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Review

The relationship between sedentary behaviour and physical activity in adults: A systematic review

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ABSTRACT

To ascertain, through a systematic review, the associations between sedentary behaviour (SB) and physical activity (PA) among adults aged 18–60 years. Studies published in English up to and including June 2013 were located from computerized and manual searches. Studies reporting on at least one measure of SB and an association with one measure of PA were included. 26 studies met the inclusion criteria. Six studies examined associations between SB and PA prospectively, and 20 were cross-sectional. The most commonly assessed subtype of sedentary behaviours were television viewing (11 studies), total sedentary time (10), total sitting time (4), general screen time (3) and occupational sedentary time (2). All studied types of SB were associated with lower levels of PA in adults. Findings of this review suggest inverse associations between SB and PA were weak to moderate. Objective monitoring studies reported larger negative associations between SB and light intensity activity. Current evidence, though limited, supports the notion that sedentary behaviour displaces light intensity activity.

Contents

Introduction . . . 28
Methods . . . 31
Search strategy . . . 31
Inclusion and exclusion criteria . . . 31
Identification of relevant articles . . . 31
Data extraction and coding . . . 31
Strength of association . . . 31
Study quality . . . 31
Results . . . 32
Study quality . . . 32
Measurements . . . 32
Associations between sedentary behaviour and physical activity . . . 32
Discussion . . . 32
Conclusions . . . 34
Conflict of interest statement . . . 34
Appendix A. Supplementary data . . . 34
References . . . 34

Introduction

Over the past few decades, the way in which we live our daily lives has changed dramatically. Technological advances, societal influences and environmental attributes have significantly influenced the way

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Table 1
Characteristics of included studies, along with the results of the study quality assessment for each study.

Study	Sample	Measure SB	Measure PA	Association	Study quality
1 — Kronenberg et al., 2000 (USA)	1778 participants, women mean age 49 ± 13; men mean age 48 ± 14 years	Self-reported television viewing	Questionnaires on physical activity were based on those used in the CARDIA study with minor modifications.	Weak inverse associations between total LTPA and TV viewing in women (Spearman $r = -0.084$, $p = 0.009$) and men ($r = -0.115$, $p = 0.001$).	4/8 50%
2 — Jacoby et al., 2003 (Peru)	1176 families, men mean age 42.1 ± 9.0; women mean age 37.5 ± 7.6 years	Self-reported television viewing	Self-reported physical activity using questions adapted from the Health Insurance Plan of New York (HIP) Activity Questionnaire.	Significant positive associations between hours reported sitting, watching TV and physical inactivity in men and women ($p < 0.001$).	3/8 37.5%
3 — Zhang et al., 2004 (China)	254 females with ovarian cancer and 652 healthy female controls, aged 45–65 years.	Self-reported domain-specific sitting time (work, travel, TV meals, other)	Self-reported leisure-time and occupational physical activity	The association with sedentary behaviours was weak and varied across the three intensity levels of physical activity. Total sitting time was significantly associated with strenuous sport ($r = 0.31$), vigorous work ($r = -0.44$), and moderate PA ($r = -0.41$). No associations between TV viewing and PA, or sitting at work and strenuous sport.	6/8 75%
