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Differences of energy expenditure while sitting versus standing: A systematic review and meta-analysis

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Abstract

Background: Replacing sitting with standing is one of several recommendations to decrease sedentary time and increase the daily energy expenditure, but the difference in energy expenditure between standing versus sitting has been controversial. This systematic review and meta-analysis aimed to determine this difference.

Designs and methods: We searched Ovid MEDLINE, Ovid Embase Scopus, Web of Science and Google Scholar for observational and experimental studies that compared the energy expenditure of standing versus sitting. We calculated mean differences and 95% confidence intervals using a random effects model. We conducted different predefined subgroup analyses based on characteristics of participants and study design.

Results: We identified 658 studies and included 46 studies with 1184 participants for the final analysis. The mean difference in energy expenditure between sitting and standing was 0.15 kcal/min (95% confidence interval (CI) 0.12–0.17). The difference among women was 0.1 kcal/min (95% CI 0.0–0.21), and was 0.19 kcal/min (95% CI 0.05–0.33) in men. Observational studies had a lower difference in energy expenditure (0.11 kcal/min, 95% CI 0.08–0.14) compared to randomised trials (0.2 kcal/min, 95% CI 0.12–0.28). By substituting sitting with standing for 6 hours/day, a 65 kg person will expend an additional 54 kcal/day. Assuming no increase in energy intake, this difference in energy expenditure would be translated into the energy content of about 2.5 kg of body fat mass in 1 year.

Conclusions: The substitution of sitting with standing could be a potential solution for a sedentary lifestyle to prevent weight gain in the long term. Future studies should aim to assess the effectiveness and feasibility of this strategy.

Keywords

Sitting, standing, energy expenditure, sedentary behaviour, non-exercise activity thermogenesis, indirect calorimetry

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Introduction

Total energy consumption and expenditure are the two components of energy balance, and determine the long-term content of body fat.[1–3] The current evidence suggests that energy consumption could increase the risks of various cardiovascular diseases (CVDs), cancers and diabetes mellitus (DM) while energy expenditure (EE) may have an inverse relationship with those conditions.[1,4–7] EE while sitting is considered to be close to the basal metabolic rate, with EE of less than 1.5 metabolic equivalent of tasks (METs).[8] To that end, sitting is considered the most common type of sedentary behaviour. Population-based studies have reported the daily sitting time ranging from 3.2 to 6.8 hours (20–43% of adults' waking hours) across 32 European

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countries[9] to more than 7 hours in the United States.[10] The pervasive nature of sedentary behaviour, expressed mainly as extended sitting time, has been blamed as one of the contributors to the obesity epidemic and high prevalence of CVD and DM, regardless of whether physical activity has been self-reported or measured objectively.[11–13]

Moderate to vigorous physical activities (MVPAs) have been suggested as a solution to increase daily EE and decrease the risk of CVD and mortality. The amount of EE during these types of physical activities is more than 3.5 METs.[14,15] However, decreasing sedentary behaviour by increasing MVPAs has been shown to be difficult due to several barriers in performing MVPAs in the adult population, such as lack of time, knowledge, motivation, social support or environmental factors such as lack of facilities.[16,17] Furthermore, people can perform 150 minutes of MVPA per week and still be sedentary if they spend most of the day sitting.[18] Therefore, strategies have focused on decreasing sitting time to reduce CVD risks and other conditions.

Non-exercise activity thermogenesis (NEAT), a major component of total EE, has become a concept of interest in recent years to reduce sitting time, increase EE and prevent obesity.[19–22] NEAT includes a series of low energy movements or activities with a metabolic expenditure greater than 1.5 but lower than 3.5, which occur on a daily basis for minutes to hours representing a key determinant of the daily EE beyond basal metabolic rate.[23] Standing is an example of NEAT that is the simplest and perhaps the most feasible substitute for sitting.[24–29] In this regard, several studies have suggested that the amount of EE of standing is significantly higher than sitting, while some other studies have refuted the beneficial effect of standing on daily EE or the risk of CVD.[8,30–33]

The objective of this systematic review and meta-analysis was to investigate the difference in EE between sitting and standing by pooling all available evidence. These results could determine if decreasing sitting time may be considered a valid strategy to decrease sedentary behaviour, increase the amount of daily EE and possibly decrease the risk of obesity and other metabolic and cardiovascular conditions.

Methods

This study was designed according to the guidelines of the 2009 Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement.[34] The institutional review board of Mayo Clinic approved the protocol of the study.

Inclusion criteria for this study were randomised and non-randomised trials and observational studies that measured the difference in EE between sitting and standing among non-pregnant adults. We excluded studies with incomplete data, review articles, letters, editorials and case reports.

