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Review

Accelerometer-measured sedentary time and cardiometabolic biomarkers: A systematic review

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ABSTRACT

Objective. We conducted a systematic review to investigate the cross-sectional and prospective associations of accelerometer-measured total sedentary time and breaks in sedentary time with individual cardiometabolic biomarkers in adults ≥18 years of age.

Methods. Ovid Medline, Embase, Web of Science and the Cochrane Library were searched for studies meeting the inclusion criteria. Due to inconsistencies in the measurement and analysis of sedentary time, data was synthesised and presented narratively rather than as a meta-analysis.

Results. Twenty-nine studies were included in the review; twenty-eight reported on total sedentary time and six on breaks in sedentary time. There was consistent evidence from cross-sectional data of an unfavourable association between total sedentary time and insulin sensitivity. There was also some evidence that total sedentary time was unfavourably associated with fasting insulin, insulin resistance and triglycerides. Furthermore, there was some evidence from cross-sectional data of a favourable association between breaks in sedentary time and triglycerides.

Conclusion. Total sedentary time was consistently shown to be associated with poorer insulin sensitivity, even after adjusting for time spent in physical activity. This finding supports the proposed association between sedentary time and the development of Type 2 diabetes and reinforces the need to identify interventions to reduce time spent sedentary.

Contents

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Introduction

Physical activity is considered to be central to the prevention and management of Type 2 diabetes because of its potential to improve glycaemic control, lipid profiles and blood pressure, and in combination with dietary intervention, to aid weight loss and maintenance (Colberg et al., 2010). However, fewer people with Type 2 diabetes meet physical activity recommendations (at least 150 min of moderate-to-vigorous-intensity physical activity [MVPA] per week) than in the general population (Morrato et al., 2007) and people with Type 2 diabetes often find it difficult to increase their physical activity levels by a sufficient amount to improve cardiometabolic health outcomes (Andrews et al., 2011). Therefore, alternative interventions for improving cardiometabolic health may be required.

Recent interest has focussed on the potential role of sedentary behaviour in the development of chronic diseases. Sedentary behaviour is defined as any waking behaviour characterised by an energy expenditure ≤1.5 metabolic equivalents (METs) whilst in a sitting or reclining posture. Sedentary behaviour is distinct from physical inactivity, which is defined as failure to meet the current physical activity recommendations (Sedentary Behaviour Research, 2012).

In previous systematic reviews, more time spent in sedentary behaviours has been shown to be adversely associated with both risk of chronic diseases and with poorer cardiometabolic health (de Rezende et al., 2014; Edwardson et al., 2012; Wilmot et al., 2012). However, the majority of the studies included in these reviews measured sedentary time with self-report questionnaires, which are susceptible to recall and social desirability bias (Clark et al., 2009; Corder et al., 2007). Therefore, the aim of the current systematic review is to investigate the cross-sectional and prospective associations of accelerometer-measured total sedentary time and breaks in sedentary time with individual cardiometabolic biomarkers in adults ≥18 years of age.

Methods

Search strategy and inclusion criteria

Ovid Medline, Embase, Web of Science and the Cochrane Library were searched for relevant publications (24 June 2014). The search strategy used in Ovid Medline is shown in Supplementary Methods and the same search terms were used in the other databases.

To be included in the systematic review, studies had to meet the following inclusion criteria: (1) written in English; (2) cross-sectional or prospective study design; (3) report data on adults ≥18 years of age; (4) use an accelerometer to measure total sedentary time and/or breaks in sedentary time; (5) measure at least one cardiometabolic biomarker of interest (fasting plasma glucose, fasting insulin, 2-hour plasma glucose, insulin sensitivity, homeostasis model assessment of insulin resistance [HOMA-IR], total cholesterol, high-density lipoprotein cholesterol [HDL-cholesterol], low-density lipoprotein cholesterol [LDL-cholesterol] and triglycerides); and (6) report cross-sectional and/or prospective associations of total sedentary time and/or breaks in sedentary time with at least one cardiometabolic biomarker of interest. Studies were excluded if they defined sedentary behaviour as failure to meet the current physical activity recommendations.

Titles and abstracts were independently reviewed by LB and CF for retrieval of full-text articles meeting the inclusion criteria. If any uncertainty or disagreement existed, the full-text was obtained for discussion with AC. Studies that did not meet the inclusion criteria were disregarded at this stage.

Quality assessment

LB and CF developed a quality assessment tool with reference to the Newcastle-Ottawa Scale (Wells et al., 2014) and the STROBE (Strengthening the Reporting of Observational studies in Epidemiology) Statement (von Elm et al., 2008). The total score available was 7 points: 1 point for reporting a prospective association(s), 1 if analysis adjusted for MVPA (studies reporting on total sedentary time) or MVPA and total sedentary time (studies reporting on breaks in sedentary time), 1 if analysis adjusted for body mass index (BMI) and/or waist circumference (WC), 1 if analysis adjusted for sex (if males and females combined), age and ethnicity, 1 for an objective measure of the health outcome(s), 1 for at least 7 valid days (≥10 h) of accelerometer wear time (Matthews et al., 2002) and 1 for an adequate description of the population, including sex, age, BMI and metabolic health. Two authors (LB and AC) independently assessed all studies for quality and any discrepancies were discussed with CF. A score of 5 to 7 was considered high quality, 3 or 4 moderate quality and 0 to 2 poor quality.

Data extraction and synthesis

Two authors (LB and AC) independently extracted data using a data extraction form developed for this review. The primary outcomes were the cross-sectional and prospective associations of total sedentary time and breaks in sedentary time with individual cardiometabolic biomarkers (Pearson correlation coefficients, regression coefficients and P for trend). Due to inconsistencies in the way in which sedentary time was measured, defined and analysed, data was synthesised and presented narratively rather than as a meta-analysis.

The findings for each cardiometabolic biomarker were interpreted on the following basis: there was no evidence of an association if more than 50% of the cross-sectional and prospective studies reported no association; the evidence for an association was inconclusive if 50% of the studies reported no association and 50% reported a positive or negative association; there was some evidence of an association if more than 50% of the studies reported a positive or negative association; and there was consistent evidence of an association if all of the studies reported a positive or negative association.