4 — McCormack and Giles-Corti, 2004 (Australia)	1803 participants, aged 18–59 years	Self-reported television viewing via interview	Self-reported time spent walking, and time in light, moderate and vigorous intensity physical activity	Participation in recommended levels of vigorous-intensity PA was associated with a reduced likelihood of watching television more than 10 h per/week ($OR = 0.71$).	3/8 37.5%
5 — Buckworth and Nigg, 2004 (USA)	493 college students, mean age 21 ± 4.0 years	Self-reported time spent watching television, using a computer, and studying	Self-reported physical activity using the CARDIA Physical Activity History questionnaire	For males, computer use was inversely associated with MVPA. No associations observed for males between TV viewing and PA. In females, TV viewing was inversely associated with PA, no associations were seen with computer use and PA.	3/8 37.5%
6 — Martinez-Gonzalez et al. (2005) Spain	40 obese women, aged 20–50 years	Self-reported television viewing, computer use, driving, socialising. Values combined to provide total sitting time	RT3 accelerometer	Inverse association between total sedentary time and energy expenditure estimated using the RT3 accelerometer (Spearman $r = -0.42$, $p < 0.01$).	6/8 75%
7 — Bennet et al., 2006 (USA)	486 participants, aged >18 years	Self-reported television viewing	Pedometer step counts (Yamax SW-200)	Each hour of TV viewing was associated with 144 fewer steps/day. For each hour of TV viewing, there was a 16% decrease in the likelihood of accumulating 10,000 steps/day.	6/8 75%
8 — Oppert et al., 2006 (France)	213 men, mean age 44 ± 5 years; 192 women, mean age 42 ± 4 years	Self-reported screen time and reading	Self-reported leisure-time and occupational physical activity, using the Modifiable Activity Questionnaire	Reading was inversely associated with occupational PA ($r = -0.26$, $p < 0.001$) in men, no association seen in women. In women, reading was positively associated ($r = 0.36$, $p < 0.001$) with LTPA, no association seen in men.	6/8 75%
9 — Sugiyama et al., 2007 (Australia)	2650 participants, aged 20–65 years	Self-reported television viewing	Leisure-time physical activity, from the IPAQ Long.	A significant negative association was found between TV time and LTPA in women but not in men (statistical values not given).	5/8 62.5%
10 — Healy et al., 2008 (Australia)	169 participants, aged 30–87 years	Accelerometer-determined total sedentary time	ActiGraph 7164	Sedentary and light-intensity time were strongly inversely correlated (Pearson's $r = 0.96$); correlations were weak between sedentary and moderate-to-vigorous-intensity time (Pearson's $r = 0.27$)	8/8 100%
11 — Chang et al., 2008 (Taiwan)	2,353 participants, aged >40 years	Self-reported television viewing	Self-reported leisure time physical activity	Weak inverse associations between TV viewing and occupational PA ($r = -0.08$, $p < 0.05$), and total activity ($r = -0.09$, $p < 0.001$).	4/8 50%
12 — Sugiyama et al., 2008 (Australia)	2210 participants, aged 20 — 65 years	Self-reported leisure-time sedentary behaviour	International Physical Activity Questionnaire (IPAQ Short)	Weak inverse association between leisure time sedentary behaviour and LTPA ($r = -0.07$).	6/8 75%
13 — Ballard et al., 2009 (USA)	116 male undergraduates, mean age 19.5 years	Self-reported time spent watching television, playing video games and reading	International Physical Activity Questionnaire (IPAQ Short)	Small but significant inverse associations seen between measures of video game play and frequency and intensity of PA (correlations range: $r = 0.20$–0.22).	5/8 62.5%
14 — Ekelund et al., 2009 (UK)	192 participants	Accelerometer-determined total sedentary time	ActiGraph 7164	Time spent sedentary was inversely associated with time spent in light-intensity activity ($r = 0.52$, $p < 0.0001$).	8/9 88.9%