An expert librarian (PJE) conducted a comprehensive systematic literature search of Ovid MEDLINE, Ovid Embase Scopus, Web of Science, Google Scholar and EBSCO CINAHL from inception up to 22 June 2017, without language or year of publication restrictions. Supplementary Appendix 1 shows the search terms and strategy that were used by the librarian to search the literature in Scopus.

The search result was uploaded into a systematic review software (Covidence, London, UK). Three authors (FS, JRMI and MS) independently and in duplicate, identified the relevant titles and abstracts and selected the studies for full-text review, based on the inclusion and exclusion criteria. Figure 1 shows the details of the screening and exclusion of the studies in different stages with detailed reasons for exclusion. The references of the studies included in the full-text review were searched for cross-references, to find the studies that could have been missed in the original search. The reviewers calibrated their judgements using a smaller set of reports. Subsequently, disagreements were harmonised by consensus; if this was not possible, the senior author (FLJ) made the final decision as to whether or not to include a publication for final analysis. The interobserver agreement was measured using the kappa statistic.

Data extraction

We extracted predefined data elements including general study characteristics (the name of the first author and the year of publication), study design (e.g. randomised trial, observational studies, etc.), EE measurement method, number of participants, age, gender, weight, body fat mass, lean body mass, body mass index (BMI), location of the study, specific group of participants, the order of sitting and standing in the study and outcome (i.e. EE) in different units of kJ/min, kcal/min and METs in all the participants and different subgroups (if applicable).

As standard tools to assess risk of bias could not be applied to our studies, we developed a customised quality assessment tool assessing 25 characteristics relevant for a comparison of EE, including: factors related to participants (nine criteria), to setting (six criteria) and to methods (10 criteria) (Supplementary Appendix 2). The maximum possible score was 36. The studies were classified as excellent quality ($\geq$18 out of 36), good quality (10–18 out of 36) and fair quality ($<$10 out of 36), in terms of their methodological quality and the risk of bias.