Results

The initial search identified 4858 studies (Fig. 1). Twenty-nine studies were included in the systematic review; twenty-eight reported on total

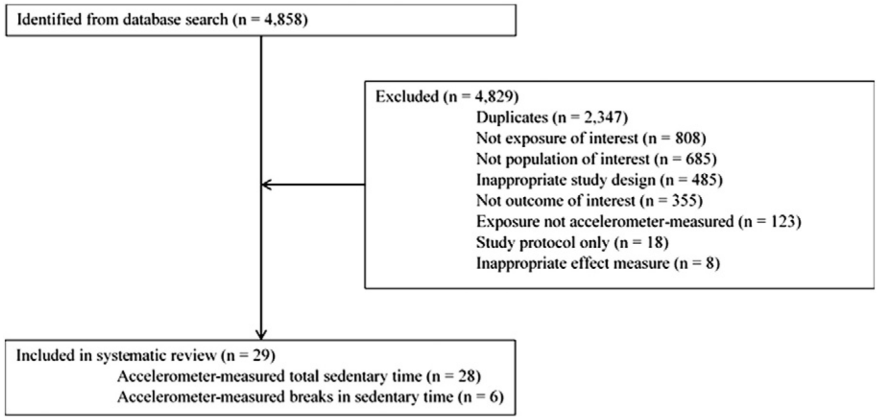

Fig. 1. Flow diagram of study selection process, from initial search to included studies. N, number of studies.

sedentary time and six on breaks in sedentary time[4, 9, 15, 16, 18, 27]. Four studies were prospective[9, 10, 20, 29] and the remaining were cross-sectional. Twenty-two studies adjusted for MVPA and total sedentary time (if applicable), fourteen adjusted for BMI and/or WC and eight adjusted for sex (if applicable), age and ethnicity. However, only five studies adjusted for all of these confounding variables[12, 16, 18, 22, 24].

Sample sizes ranged from 35[23] to 4935[4]. The majority of studies were conducted in the US or the UK. Five studies included women only[13, 21–24] and the remaining included both men and women. Mean ages ranged from 24.0[13] to 74.6 years[12] and mean body mass indexes ranged from 23.2[1] to 32.9 kg/m^2[26]. Sixteen studies investigated adults without diagnosed diabetes, four investigated adults with a higher risk of developing Type 2 diabetes[10, 11, 18, 29], two investigated adults with newly diagnosed Type 2 diabetes[8, 9] and seven did not give an adequate description of metabolic health[5, 6, 12, 22, 25, 27]. Three studies were of high quality, seventeen were of moderate quality and nine were of low quality. Full descriptions of included studies can be seen in Table 1.

Table 2 describes the methods used to measure and analyse sedentary time in the included studies. Twenty-two studies measured sedentary time with an Actigraph accelerometer, two used ActiTrainer[5, 6], two used Sensewear Pro Armband[7, 27], one used Actical[4], one used Actiheart[8] and one used Active Style Pro[19]. All of the studies analysed accelerometer data as frequency counts. Twenty-three studies measured sedentary time for 7 days, four measured it for four days[8, 10, 11, 29] and two measured it for 8 days[2, 20]. Eleven studies required at least 4 valid days of accelerometer wear time to be included in the final analysis, two studies used a criterion of $\geq$1 day[12, 28], six used $\geq$3 days[2, 9–11, 20, 29], three used $\geq$5 days[7, 14, 15], one used $\geq$6 days[27], one used $\geq$7 days[19] and five did not report any inclusion criteria for days of wear[8, 17, 21, 23, 24]. Twenty-one studies defined sedentary time as <100 counts per minute (cpm), four used $\leq$1.5 METs[7, 8, 19, 27], one used <150 cpm[13], one used <25 counts per 15 s[18], one used <200 cpm[28] and one did not report how sedentary time was defined[21].

Twenty-three studies presented total sedentary time as average minutes or hours per day, three presented it as percentage of wear time[1, 2, 26], one presented it as percentage of monitoring time[17], one presented it as percentage of waking hours[14], one presented it as total hours[20] and one did not report any units for total sedentary time[21]. Four of the six available studies presented breaks in sedentary time as average number per day[4, 9, 18, 27], whilst the remaining two presented total breaks in sedentary time[15, 16]. Seventeen studies analysed total sedentary time and/or breaks in sedentary time as continuous variables, six analysed them as categorical variables[5, 12, 16, 20, 21, 24] and six analysed them as both continuous and categorical variables[6, 9, 14, 15, 18, 25]. Of the twelve studies that analysed total sedentary time and/or breaks in sedentary time as categorical variables, nine used quartiles[6, 9, 12, 14–16, 20, 24, 25] and three used tertiles [5, 18, 21].

Total sedentary time and cardiometabolic health

Fasting plasma glucose

There was no evidence of an association between total sedentary time and fasting plasma glucose; thirteen of eighteen cross-sectional analyses[3, 4, 7, 9, 11, 13, 16–18, 20, 22, 24, 27] and two of three prospective analyses[9, 29] reported no association.

Fasting insulin

There was some evidence from cross-sectional data of an unfavourable association between total sedentary time and fasting insulin, but the evidence from prospective data was inconclusive. Nine of twelve cross-sectional analyses reported a positive association between total sedentary time and fasting insulin[3, 4, 6, 9, 11, 16, 23–25]; six following adjustment for MVPA[4, 6, 9, 16, 24, 25], but only one following additional adjustment for WC[16]. The remaining three analyses reported no association[10, 13, 20].

Four studies analysed the prospective association between total sedentary time and fasting insulin. One study reported a positive association between baseline total sedentary time and fasting insulin at 6-month follow-up, following adjustment for MVPA and WC[9]. Another study also reported a positive association between baseline total sedentary time and 3-year change in fasting insulin, but only in the 50% of participants who had increased their BMI by $\geq$0.3 kg/m^2 (MVPA was not adjusted for in the analysis)[20]. The remaining two studies reported no association; one between baseline total sedentary time and fasting insulin at 1-year follow-up[10] and the other between 6-year change in total sedentary time and 6-year change in fasting insulin[29].

2-Hour plasma glucose

The evidence for a cross-sectional association between total sedentary time and 2-hour plasma glucose was inconclusive and no prospective analyses were available. Three of six cross-sectional analyses reported a positive association, following adjustment for MVPA, between total sedentary time and 2-hour plasma glucose[14, 18, 25]; two following additional adjustment for WC[14] or BMI[18]. The remaining three analyses reported no association[16, 20, 26].

HOMA-IR

There was some evidence from cross-sectional data of an unfavourable association between total sedentary time and HOMA-IR, but the evidence from prospective data was inconclusive. Five of nine cross-sectional analyses reported a positive association between

Table 1
Descriptions of all the studies included in the systematic review.