(continued on next page)

Table 1 *(continued)*

Study	Sample	Measure SB	Measure PA	Association	Study quality
15 — Helmerhorst et al., 2009 (UK)	376 participants, mean age 49.4 ± 7.7 years	Total sedentary time measured via calibrated heart rate monitoring	Individually calibrated minute-by-minute heart rate monitoring	Sedentary time was inversely correlated with MVPA ($r = -0.34$; $p < 0.001$)	8/9 88.9%
16 — Dunton et al., 2009 (USA)	10 984 participants, aged >21 years	Self-reported total leisure time and transport related sedentary behaviour	Self-reported total leisure time and transport related moderate to vigorous physical activity	Total time spent in PA was inversely associated with total time spent in sedentary behaviours ($\chi^2 = 59.35$, $p < 0.001$). Time spent watching TV was inversely related to time spent in LTPA ($\chi^2 = 124.01$, $p < 0.001$). Time spent in LTPA was positively associated with time spent playing games ($\chi^2 = 23.55$, $p < 0.001$) and reading ($\chi^2 = 79.62$ $p < 0.001$). Computer use was unrelated to LTPA.	5/8 62.5%
17 — Rouse and Biddle, 2010 (UK)	46 males (mean age 20.2 years), 38 females (mean age 19.5 years).	Multiple domains of sedentary time assessed via ecological momentary assessment diaries	Multiple domains of physical activity assessed via ecological momentary assessment diaries	Significant inverse association between PA and sedentary technology for males ($r = -0.217$, $p < 0.05$), no association seen in females. No associations observed between sedentary social and sedentary study and PA in males and females.	4/8 50%
18 — Patel et al., 2010 (USA)	53,440 men and 69,776 women	Self-reported leisure-time sitting	Self-reported leisure-time physical activity	No significant association between leisure time sitting and PA ($r = -0.03$).	3/9 33.3%
19 — Touvier et al., 2010 (France)	698 men and 691 women, aged 45–64 years	Self-reported television viewing	French self-administered version of the Modifiable Activity Questionnaire (MAQ)	Changes in TV viewing differed according to category of changes in walking habits in women; those who increased their duration of walking by 2 h/week or more decreased time spent watching TV by 11.5 min/day.	7/9 77.8%
20 — Teychenne et al., 2010 (Australia)	3645 women, aged 18–45 years	Self-reported total siting time, watching television, sitting at a computer	International Physical Activity Questionnaire (IPAQ Long)	No significant interactions between LTPA, sitting time and risk of depression in unadjusted or adjusted models.	6/8 75%
21 — Dunstan et al., 2010 (Australia)	8800 participants, aged >25 years	Self-reported television viewing	Self-reported physical activity, using the Active Australia questionnaire	Weak, but statistically significant association between leisure-time exercise and TV viewing (Spearman $r = -0.03$, $p < 0.01$).	8/9 88.9%
22 — Lynch, 2010 (USA)	111 breast cancer survivors, mean age 48.5 ± 18.7 years	Accelerometer-determined total sedentary time	ActiGraph 7164	Correlation between log moderate-to-vigorous intensity activity and sedentary time was strong (Pearson's $r = -0.66$). Light intensity activity and sedentary time were almost completely inversely correlated (Pearson's $r = -0.99$)	7/8 87.5%
23 — Bauman et al., 2011 (20 Countries)	49,493 adults, aged 18–65 years	Total sitting time (IPAQ short)	International Physical Activity Questionnaire (IPAQ Short)	Linear inverse association between decreasing levels of high PA and increasing sitting time ($p < 0001$). Those reporting low or moderate PA were 3 and 2.2 times more likely to be in highest sitting category (versus high PA group).	6/8 75%
24 — Lakerveld et al., 2011 (Australia)	2,191 men and 2,650 women aged ≥25 years	Self-reported television viewing	Physical activity assessed using the Active Australia Survey	Linear regression analyses revealed that every additional hour of TV viewing measured at baseline was associated with a decrease in PA 5 years later in women (OR = 1.46). No associations observed in men.	4/9 44.45%
25 — Tudor-Locke et al., 2011 (USA)	1781 males, mean age 46.5 years; 1963 females, mean age 47.7 years	Accelerometer-determined total sedentary time	ActiGraph 7164-derived steps/day and activity counts/day	The relationship between steps/day and time spent in sedentary behaviour was inverse and moderate ($R^2 = 0.25$).	8/8 100%
26 — Bonomi et al., 2012 (Netherlands)	20 participants, aged 26–60 years	Tracmor accelerometer	Tracmor accelerometer, activity intensity classified using classification tree algorithm.	Inverse association observed between sedentary time and active standing ($r = -0.87$, $p < 0.001$).	8/8 100%

Numbers have been added to the references contained in the above table to enable cross-comparisons to the same papers summarised in Tables 2 and 3.
Papers with a study quality score equal to or over 75% were classified as high quality, based on a medium split using the ratings of the included studies.

we spend our leisure, work and travel time, and how we live our lives at home and in our communities, resulting in substantial proportions of the day spent in sedentary pursuits, or sitting. For example, estimates from objective monitoring in the US show that adults spend 7–9 h of their working day sedentary (Matthews et al., 2008). Sedentary behaviour has been defined as "any waking behaviour characterised by an energy expenditure ≤1.5 METs whilst in a sitting or reclining posture" (Sedentary Behaviour Research Network, 2012, p. 540). This definition includes activities such as sitting, lying down, watching television, reading, screen-based entertainment and driving a vehicle

(Pate et al., 2008). A growing body of epidemiological evidence has linked sedentary behaviour to health risks including an increased risk of type 2 diabetes (Proper et al., 2011; Van Uffelen et al., 2010; Wilmot et al., 2012), metabolic syndrome (Edwardson et al., 2012), cancer (Lynch, 2010; Schmid and Leitzmann, 2014), and all-cause and CVD mortality (Proper et al., 2011; Van Uffelen et al., 2010; Wilmot et al., 2012; Chau et al., 2013). These associations have been shown to be at least partially independent of levels of moderate-to-vigorous physical activity (MVPA), suggesting that sedentary behaviours have the potential to influence risk of disease, independent of physical activity levels typically recommended for good health.

