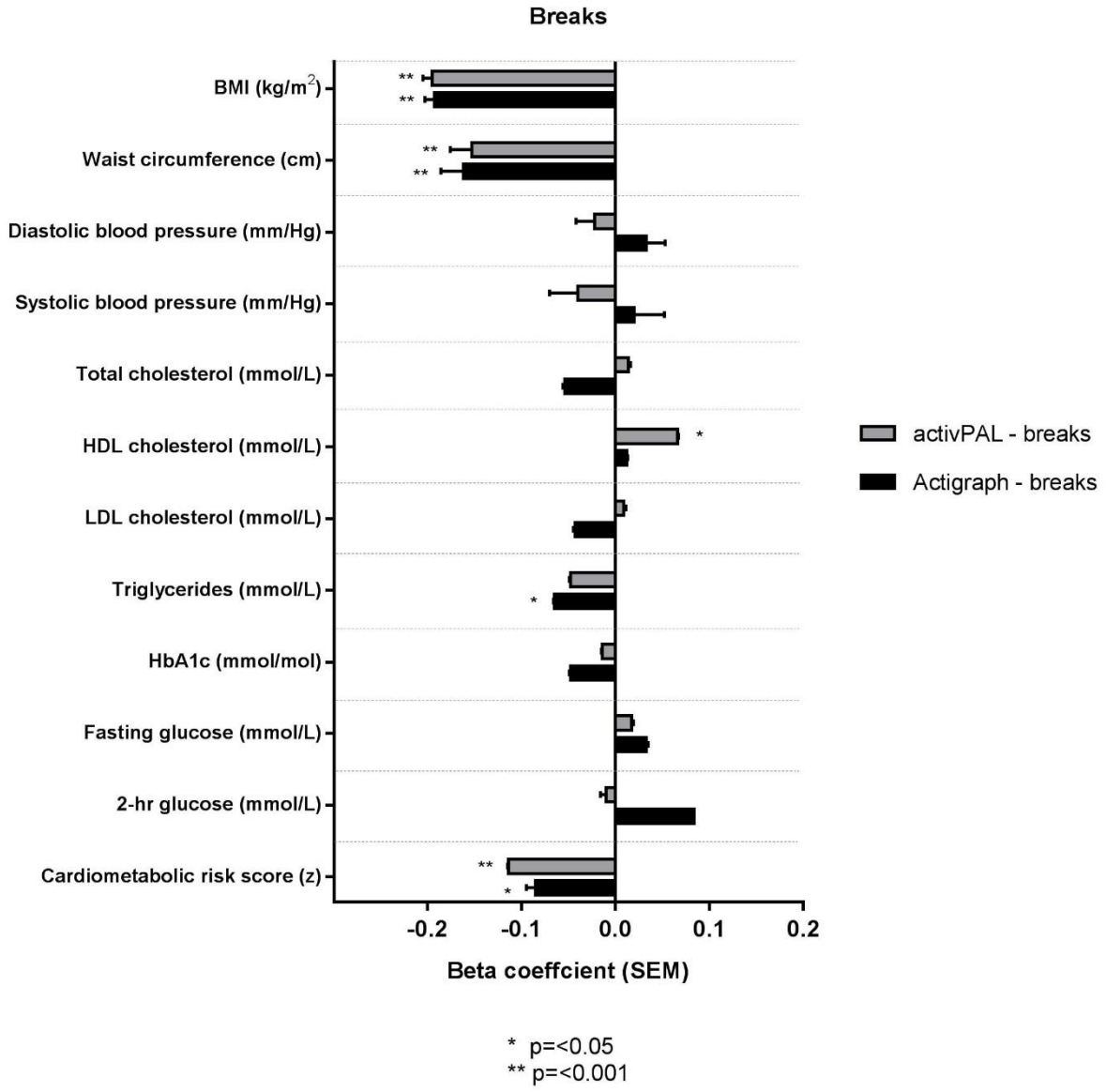

Figure 3. Associations between activPAL breaks in sitting time and ActiGraph breaks in sedentary time and cardio-metabolic health. Adjusted for age, sex, ethnicity, smoking status, family history of T2DM, β-blocker and lipid lowering medication status, activPAL/ActiGraph wear time.