Reference[SN]	Exposure(s)	Outcome(s)	Variables adjusted for in the analysis			Cross-sectional or prospective?	Population (*n* [sex], age [M ± SD], country, BMI [M ± SD], metabolic health)	Quality score
			Socio-demographic	Medical history	Behaviour			
Aadland et al. (2013)[1]	ST (% valid wear time)	TC (mmol/L) HDL-C (mmol/L) LDL-C (mmol/L) TG (mmol/L)*	Sex, age, WC		Diet	Cross-sectional	78 (58% ♀), 40.7 ± 10.9 (♂) and 40.4 ± 10.6 years (♀), Norway, 25.2 ± 3.2 (♂) and 23.2 ± 2.2 kg/m^2 (♀), not diagnosed with T2DM	3
Balkau et al. (2008)[2]	ST (% wear time)	IS (μmol/min/kg$_{FFM}$/nmol/L)*	Age, sex, recruitment centre		Total activity, LPA, activity intensity	Cross-sectional	801 (57% ♀), 43 ± 9 (♂) and 45 ± 8 years (♀), Europe, 25.9 ± 3.1 (♂) and 24.4 ± 4.1 kg/m^2 (♀), not diagnosed with DM	2
Buman et al. (2014)[3]	ST (30 min/d)	FPG (mmol/L)* FI (pmol/L)* HOMA-%S* HDL-C (mmol/L)* LDL-C (mmol/L)* TG (mmol/L)*	Age, sex, ethnicity, marital status, education, work status, poverty	Depressive symptoms, general health rating, previous diagnosis of cancer/malignancy, CVD or diabetes, current diabetic, antihypertensive, lipidemic or other CVD medications	Smoking, EI, saturated fat, caffeine, alcohol use, sleep duration, LPA, MVPA	Cross-sectional	2187 (52% ♀), 46.6 ± 18.4 years, US, 6.3% diagnosed with DM, *mean BMI not reported*	3
Carson et al. (2014)[4]	ST (h/d) BST (10/d)	FPG (mmol/L)* FI (pmol/L)* HDL-C (mmol/L) LDL-C (mmol/L) TG (mmol/L)*	Age, sex, income, survey cycle	Blood pressure medication, medical history of Type 2 diabetes, heart disease or cancer	Smoking, alcohol use, MVPA, ST	Cross-sectional	4935 (50% ♀), 45.9 ± 15.1 years, Canada, 5% diagnosed with T2DM, *mean BMI not reported*	2
Celis-Morales et al. (2011)[5]	ST (min/d)	HOMA-IR*	Age, sex, environment, socio-economic level, education level, BMI, WC, body fat		Smoking status, accelerometer wear time, MVPA, fitness EI	Cross-sectional	472 (63% ♀), Chile, not taking any diabetes medication, *mean age and BMI not reported*	3
Celis-Morales et al. (2012)[6]	ST (100 min/d and min/d)	FPG (mmol/L) FI (mU/L) HOMA-IR TC (mmol/L) HDL-C (mmol/L) LDL-C (mmol/L) TG (mmol/L)	Age, sex, ethnicity, environment, SES		Smoking status, MVPA	Cross-sectional	317 (56% ♀), 37.5 ± 12.8 years, Chile, 29.2 ± 5.1 kg/m^2, not taking any diabetes medication	3
Chase et al. (2014)[7]	ST (min/d)	FPG (mmol/L)* HDL-C (mmol/L) LDL-C (mmol/L) TG (mmol/L)*				Cross-sectional	50 (54% ♀), 71.5 ± 0.6 years, Canada, 24.2 ± 0.4 kg/m^2, not diagnosed with DM	2
Cooper et al. (2014)[8]	ST (h/d)	HDL-C (mmol/L) TG (mmol/L)*	Age, sex, intervention group, occupational socioeconomic class, WC	Use of lipid-lowering drugs	Smoking status, sleep duration, EI, % of energy from fat, alcohol intake, MVPA	Cross-sectional	394 (37% ♀), 60.2 ± 7.4 (♂) and 60.5 ± 7.4 years (♀), UK, 31.6 ± 5.1 (♂) and 32.9 ± 6.0 kg/m^2 (♀), newly diagnosed T2DM	4
Cooper et al. (2012)[9]	ST (h/d) BST (#/d)	FPG (mmol/L) FI (pmol/L) HOMA-IR HDL-C (mmol/L)	Age, sex, deprivation score, WC	Family history of diabetes, relevant lipid- and glucose-lowering medication	Smoking, accelerometer wear time, MVPA, ST, BST	Prospective	528 (35% ♀), 59.8 ± 10.0 years, UK, 31.5 ± 5.6 kg/m^2, newly diagnosed T2DM	5
Ekelund et al. (2009)[10]	ST (min/d)	FI (pmol/L)* HOMA-IR*	Age, sex, WC, baseline FI, baseline HOMA-IR		Smoking status, follow-up time	Prospective	192 (58% ♀), UK, 28.3 ± 4.5 (♂) and 27.5 ± 5.0 kg/m^2 (♀), parental history of T2DM, *mean age not reported*	3
Ekelund et al. (2007)[11]	ST (min/d)	FPG (mmol/L) FI (mol/L)* HDL-C (mmol/L) TG (mmol/L)*	Age, sex, WC			Cross-sectional	258 (60% ♀), 40.9 ± 6.4 (♂) and 40.7 ± 6.4 years (♀), UK, 28.4 ± 4.6 (♂) and 27.4 ± 5.1 kg/m^2, parental history of T2DM	3
Gennuso et al. (2013)[12]	ST (h/d)	FPG (mg/dL)* TC (mg/dL) HDL-C (mg/dL)* LDL-C (mg/dL) TG (mg/dL)*	Age, sex, ethnicity, education, income, marital status, BMI	CVD	Alcohol consumption, current smoking status, accelerometer wear time, MVPA	Cross-sectional	1914 (48% ♀), 74.6 ± 6.5 years, US, *mean BMI and diabetes status not reported*	4
Green et al. (2014)[13]	ST (min/d)	FPG (mmol/L) FI (pmol/L)* HOMA-IR* TC (mmol/L)	Body mass, fat mass, fat-free mass		MVPA, VO_{2peak}	Cross-sectional	50 women, 24.0 ± 4.8 years, US, 27.0 ± 4.8 kg/m^2, not diagnosed with DM	3

(continued on next page)

Table 1 (*continued*)