Traditionally it was believed that only MVPA was beneficial to health, however recent studies employing objective monitoring have shown that time spent in light physical activity may also have health benefits (Healy et al., 2007; 2008; Dunstan et al., 2012; Carson et al., 2013). For example, Healy et al. (2007) observed that, after adjustment for confounders, objectively measured light intensity physical activity was beneficially associated with blood glucose levels in a sample of adults. The temporal patterning of behaviours suggests that MVPA and some single sedentary behaviours (e.g. TV viewing and/or computer use) may compete for time at certain periods during the day, but over 24 h there appears to be time for both behaviours to co-exist (Biddle et al., 2009). However, in contrast, population level studies have shown that sedentary behaviour is strongly and inversely associated with time spent in light physical activity, such as standing and light ambulation (Healy et al., 2008). Therefore, on a population level, sedentary time appears not to displace MVPA but, instead, may displace levels of light-intensity physical activity. Given that light physical activity will include standing and light ambulation, and these are the kinds of behaviours likely to be undertaken when not sitting, it is logical to expect a relationship between sedentary behaviour and light activity. For example, a recent study examining hourly patterns of sedentary behaviour and light intensity physical activity showed that the two behaviours displayed an inverse pattern throughout waking hours (Clemes et al., 2014).

These arguments may assist researchers in better understanding the nature of the displacement hypothesis — a notion suggesting that time in sedentary behaviour is displacing physical activity (Mutz et al., 1993). A recent meta-analysis conducted in children and adolescents has shown a small but significant inverse association between sedentary time and physical activity (Pearson et al., 2014), however associations between sedentary behaviour and all intensities of physical activity have received limited attention in adults. Understanding the presence of any association between sedentary behaviour and physical activity will provide insight into how certain behaviours may displace others and could aid in the development of effective interventions to reduce sedentary behaviour in adults. It is opportune, therefore, to review whether sedentary behaviours are associated with physical activity in adults. Therefore the aim of this study was to systematically review the literature to determine the nature and strength of the relationship between sedentary behaviour and different types and intensities of physical activity.

Methods

Search strategy

Potential studies were located from computerized (PubMed, Science Direct, Cochrane Library and Web of Knowledge) and manual searches of personal files and review articles. Search strategies were built around four groups of key words: sedentary behaviour (e.g. sitting, lying, seated, TV viewing, computers), physical activity (e.g. exercise, light physical activity, MVPA, walking, sports, cycling, active travel, active transport), sample type (e.g. healthy adults, young adults, middle age adults) and study type (e.g. cohort, prospective, cross-sectional) (see Supplementary Table 1).

Inclusion and exclusion criteria

For inclusion, studies were required to (1) include adults aged 18 years and over as participants of the study at baseline; (2) have a point estimate (mean) of at least one aspect of sedentary behaviour; (3) have a point estimate (mean) of at least one aspect of physical activity; (4) be observational and report on the statistical association between at least one aspect of sedentary behaviour and one aspect of physical activity; (5) be published in peer reviewed journals in the English language; (6) be published up to and including June 2013.

Identification of relevant articles

Potentially relevant articles were selected by (1) screening the titles; (2) screening the abstracts; and (3) if abstracts were not available or did not provide sufficient data, the entire article was retrieved and screened to determine whether it met the inclusion criteria.

Data extraction and coding

Data were extracted on standardized forms developed for this review. This information is summarised in Table 1. Identified sedentary and physically active behaviours were tabulated to highlight the state of the literature for the associations between sedentary behaviour and physical activity among adults (see Table 2). Associations between sedentary behaviours and physical activities in adults are reported as positive (+), inverse (−) or no association (0).

Strength of association

The strength of association was graded as none, small, medium, or large for data using Pearson correlation (r), standardized regression coefficient (β) (Sawyer et al., 2004), multiple regression (R, partial R, R^2, partial R^2), Cohen's *d* effect size, and odds ratio (OR) (Allen and Le, 2008).

Study quality

Methodological quality of the included articles was assessed using a 13-item scale, adapted from previously reported scales (Craggs et al., 2011; Chinapaw et al., 2011; Uijtdewilligen et al., 2011), and used in a recent systematic review and meta-analysis (Pearson et al., 2014). The scale focused on quality of reporting (3-items, with an additional item for prospective studies) and study quality (validity/precision: 8-items with one additional item for prospective studies). Items were marked "positive", "negative", or "not sufficiently described". A total score for quality of reporting and for study quality respectively was calculated by adding all positive scores for each assessed study. The

Table 2
Associations between domains of sedentary behaviour and domains of physical activity.