Reference[SN]	Exposure(s)	Outcome(s)	Variables adjusted for in the analysis			Cross-sectional or prospective?	Population (*n* [sex], age [M ± SD], country, BMI [M ± SD], metabolic health)	Quality score
			Socio-demographic	Medical history	Behaviour			
		HDL-C (mmol/L) LDL-C (mmol/L) TG (mmol/L)*						
Healy et al. (2007)[14]	ST (h/d and % waking hours)	FPG (mmol/L) 2hPG (mmol/L)	Age, sex, height, WC, education, income	Family history of diabetes	Time accelerometer worn, accelerometer unit, alcohol intake, smoking status, MVPA	Cross-sectional	173 (61% ♀), 53.3 years, Australia, 27.2 kg/m^2, 2% newly diagnosed DM	4
Healy et al. (2008a)[15]	BST (total)	FPG (mmol/L) 2hPG (mmol/L) HDL-C (mmol/L) TG (mmol/L)*	Age, sex, employment, income, education	Family history of diabetes, lipid-lowering medication	Alcohol intake, smoking, diet quality, MVPA, mean intensity of breaks, ST	Cross-sectional	168, 53.4 ± 11.8 years, Australia, 27.2 ± 4.7 kg/m^2, not diagnosed with DM, *percentage female not reported*	2
Healy et al. (2011)[16]	ST (h/d) BST (total)	FPG (mmol/L)* FI (pmol/L)* 2hPG (mmol/L)* HOMA-%S* HDL-C (mmol/L)* TG (mmol/L)*	Age, sex, ethnicity, education, height, marital status, poverty-to-income ratio, WC	Diabetes, cancer, anti-hypertensive medication, other CVD medications, family history of CHD, family history of diabetes, CVD history, lipidemic medication	MVPA, ST, smoking, % saturated fat, alcohol intake, EI, potassium, caffeine	Cross-sectional	4757 (50% ♀), 46.5 ± 14.2 years, US, 7.5% diagnosed with DM or borderline DM, *mean BMI not reported*	4
Healy et al. (2008b)[17]	ST (% monitoring time)	FPG (mmol/L) HDL-C (mmol/L) TG (mmol/L)*	Age, sex, employment status, income, education,	Family history of diabetes, lipid-lowering medication	Alcohol intake, smoking status, diet quality, MVPA	Cross-sectional	169 (60% ♀), 53.4 years, Australia, not diagnosed with DM, *mean BMI not reported*	1
Henson et al. (2013)[18]	ST (h/d) BST (#/d)	FPG (mmol/L)* 2hPG (mmol/L)* HDL-C (mmol/L)* TG (mmol/L)*	Age, sex, ethnicity, social deprivation, BMI	Family history of Type 2 diabetes, beta-blockers, lipid-lowering medication	Smoking status, time accelerometer worn, MVPA, ST	Cross-sectional	878 (41% ♀), 58.4 ± 13.8 years, UK, 32.5 ± 5.2 kg/m^2, with known risk factors for T2DM	5
Kim et al. (2013)[19]	ST (h/d)	FPG (mg/dL) HDL-C (mg/dL) TG (mg/dL)	Age, sex		Smoking status, calorie intake, accelerometer wear time, MVPA	Cross-sectional	483 (63% ♀), 47.9 ± 9.0 years, Japan, 25.6 ± 4.0 kg/m^2, not diagnosed with DM	4
Lahjibi et al. (2013)[20]	ST (h)	FPG (mmol/L) FI (pmol/L)* 2hPG (mmol/L) HOMA-IR* IS (μmol/min/kg$_{FFM}$/nmol/L)* TC (mmol/L) HDL-C (mmol/L) LDL-C (mmol/L) TG (mmol/L)*	Age, sex, recruiting centre		MVPA	Prospective	727 (57% ♀), 43 ± 9 (♂) and 45 ± 8 years (♀), Europe, 25.8 ± 3.1 (♂) and 24.3 ± 4.0 kg/m^2 (♀), not diagnosed with DM	4
LeCheminant and Tucker (2011)[21]	ST (units not reported)	HOMA-IR	Age, weight, BMI, body fat %, abdominal circumference			Cross-sectional	264 women, 40.1 ± 3.0 years, US, 23.8 ± 3.3 kg/m^2, healthy (PAR-Q)	2
Loprinzi et al. (2013)[22]	ST (min/d)	FPG (mg/dL) TC (mmol/L) HDL-C (mg/dL) LDL-C (mg/dL) TG (mg/dL)	Age, education, marital status, poverty-to-income ratio, ethnicity, BMI	Gestation	Smoking, MVPA	Cross-sectional	206 pregnant women, 28.4 years, US, 29.2 kg/m^2, *diabetes status not reported*	4
Lynch et al. (2010)[23]	ST (h/d)	FI (pmol/L)*	Age, ethnicity		MVPA	Cross-sectional	111 women − 35 in FI analysis, 69.2 ± 13.0 years, US, 27.6 ± 6.4 kg/m^2, 24.3% diagnosed with DM or borderline DM	4
Lynch et al. (2011)[24]	ST (h/d)	FPG (mmol/L)* FI (pmol/L)* HOMA-IR*	Age, marital status, annual family income, ethnicity, WC	Age at last period, years of hormone replacement therapy use, age at first birth	MVPA, alcohol intake, smoking status	Cross-sectional	467 postmenopausal women, 62.4 ± 9.5 years, US, 27.1 kg/m^2, not diagnosed with DM	5
Maher et al. (2014)[25]	ST (h/d and min/d)	FPG (mmol/L)* FI (pmol/L)* 2hPG (mmol/L)* HOMA-%S* HDL-C (mmol/L)* TG (mmol/L)*	Age-squared, educational attainment, poverty-to-income ratio	Relative with diabetes, CVD medication, diabetes medication, ever been told cancer, ever been told diabetes, ever been told CVD, hypertension medication, lipidemic medication	Accelerometer wear time, smoking status, % saturated fat, alcohol intake, EI, MVPA, total physical activity	Cross-sectional	4618 (48% ♀), US, 28.2 (♂) and 28.0 kg/m^2 (♀), *mean age and diabetes status not reported*	2
McGuire and Ross (2011)[26]	ST* (min/d and % wear time)	2hPG (mmol/L) HOMA-IR* TC (mmol/L) HDL-C (mmol/L)*	Sex, age, WC		Time accelerometer worn, LPA, MVPA	Cross-sectional	135 (68% ♀), 53.1 ± 7.6 years, Canada, 32.9 ± 4.6 kg/m^2, not diagnosed with DM	4

		TG (mmol/L)*						
Scheers et al. (2013)[27]	ST (h/d) BST (#/d)	FPG (mg/dL) HDL-C (mg/dL) TG (mg/dL)	Sex, age, education		Smoking status, alcohol consumption	Cross-sectional	370 (52% ♀), 41.7 ± 9.8 years, Belgium, *mean BMI and diabetes status not reported*	1
Stamatakis et al. (2012)[28]	ST (10 min/d)	TC (mmol/L) HDL-C (mmol/L)	Age, sex, social class, occupational status	Depression, CVD medication	Smoking, alcohol consumption, fruit and vegetable consumption, accelerometer wear time, frequency of unhealthy foods, MVPA	Cross-sectional	1150 − 971 in TC and HDL-C analyses (55% ♀), UK, *mean age, mean BMI and diabetes status not reported*	2
Wijndaele et al. (2014)[29]	ST (h/d)	FPG (mmol/L)* FI (pmol/L) HDL-C (mmol/L) TG (mmol/L)	Baseline age, sex, baseline SES	Baseline FPG, FI, HDL-C and TG, change in medication for dyslipidaemia and dysglycaemia	Baseline ST, baseline and change in smoking status, change in monitor wear time, follow-up time, baseline and change in MVPA	Prospective	171 (54% ♀), 42.5 ± 6.2 years, UK, 28.0 ± 4.8 kg/m^2, parental history of T2DM	4

SN, study number; *n*, sample size; M, mean; SD, standard deviation; BMI, body mass index; quality score, methodological quality score (range 0–7, higher score indicates better quality); ST, total sedentary time; BST, breaks in sedentary time; %, percentage; min, minute(s); h, hour(s); #, number; d, day(s); FPG, fasting plasma glucose; FI, fasting insulin; 2hPG, 2-hour plasma glucose; HOMA-IR, homeostasis model assessment of insulin resistance; HOMA-%S, homeostasis model assessment of insulin sensitivity; IS, insulin sensitivity; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TG, triglycerides; *, log transformed; WC, waist circumference; SES, socio-economic status; CVD, cardiovascular disease; CHD, coronary heart disease; LPA, light-intensity physical activity; EI, energy intake; MVPA, moderate-to-vigorous-intensity physical activity; VO_{2peak}, maximal aerobic capacity; ♀, female; ♂, male; T2DM, Type 2 diabetes; DM, diabetes; PAR-Q, Physical Activity Readiness Questionnaire.

total sedentary time and HOMA-IR[5, 6, 9, 21, 24]; four following adjustment for MVPA[5, 6, 9, 24], but only one following additional adjustment for BMI and WC[5]. The remaining four analyses reported no association[10, 13, 20, 26].

Three studies analysed the prospective association between total sedentary time and HOMA-IR. One study reported a positive association between baseline total sedentary time and HOMA-IR at 6-month follow-up, following adjustment for MVPA and WC[9]. Another study also reported a positive association between baseline total sedentary time and 3-year change in HOMA-IR, but only in the 50% of participants who had increased their BMI by ≥0.3 kg/m^2 (MVPA was not adjusted for in the analysis)[20]. The remaining study reported no association between baseline total sedentary time and HOMA-IR at 1-year follow-up[10].

Insulin sensitivity

There was consistent evidence from cross-sectional data of an unfavourable association between total sedentary time and insulin sensitivity. All of the five available cross-sectional analyses reported a negative association between total sedentary time and insulin sensitivity[2, 3, 16, 20, 25]; three following adjustment for MVPA[16, 20, 25], but only one following additional adjustment for WC[16]. However, to our knowledge, no studies to date have analysed the prospective association between accelerometer-measured total sedentary time and insulin sensitivity.

Total cholesterol

There was no evidence of an association between total sedentary time and total cholesterol; six of eight cross-sectional analyses reported no association[1, 12, 13, 20, 22, 26] and no prospective analyses were available.

HDL-cholesterol

The evidence for an association between total sedentary time and HDL-cholesterol was inconclusive. Eleven of twenty cross-sectional analyses reported no association between total sedentary time and HDL-cholesterol[1, 3, 4, 7, 11–13, 17, 22, 26, 28]. The remaining nine analyses reported a negative association[6, 8, 9, 16, 18–20, 25, 27]; eight following adjustment for MVPA[6, 8, 9, 16, 18–20, 25], but only four following additional adjustment for WC[8, 9, 16] or BMI[18]. Two studies analysed the prospective association between total sedentary time and HDL-cholesterol; one reported a negative association, following adjustment for MVPA and WC, between baseline total sedentary time and HDL-cholesterol at 6-month follow-up[9], whilst the other reported no association between 6-year change in total sedentary time and 6-year change in HDL-cholesterol[29].

LDL-cholesterol

There was no evidence of an association between total sedentary time and LDL-cholesterol; six of nine cross-sectional analyses reported no association[1, 3, 4, 12, 13, 20] and no prospective analyses were available.

Triglycerides

There was some evidence from both cross-sectional and prospective data of an unfavourable association between total sedentary time and triglycerides. Twelve of eighteen cross-sectional analyses reported a positive association between total sedentary time and triglycerides[1, 3, 6, 8, 13, 16–20, 25, 27]; nine following adjustment for MVPA[6, 8, 13, 16–20, 25], but only three following additional adjustment for WC[8, 16] or BMI[18]. The remaining six analyses reported no association[4, 7, 11, 12, 22, 26]. The

Table 2
Descriptions of the methods used to measure and analyse sedentary time in the included studies.

Study number	Exposure(s)	Device	Monitoring period (days)	Accelerometer inclusion criteria	How was sedentary time defined?	Was sedentary time analysed as frequency counts?	Effect measure(s)
1	ST (% valid wear time)	Actigraph GT1M or GT3X+	7	≥10 h/d for ≥4 d	<100 cpm	Yes	Pearson
2	ST (% wear time)	Actigraph AM7164-2.2	8	>10 h/d for ≥3 d	<100 cpm	Yes	Regression
3	ST (30 min/d)	Actigraph 7164	7	≥10 h/d for ≥4 d	<100 cpm	Yes	Regression
4	ST (h/d) BST (10/d)	Actical	7	≥10 h/d for ≥4 d (including 1 weekend day)	<100 cpm	Yes	Regression
5	ST (min/d)	ActiTrainer	7	≥10 h/d for ≥4 d	<100 cpm	Yes	P_{trend} (tertiles)
6	ST (100 min/d and min/d)	ActiTrainer	7	≥10 h/d for ≥4 d	<100 cpm	Yes	Regression and P_{trend} (quartiles)
7	ST (min/d)	Sensewear Pro Armband	7	≥21 h/d for ≥5 d	<1.5 METs	Yes	Pearson
8	ST (h/d)	Actiheart	4	Not reported	<1.5 METs	Yes	Regression
9	ST (h/d) BST (#/d)	Actigraph GT1M	7	>10 h/d for ≥3 d	<100 cpm	Yes	Regression and P_{trend} (quartiles)
10	ST (min/d)	Actigraph 7164	4	≥500 min/d for ≥3 d	<100 cpm	Yes	Regression
11	ST (min/d)	Actigraph 7164	4	≥500 min/d for ≥3 d	<100 cpm	Yes	Regression (standardised)
12	ST (h/d)	Actigraph AM-7164	7	≥10 h/d for ≥1 d	<100 cpm	Yes	P_{trend} (quartiles)
13	ST (min/d)	Actigraph GT3X+	7	≥10 h/d for ≥4 d (including 1 weekend day)	<150 cpm	Yes	Pearson and regression (standardised)
14	ST (h/d and % waking hours)	Actigraph 7164	7	≥10 h/d for ≥5 d (including ≥1 weekend day)	<100 cpm	Yes	Regression and P_{trend} (quartiles)
15	BST (total)	Actigraph 7164	7	≥10 h/d for ≥5 d (including ≥1 weekend day)	<100 cpm	Yes	Regression (standardised) and P_{trend} (quartiles)
16	ST (h/d) BST (total)	Actigraph 7164	7	≥10 h/d for ≥4 d (including ≥1 weekend day)	<100 cpm	Yes	P_{trend} (quartiles)
17	ST (% monitoring time)	Actigraph 7164	7	Not reported	<100 cpm	Yes	Regression (standardised)
18	ST (h/d) BST (#/d)	Actigraph GT3X	7	≥10 h/d for ≥4 d	<25 counts per 15 s	Yes	Regression (standardised) and P_{trend} (tertiles)
19	ST (h/d)	Active Style Pro (HJA-350IT)	7	≥10 h/d for 7 d	≤1.5 METs	Yes	Regression
20	ST (h)	Actigraph AM7164-2.2	8	>10 h/d for ≥3 d	<100 cpm	Yes	P_{trend} (quartiles)
21	ST (units not reported)	Actigraph	7	Not reported	Not reported	Yes	P_{trend} (tertiles)
22	ST (min/d)	Actigraph 7164	7	≥10 h/d for ≥4 d	<100 cpm	Yes	Regression
23	ST (h/d)	Actigraph 7164	7	≥10 h/d	<100 cpm	Yes	Regression
24	ST (h/d)	Actigraph 7164	7	≥10 h/d	<100 cpm	Yes	P_{trend} (quartiles)
25	ST (h/d and min/d)	Actigraph 7164	7	≥10 h/d for ≥4 d (including ≥1 weekend day)	<100 cpm	Yes	Regression and P_{trend} (quartiles)
26	ST (min/d and % wear time)	Actigraph GT3X	7	≥10 h/d for ≥4 d (including 1 weekend day)	<100 cpm	Yes	Regression
27	ST (h/d) BST (#/d)	Sensewear Pro 3 Armband	7	≥1368 min/d for ≥6 d (including Saturday and Sunday)	≤1.5 METs	Yes	Pearson
28	ST (10 min/d)	Actigraph GT1M	7	≥10 h/d for ≥1 d	0–199 cpm	Yes	Regression
29	ST (h/d)	Actigraph	4	>500 min/d for ≥3 d	<100 cpm	Yes	Regression