PA / SB	Work PA (n = 4)	Transport PA (n = 6)	LTPA (n = 9)	Domestic PA (n = 1)	Walking (n = 5)	General PA (n = 5)	Light PA (n = 4)	MVPA (n = 4)	Exercise (n = 6)
Television viewing		4^0, 5^-	9^-, **12^-**, 24^-L		**7^0**	1^-, **2^-**, 19^-L			5^-, 9^-, **2^-**, **21^-L**, **22^-**
General Screen time	13^-, **20^-**	5^-, 13^-	13^-	13^-	13^-				
Occupational sedentary time			**8^-**, 11^-						
Overall sitting time	**23^-**		**3^-**, **20^-**		18^0 L, **23^-**				18^0 L
Overall sedentary time	**8^-**	17^-	16^-		**26^-**	**6^-**, **15^-L**	**10^-**, **14^-L**, **22^-**, **25^-**	**10^-**, **14^-L**, **22^-**, **25^-**	17^-

(0): No association (-): Inverse and Small association (−): Inverse and Moderate association (—): Inverse and Large association
*Domestic PA: such as; yard activities and gardening, *L: Longitudinal study *Exercise: such as; running, biking, aerobic, swimming, *General screen time: (e.g. composite score of television viewing plus computer use), and *Bold numbers: high quality studies (studies with scores higher than 75% in quality of study).

scoring system placed an emphasis on positive scores. Negative and not sufficiently described items were treated equally in that no points were scored for either (see Supplementary Table 2). For analytical purposes, study quality scores (ranging from 0 to 8 for cross-sectional studies and from 0 to 9 for prospective studies) were converted into a percentage to enable comparisons in quality across the different study types, with higher percentages meaning higher quality. Based on their study quality score, papers were categorised into low and high quality studies using a medium split.

Results

The literature searches yielded 17,499 titles of potentially relevant articles, 26 of which met the inclusion criteria and were included in this review (see Fig. 1). The included studies are summarised in Table 1. Twenty studies examined associations between sedentary behaviour and physical activity cross-sectionally, and 6 examined associations prospectively. (For ease of reading and space, references for studies in the results are numbered as in Table 1).

Study quality

All 20 cross-sectional studies were evaluated for study quality and scores ranged from 3/8 to 8/8 (mean score: 68%). Among the 6 prospective studies, study quality scores ranged from 3/9 to 8/9 (mean: 70%) (see Table 1). Across all studies, papers with a study quality score equal to or above 75% were classified as high quality (n = 15).

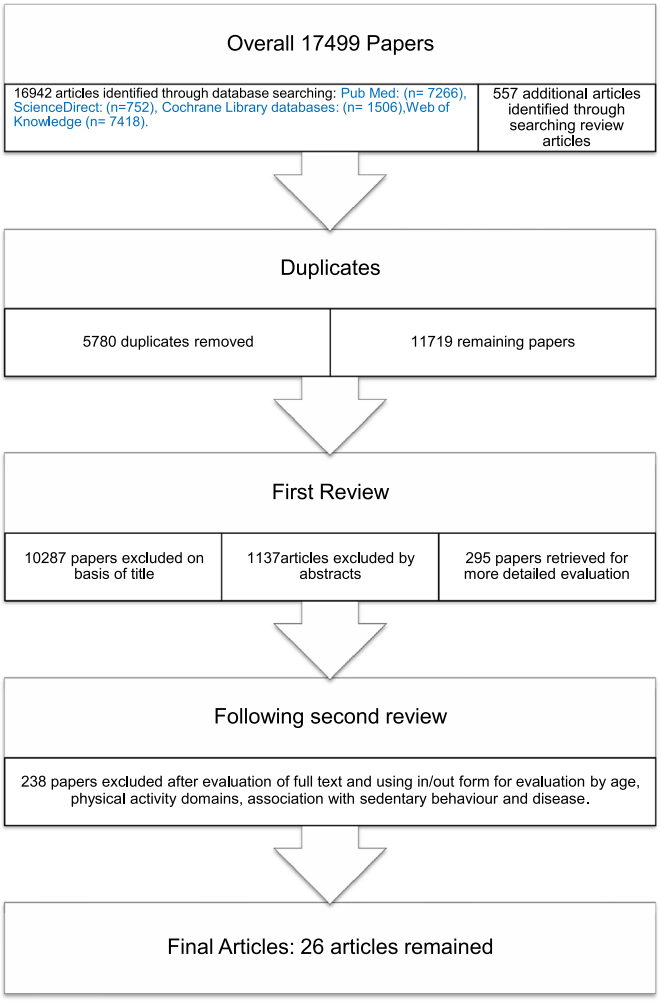

Fig. 1. Systematic review flow diagram.