ST, total sedentary time; BST, breaks in sedentary time; %, percentage; min, minute(s); h, hour(s); #, number; d, day(s); cpm, counts per minute; s, second(s); METs, metabolic equivalents.

one available prospective analysis reported a positive association, following adjustment for MVPA, between 6-year change in total sedentary time and 6-year change in triglycerides (neither BMI nor WC was adjusted for in the analysis)[29].

Overview of findings

For each cardiometabolic biomarker, an overview of findings, methodological quality scores and sample sizes are presented in Table 3. There was consistent evidence from cross-sectional data of an unfavourable association between total sedentary time and insulin sensitivity. There was also some evidence that total sedentary time was unfavourably associated with fasting insulin, HOMA-IR and triglycerides. The majority of analyses adjusted for MVPA, with unfavourable associations surviving this adjustment. However, fewer analyses additionally adjusted for BMI and/or WC. The evidence for associations of total sedentary time with 2-hour plasma glucose and HDL-cholesterol was inconclusive and there was no evidence of associations with fasting plasma glucose, total cholesterol or LDL-cholesterol.

Breaks in sedentary time and cardiometabolic health

Fasting plasma glucose

There was no evidence of an association between breaks in sedentary time and fasting plasma glucose; five of six cross-sectional analyses[9, 15, 16, 18, 27] and the one available prospective analysis[9] reported no association.

Fasting insulin

There was no evidence of an association between breaks in sedentary time and fasting insulin; two of three cross-sectional analyses[9, 16] and the one available prospective analysis[9] reported no association.

2-Hour plasma glucose

The evidence for a cross-sectional association between breaks in sedentary time and 2-hour plasma glucose was inconclusive and no prospective studies were available. One study reported a negative association between breaks in sedentary time and 2-hour plasma glucose, following adjustment for MVPA and total sedentary time, but the association did not survive additional adjustment for BMI[18]. Another study also reported a negative association, following adjustment for MVPA and total sedentary time, when breaks in sedentary time were analysed as a continuous variable, but no association when 2-hour plasma glucose was compared across quartiles of breaks in sedentary time (neither BMI nor WC was adjusted for in the analyses)[15]. The remaining study reported no association[16].

HOMA-IR

There was no evidence of an association between breaks in sedentary time and HOMA-IR in the one available prospective study[9].

Insulin sensitivity

There was no evidence of an association between breaks in sedentary time and insulin sensitivity in the one available cross-sectional study[16].

HDL-cholesterol

The evidence for an association between breaks in sedentary time and HDL-cholesterol was inconclusive. Two of six cross-sectional analyses reported a positive association between breaks in sedentary time and HDL-cholesterol[4, 18]; one following adjustment for MVPA and total sedentary time[4], but none following additional adjustment for BMI or WC. Another study also reported a positive association, following adjustment for MVPA, total sedentary time and WC, when HDL-cholesterol was

Table 3
Cross-sectional and prospective associations of accelerometer-measured total sedentary time with cardiometabolic biomarkers: overview of findings, methodological quality scores and sample sizes.

			Number of studies																			
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
FPG	X	Quality[SN]	*3[6]	a,b4[12]	4[14]	a4[19]	2[25]	3[3]	2[4]	*3[6]	2[7]	5[9]	3[11]	3[13]	4[16]	1[17]	5[18]	4[20]	4[22]	5[24]	1[27]	
		N	317	809	173	483	4,618	923	2,551	317	50	528	258	50	2,118	169	878	727	206	467	370	
	P	Quality[SN]	#4[20]	5[9]	#4[20]	4[29]																
		N	727	380	727	171																
FI	X	Quality[SN]	3[3]	a2[4]	a3[6]	a5[9]	b3[11]	a,b4[16]	4[23]	a5[24]	a2[25]	3[10]	3[13]	4[20]								
		N	923	2,551	317	528	258	2,118	35	467	4,618	192	50	727								
	P	Quality[SN]	a,b5[9]	#4[20]	3[10]	#4[20]	4[29]															
		N	380	727	192	727	171															
2hPG	X	Quality[SN]	a,b4[14]	a,b5[18]	a2[25]	4[16]	4[20]	4[26]														
		N	173	878	4,618	910	727	135														
HOMA-IR	X	Quality[SN]	a,b3[5]	a3[6]	a5[9]	2[21]	a5[24]	3[10]	3[13]	4[20]	4[26]											
		N	472	317	528	264	467	192	50	727	99											
	P	Quality[SN]	a,b5[9]	#4[20]	3[10]	#4[20]																
		N	380	727	192	727																
IS	X	Quality[SN]	2[2]	3[3]	a,b4[16]	a4[20]	a2[25]															
		N	801	923	2,118	727	4,618															
TC	X	Quality[SN]	a3[6]	a2[28]	3[1]	4[12]	3[13]	4[20]	4[22]	4[26]												
		N	317	971	78	1,914	50	727	206	135												
HDL-C	X	Quality[SN]	3[1]	3[3]	2[4]	2[7]	3[11]	4[12]	3[13]	1[17]	4[22]	4[26]	2[28]	a3[6]	a,b4[8]	a,b5[9]	a,b4[16]	a,b5[18]	a4[19]	a4[20]	a2[25]	1[27]
		N	78	2,187	4,935	50	258	1,914	50	169	206	135	971	317	394	528	4,757	878	483	727	4,618	370
	P	Quality[SN]	4[29]	a,b5[9]																		
		N	171	380																		
LDL-C	X	Quality[SN]	a3[6]	2[7]	a,b4[22]	3[1]	3[3]	2[4]	4[12]	3[13]	4[20]											
		N	317	50	206	78	923	2,551	809	50	727											
TG	X	Quality[SN]	3[1]	3[3]	a3[6]	a,b4[8]	a3[13]	a,b4[16]	a1[17]	a,b5[18]	a4[19]	a4[20]	a2[25]	1[27]	2[4]	2[7]	3[11]	4[12]	4[22]	4[26]		
		N	78	923	317	394	50	2,118	169	878	483	727	4,618	370	2,551	50	258	809	206	135		
	P	Quality[SN]	a4[29]																			
		N	171																			