Measurements

The majority of studies (n = 20) used self-reported methods to measure both physical activity and sedentary behaviour. The remaining studies (n = 6) used objective measures, of which 4 were cross-sectional and 2 were prospective. In studies utilising objective methods, 4 used the ActiGraph (10, 14, 22, 25) for both sedentary behaviour and physical activity. One study used flex heart rate (15) for both sedentary behaviour and physical activity and one used RT3 accelerometer for monitoring sedentary behaviour and physical activity (6) (Table 3).

Associations between sedentary behaviour and physical activity

Table 2 summarises the associations between sedentary behaviours and physical activity. From the 26 included studies, 5 domains of sedentary behaviour and 9 domains of physical activity were examined.

Television viewing (TV) was the most commonly assessed sedentary behaviour (n = 12). In these studies, six papers (50%) reported a small inverse association (1, 2, 5, 12, 19, 21), three studies (25%) reported a moderate inverse association (9, 23, 24), one paper (8%) reported a large inverse association (22), and two studies (16.7%) found no association between TV viewing and all evaluated aspects of physical activity (4, 7). 'Exercise' was the most commonly assessed domain of physical activity in association with TV viewing time. TV viewing was inversely associated with exercise in five out of five studies (Table 2).

Total daily sedentary time was the second most commonly assessed sedentary behaviour (n = 10). In these studies, three papers (30%) reported a small inverse association (8, 10, 17), three studies (30%) a moderate inverse association (6, 15, 25), and five studies (50%) found a large inverse association between overall sedentary time and all reported domains of physical activity (10, 14, 16, 22, 26). Light activity and MVPA were the most commonly assessed domains of physical activity in association with total daily sedentary time. Total daily sedentary time was inversely associated with time spent in light activity in four studies (40%) and MVPA in four studies (40%) (Table 2).

'Sitting time' was assessed in four studies with two papers (50%) reporting a small inverse association (20, 23), one study (25%) a moderate inverse association (3) and one (25%) found no association between sitting time and all reported domains of physical activity (18). Leisure-time physical activity (LTPA) and walking were the most commonly assessed domains of physical activity in association with sitting time. Sitting time was inversely associated with LTPA in two studies (50%) and walking in two studies (50%) (Table 2).

General screen time was assessed in three studies which all reported a small inverse association (5, 13, 20) with all evaluated aspects of physical activity (Table 2).

Occupational sedentary time was assessed in two studies, in which both studies (8, 11) reported a small inverse association with LTPA (Table 2).

Discussion

The purpose of this systematic review was to appraise and summarise the literature on associations between sedentary behaviour and physical activity in adults. The associations between these behaviours were evaluated across five domains of sedentary behaviour and nine domains of physical activity. The most commonly reported method of assessing sedentary behaviour and physical activity in the included studies was via self-report. The majority of these studies reported small to medium inverse associations between sedentary behaviour and physical activity. Six studies objectively assessed sedentary behaviour and physical activity, with these studies generally demonstrating small to medium inverse associations between sedentary time and MVPA, but medium to large inverse associations between sedentary behaviour and light intensity physical activity.

Table 3
Studies with objective measurements of sedentary behaviour and physical activity.

Study identifier, author (year), country	Measurement tool, including accelerometer cut-points where relevant in counts/min	Number of days of monitoring, plus daily wear time (mins/day)	Light intensity activity (mins/day)	Moderate–vigorous intensity activity (mins/day)	Sedentary time (mins/day)	Analysis and results
6 — Martinez-Gonzalez et al. (2005) Spain	Triaxial accelerometer (RT3 Triaxial Research Tracker) energy expenditure estimation (kcal day^{-1})	The participants wore the RT3 for 3 days in a typical week and 2 days at the weekend. They could take it off for sleeping at night and for hygiene.	———	————	———	Inverse association between total sedentary time and energy expenditure estimated using the RT3 accelerometer (Spearman $r = -0.42$, $p < 0.01$).
10 — Healy et al. (2008) Australia	•ActiGraph 7164 •SB: <100 •LPA: 100–1951 •MVPA: ≥1952	Participants requested to wear the accelerometer throughout waking hours for 7 consecutive days. Daily wear time not given.	39% of wear time	4% of wear time	57% of wear time	Sedentary and light-intensity time were strongly inversely correlated ($r = 0.96$); correlations were weak between sedentary time and MVPA ($r = 0.27$).
14 — Ekelund et al. (2009) UK	•ActiGraph 7164 •SB: <100 •LPA: 101–1951 •MPA:1952–5724 •VPA: >5725	Participants required to have >4 consecutive days of monitoring. Daily wear time: Men: 778 mins/day Women: 765 mins/day	Men: 297 ± 77 Women: 321 ± 70	Men: 29 ± 16 Women: 25 ± 17	Men: 452 ± 84 Women: 419 ± 85	Time spent sedentary was significantly and inversely associated with time spent in light-intensity activity. ($r = 0.52$, $p < 0.0001$)
15 — Helmerhorst et al. (2009) UK	Physical activity and sedentary time measured objectively by individually calibrated minute-by-minute heart rate monitoring. Sedentary time was calculated as the heart rate observations (in minutes) below an individually predetermined threshold (flex heart rate) and expressed as a percentage of total monitored time. The percentage of time spent above 1.75 × resting heart rate represented MVPA.	Heart rate monitor worn throughout waking hours for 4 days. Daily wear time not given.	66.1% of wear time	1.9% of wear time	32.9% of wear time	Sedentary time was inversely correlated with time in MVPA ($r = -0.34$; $p < 0.001$).
22 — Lynch et al. (2010) USA	•ActiGraph 7164 •SB: <100 •LPA: 100–1951 MVPA: ≥1952	Participants requested to wear the accelerometer throughout waking hours for 7 consecutive days Daily wear time: 14.0 ± 1.9 h/day	32.6% of wear time	1.1% of wear time	66.3% of wear time	LPA and sedentary time were almost completely inversely correlated ($r = -0.99$), strong inverse correlation between MVPA and sedentary time ($r = -0.66$).
25 — Tudor-Locke et al., 2011 (USA)	•ActiGraph 7164 •SB: <100 •Low PA: 100–499 •LPA: 500–2019 •MPA: 2020–5998 •VPA: ≥5999	Participants requested to wear the accelerometer throughout waking hours for 7 consecutive days. Daily wear time: 14.0 ± 0 h/day.	Low PA (n = 3744): 199.9 (95% CI: 196.8–203.1) mins/day LPA (n = 3744): 141.1 (95% CI: 137.3–145.0) mins/day	MPA (n = 3710): 22.3 (95% CI: 21.0–23.6) mins/day VPA (n = 1143): 5.4 (95% CI 5.0–5.9) mins/day	Sedentary (n = 3744): 479.1 (95% CI: 473.5–484.7) mins/day	There was a moderate, inverse association between steps/day and time in sedentary behaviour ($R^2 = -0.25$)

Abbreviations: SB — Sedentary behaviour; PA — physical activity; LPA — light physical activity; MPA — moderate physical activity; MVPA — moderate to vigorous physical activity; VPA — vigorous physical activity.

Based on the assessment of study quality, 15 studies were categorised as high quality, with an overall quality score equal to or above 75%. These studies provided evidence of an inverse association between sedentary behaviour and physical activity, ranging from small to large, with only one high quality study reporting no association between sedentary time and physical activity (Teychenne et al., 2010). In contrast, those studies deemed of lower quality reported small or no associations (n = 3) between sedentary behaviour and physical activity. Findings suggest that relationships between sedentary behaviour and physical activity exist, however the strength of the association varies depending on the domain studied, the method of measurement (self-report versus objective assessment), and on study quality. This finding is similar to that of Pearson et al. (2014) who recently conducted a systematic review examining the association between sedentary behaviour and physical activity in children and adolescents. In their review, studies employing objective measurements and those assessed to be of higher quality reported stronger associations between these behaviours.

TV viewing was the most commonly reported sedentary behaviour, with the majority of studies reporting small to medium inverse associations between TV viewing time and physical activity across multiple domains. In the studies assessing general screen time, similar small to medium inverse associations were seen with physical activity. Due to the self-report nature of these particular sedentary behaviours, it is difficult to conclude whether TV viewing and screen time displaces physical activity.