*, listed twice because different findings were reported depending on whether total sedentary time was analysed as a continuous or categorical variable. #, listed twice because different findings were reported depending on body mass index (BMI) strata. [a], association survived adjustment for moderate-to-vigorous-intensity physical activity (MVPA). [b], association survived adjustment for BMI and/or waist circumference (WC). Dark shading = positive association; light shading = no association; medium shading = negative association. FPG, fasting plasma glucose; FI, fasting insulin; 2hPG, 2-hour plasma glucose; HOMA-IR, homeostasis model assessment of insulin resistance; IS, insulin sensitivity; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TG, triglycerides; X, cross-sectional association; P, prospective association; quality, methodological quality score (range 0–7, higher score indicates better quality); SN, study number; N, sample size.

compared across quartiles of breaks in sedentary time, but no association when breaks in sedentary time were analysed as a continuous variable[9]. The remaining three analyses reported no association[15, 16, 27]. The one available prospective analysis reported no association between the number of breaks in sedentary time at baseline and HDL-cholesterol at 6-month follow-up[9].

LDL-cholesterol

There was no evidence of an association between breaks in sedentary time and LDL-cholesterol in the one available cross-sectional study[4].

Triglycerides

There was some evidence from cross-sectional data of a favourable association between breaks in sedentary time and triglycerides. Three of five cross-sectional studies reported a negative association between breaks in sedentary time and triglycerides[4, 15, 18]; two following adjustment for MVPA and total sedentary time[4, 15], but none following additional adjustment for BMI or WC. The remaining two studies reported no association[16, 27]. However, to our knowledge, no studies to date have analysed the prospective association between accelerometer-measured breaks in sedentary time and triglycerides.

Overview of findings

For each cardiometabolic biomarker, an overview of findings, methodological quality scores and sample sizes are presented in Table 4. There was some evidence from cross-sectional data of a favourable association between breaks in sedentary time and triglycerides. The majority of studies reported a favourable association following adjustment for MVPA and total sedentary time, but none following additional adjustment for BMI and/or WC. The evidence for associations of breaks in sedentary time with 2-hour plasma glucose and HDL-cholesterol was inconclusive and there was no evidence of associations with fasting plasma glucose, fasting insulin, HOMA-IR, insulin sensitivity or LDL-cholesterol.

Table 4
Cross-sectional and prospective associations of accelerometer-measured breaks in sedentary time with cardiometabolic biomarkers: overview of findings, methodological quality scores and sample sizes.

			Number of studies						
			1	2	3	4	5	6	7
FPG	X	Quality[SN]	5[9]	2[15]	4[16]	5[18]	1[27]	[a]2[4]	
		N	528	168	2,118	878	370	2,551	
	P	Quality[SN]	5[9]						
		N	380						
FI	X	Quality[SN]	5[9]	4[16]	[a]2[4]				
		N	528	2,118	2,551				
	P	Quality[SN]	5[9]						
		N	380						
2hPG	X	Quality[SN]	4[16]	[*]2[15]	[*,a]2[15]	[a]5[18]			
		N	910	168	168	878			
HOMA-IR	X	Quality[SN]	5[9]						
		N	528						
	P	Quality[SN]	5[9]						
		N	380						
IS	X	Quality[SN]	4[16]						
		N	2,118						
HDL-C	X	Quality[SN]	[a]2[4]	[*,a,b]5[9]	5[18]	[*]5[9]	2[15]	4[16]	1[27]
		N	4,935	528	878	528	168	4,757	370
	P	Quality[SN]	5[9]						
		N	380						
LDL-C	X	Quality[SN]	2[4]						
		N	2,551						
TG	X	Quality[SN]	4[16]	1[27]	[a]2[4]	[a]2[15]	5[18]		
		N	2,118	370	2,551	168	878		

*, listed twice because different findings were reported depending on whether breaks in sedentary time were analysed as a continuous or categorical variable. [a], association survived adjustment for moderate-to-vigorous-intensity physical activity (MVPA) and total sedentary time. Dark shading = positive association; light-shading = no association; medium shading = negative association. FPG, fasting plasma glucose; FI, fasting insulin; 2hPG, 2-hour plasma glucose; HOMA-IR, homeostasis model assessment of insulin resistance; IS, insulin sensitivity; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TG, triglycerides; X, cross-sectional association; P, prospective association; quality, methodological quality score (range 0–7, higher score indicates better quality); SN, study number; N, sample size.

Discussion

The current systematic review investigated the cross-sectional and prospective associations of accelerometer-measured total sedentary time and breaks in sedentary time with individual cardiometabolic biomarkers in adults ≥18 years of age. There was consistent evidence from five cross-sectional analyses of an unfavourable association between total sedentary time and insulin sensitivity. Three of these associations survived adjustment for MVPA, but only one analysis additionally adjusted for WC. There was also some evidence that total sedentary time was unfavourably associated with fasting insulin, HOMA-IR and triglycerides. Furthermore, there was some evidence from three out of five cross-sectional studies of a favourable association between breaks in sedentary time and triglycerides. Two of these associations survived adjustment for MVPA and total sedentary time, but none survived additional adjustment for BMI or WC.

A previous meta-analysis reported that the risk of Type 2 diabetes was 112% greater in adults with the highest compared to the lowest self-reported sedentary time (Wilmot et al., 2012). Insulin resistance is a precursor to Type 2 diabetes and thus, this finding supports the consistent, unfavourable association between total sedentary time and insulin sensitivity that was reported in the current review. An unfavourable association between total sedentary time and insulin sensitivity was mostly reported after adjusting for MVPA, which suggests that this association is not entirely mediated by a decrease in the amount of time spent in MVPA. The physiological mechanism(s) by which sedentary behaviour adversely affects insulin sensitivity are currently debated, but potential mechanisms include a reduction in contraction-stimulated capillary recruitment and/or glucose transporter 4 (GLUT4) translocation (Hamburg et al., 2007; Lund et al., 1995).