Stronger evidence in support of the displacement hypothesis (Mutz et al., 1993) is provided from studies with objective monitoring. Five of the six studies which objectively measured sedentary time and physical activity used accelerometers, and reported small to medium inverse

associations between sedentary time and MVPA, and medium to large inverse associations between sedentary behaviour and light intensity physical activity. For example, the correlation coefficients between sedentary time and light intensity physical activity in the studies of Healy et al. (2008), Lynch et al. (2010) and Bonomi et al. (2012) ranged from 0.87 to 0.99. The studies applying objective monitoring were all classified as high quality studies, with their quality scores ranging from 88 to 100%. These studies therefore provide strong evidence for large inverse associations between sedentary time and light intensity activity.

Given light physical activity typically involves standing and light ambulation; these incidental behaviours tend to be more prevalent when an individual is not sitting, as opposed to MVPA which is likely to be more structured. It is therefore logical to expect a stronger relationship between sedentary behaviour and light activity, with sedentary time more likely to displace light intensity activities than MVPA. Given the strong links between sedentary behaviour and light physical activity, interventions targeting breaking up sedentary behaviour, and/or reductions in sedentary behaviour should initially target increases in light intensity activity. Moving populations from sedentary behaviours into activities involving light intensity activity will likely be more achievable and sustainable, and could have substantial effects on public health (Healy et al., 2007; 2008; Dunstan et al., 2012; Carson et al., 2013). For example, Dunstan et al. (2012) have recently shown that breaking up sedentary behaviour every 20 min with 2 min of light walking significantly improves glucose and insulin regulation. Such behaviour modifications may be achievable for the vast majority of adults. Experimental evidence on the optimum duration of such light intensity breaks is still in its infancy however, and further research is required before such recommendations can be incorporated into health guidelines.

Whilst the studies using objective measures were all classified as high quality, it should be cautioned that the majority of these studies used accelerometers (five out of six) which do not directly measure sitting. Accelerometers are not capable of distinguishing between different postures; they provide an estimation of sedentary time through a lack of movement counts. Hence periods of standing still can be misinterpreted as sitting (Atkin et al., 2012). Further research would benefit from the use of an inclinometer, as used elsewhere (Tigbe et al., 2011), which is capable of distinguishing between different postures.

The majority of studies included in the review were cross-sectional, with just 23% being prospective. Because of the limited evidence from prospective studies, it is necessary for researchers to pay more attention to people's sedentary behaviour and physical activity in the long term. Overall strengths of this review include the multiple domains of sedentary behaviour and physical activity included, from a range of studies with diverse sample characteristics. We utilized a broad search criteria, including both electronic and manual sources, and a large number of studies were screened for eligibility. However, few of the included studies aimed to address directly the question of interest to this review. The association between sedentary behaviour and physical activity was frequently reported as a descriptive finding within a Methods, Results or Discussion section. Therefore, we cannot rule out the possibility that some relevant studies were not identified for the current synthesis. However, the validity of this modified checklist has not been determined therefore this should be highlighted as a limitation of this study. Moreover, few studies provide time stamped data thus are unable to say whether one behaviour truly displaces another. Time of day may be an important factor in this regard. For example, TV viewing late in the evening is unlikely to displace physical activity, whereas the same sedentary behaviour during the day might do.

This review is the first of its kind to present a synthesis of the evidence documenting the associations between sedentary behaviour and physical activity in adults. The findings suggest that sedentary behaviour is inversely associated with physical activity, with the strongest associations seen with light intensity physical activity.

Conclusions

Given the high volumes of time adults reportedly spend in sedentary behaviour, along with the detrimental effects of sedentary behaviour on health (Wilmot et al., 2012), interventions are urgently needed to re-address the balance between sedentary behaviour and physical activity. Findings of this review suggest weak to moderate inverse associations between sedentary behaviour and physical activity, with stronger evidence from objective monitoring studies reporting larger associations between sedentary behaviour and light intensity activity. The evidence from this review, although limited, suggests that sedentary behaviour may displace time spent in light intensity activity. Interventions promoting reductions in sedentary behaviour through the promotion of light activities may have the potential to have a large impact on public health.

Conflict of interest statement

The authors declare that there are no conflicts of interest

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.ypmed.2014.08.028.

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