A recent systematic review investigated the cross-sectional associations between sedentary time and individual cardiometabolic biomarkers in adults ≥60 years of age, showing unfavourable associations with HDL-cholesterol, but not triglycerides (de Rezende et al., 2014). These findings do not support the unfavourable association between total sedentary time and triglycerides that was reported in the current review. However, only three studies reported on triglycerides in the review by de Rezende et al. (2014); two measured sedentary time with a self-report questionnaire and one was evaluated as very low quality. In contrast, in the current review, nineteen studies (including one prospective study) analysed the association between total sedentary time and triglycerides; all of the studies measured total sedentary time with an accelerometer and fourteen were evaluated as moderate-to-high quality.

Another explanation for why the two reviews reported different findings could be that the association between sedentary time and cardiometabolic health is different among younger (≥18 years of age) and older (≥60 years of age) adults. Nybo et al. (2003) previously reported that smoking, obesity and alcohol consumption were less predictive of mortality in older adults (≥75 years of age) (Nybo et al., 2003). In support of this, three studies included in the current review analysed the cross-sectional association between total sedentary time and triglycerides in older adults (mean age ≥60 years) and two reported no association. The association between total sedentary time and triglycerides may have differed by age because older adults tend to have a poorer cardiometabolic profile or because older adults tend to spend more time in sedentary behaviours (de Rezende et al., 2014).

The physiological mechanism(s) by which sedentary behaviour adversely affects triglycerides are currently poorly understood. However, an experimental study conducted in rats suggests that it could be due to a reduction in skeletal muscle lipoprotein lipase (LPL) activity (Bey and Hamilton, 2003).

To our knowledge, the current review is the first to investigate the association between breaks in sedentary and cardiometabolic health and provides some evidence of a favourable association between breaks in sedentary time and triglycerides. A favourable association was mostly reported following adjustment for MVPA and total sedentary time, suggesting that the health benefits associated with regularly breaking up sedentary time are additional to those associated with increasing time spent in MVPA and reducing total sedentary time.

Study strengths and limitations

The main strength of the current systematic review is that it only includes studies that used an accelerometer to measure total sedentary time and/or breaks in sedentary time. This is in contrast to previous reviews which have relied on self-report questionnaires (de Rezende et al., 2014; Edwardson et al., 2012; Wilmot et al., 2012). Self-report questionnaires provide information on the type of sedentary behaviours being undertaken and the social and environmental contexts in which they occur, which is useful for choosing which behaviour(s) to target during public health interventions (Atkin et al., 2012; Corder et al., 2007, 2008). However, they are vulnerable to recall and social desirability bias, making them less suitable for use during association studies (Clark et al., 2009; Corder et al., 2007). Accelerometers are currently the most valid and reliable tool for measuring sedentary time (de Rezende et al., 2014). However, hip-mounted accelerometers, such as the Actigraph accelerometer, are incapable of distinguishing between postures. Consequently, time spent standing may be misclassified as sedentary time, resulting in an overestimation of total sedentary time (Clemes et al., 2012). Future association studies should consider using the activPAL accelerometer to measure sedentary time. The activPAL accelerometer is worn on the thigh and uses information about thigh inclination to estimate the amount of time spent sitting or lying, standing and walking (Atkin et al., 2012; Ryan et al., 2006).

Another strength of the current review is that it investigates individual cardiometabolic biomarkers rather than global measures of cardiometabolic health, such as risk of Type 2 diabetes and CVD (Wilmot et al., 2012) or clustered metabolic risk (Edwardson et al., 2012). Global measures may be more important to patients and clinicians, but individual biomarkers allow a better understanding of the sedentary behaviour physiology, which is currently poorly understood (de Rezende et al., 2014).

The majority of studies included in the current review investigated adults without diagnosed diabetes, but other populations were also investigated. Individuals with Type 2 diabetes or with a higher risk of developing Type 2 diabetes are different from healthy individuals because they have a poorer cardiometabolic profile. In addition, they may spend more time in sedentary behaviours and less in MVPA. Despite this, the different populations showed similar associations, suggesting that the findings are generalisable. However, only six studies investigated adults with newly diagnosed Type 2 diabetes or with a higher risk of developing Type 2 diabetes and therefore, future studies should investigate further whether the relationship between sedentary behaviour and cardiometabolic health differs by the presence or absence of Type 2 diabetes.

The main limitation of the current review is that it was not possible to conduct a meaningful meta-analysis due to inconsistencies in the way in which sedentary time was measured, defined and analysed. For example, different accelerometer cut points were used to define sedentary time. The majority of studies defined sedentary time as <100 cpm, which has been shown to underestimate total sedentary time by 16.9 min (Kozey-Keadle et al., 2011). Kozey-Keadle et al. (2011) found that the cut point with the lowest bias was 150 cpm, but only one study used this cut point in the current review (Green et al., 2014). Cut points greater than 150 cpm have been shown to overestimate total sedentary time, probably due to misclassification of time spent in light-intensity physical activity as sedentary time. To improve comparability between studies in the future, methods of measuring and defining sedentary time need to be standardised. Furthermore, to aid data synthesis, future association studies should report the unit change in each cardiometabolic biomarker per 1-hour increase in total sedentary time and/or 1-break increase in breaks in sedentary time.

Another limitation of the current review is that only one study required at least 7 valid days of accelerometer wear time to be included in the final analysis (Kim et al., 2013), suggesting that current studies have undersampled total sedentary time (Matthews et al., 2002). Causality cannot be inferred from the findings of the current review because only four studies were prospective. Furthermore, we cannot rule out the possibility that physical inactivity and/or obesity at least partially mediated the reported associations because not all of the studies adjusted for MVPA plus BMI and/or WC.

Conclusion

In conclusion, there was consistent evidence from cross-sectional data that accelerometer-measured total sedentary time was unfavourably associated with insulin sensitivity, supporting a detrimental association between self-reported sedentary time and risk of Type 2 diabetes that was reported in a previous meta-analysis. There was also some evidence that total sedentary time was unfavourably associated with fasting insulin, HOMA-IR and triglycerides. Finally, there was some evidence from cross-sectional data that accelerometer-measured breaks in sedentary time were favourably associated with triglycerides. However, further studies are required to investigate the prospective associations of accelerometer-measured total sedentary time and breaks in sedentary time with individual cardiometabolic biomarkers. Consistent methods of measuring, defining and analysing sedentary time should also be used to enable comparison between such studies. Nonetheless, data presented here support the suggestion that greater volumes of sedentary time are detrimental to health and reinforce the need to identify interventions to reduce time spent sedentary.

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Conflict of interest

The authors declare that there are no conflicts of interest.

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LB and RP developed the search strategy for the electronic databases. LB and CF independently reviewed the titles and abstracts from the database search. LB and AC independently extracted data from the included studies and assessed them for quality. LB synthesised the data and presented it narratively. CF, AC and AP provided writing assistance and proof read the final manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.ypmed.2015.04.013.

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