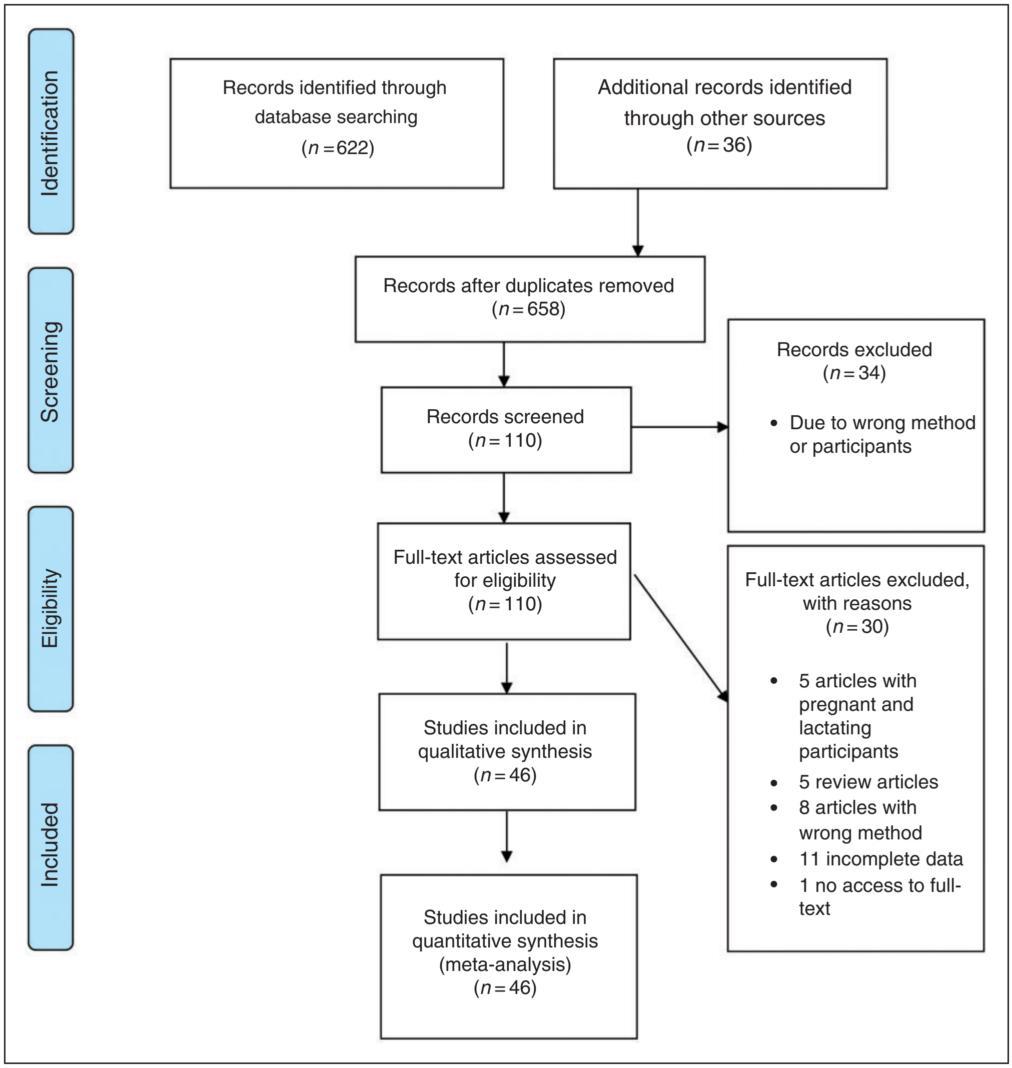

Figure 1. PRISMA flowchart detailing the literature search.

We contacted the authors of studies in which more information was needed to determine eligibility or to complete the analyses.

Statistical analysis

We extracted the weighted mean differences from each study, pooled the data across the studies and analysed the data with a random inverse variance effects model, because of expected heterogeneity across studies, using the RevMan v.5.3 Cochrane Collaboration software. We tested heterogeneity between studies using the chi-squared test (χ^2) statistic and quantified inconsistency with I^2, which represents the proportion of between-study differences that is not attributable to chance or random error. We prespecified subgroup analyses by gender, the quality score of the studies, use of sit–stand workstations in the experiment and study design dividing studies as either observational studies, randomised trials or non-randomised trials.

Publication bias

We assessed publication bias using a funnel plot to inspect asymmetry visually. We used the trim-and-fill method to identify and correct the asymmetry of the funnel plot arising from publication bias. We trimmed the small studies and filed the missing studies around the centre of the plot and compared the results to results without using this method.

Results

The systematic search yielded 658 abstracts, from which 46 studies with 1184 research participants were included in the final analysis, including 10 randomised

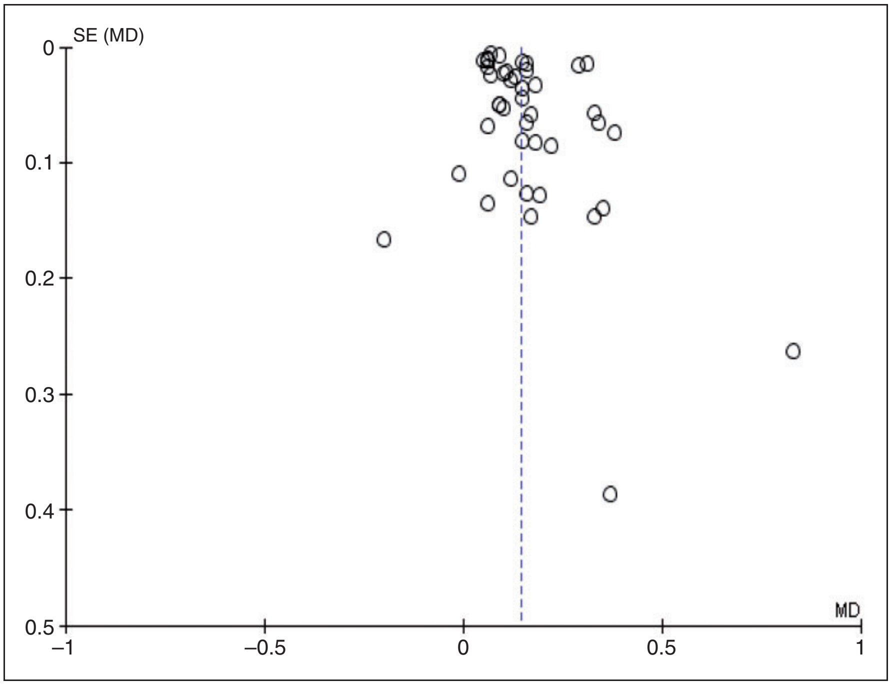

Figure 2. Funnel plot showing the distribution of the included studies based on their results of the difference in energy expenditure between sitting versus standing.

trials (Figure 2). The table shows the main characteristics of the studies included. Reviewers were in agreement over which studies should be included ($\kappa = 0.83$). Most studies came from the USA (eight studies), the UK (seven studies) and India (five studies). All articles were in English and there was no unpublished work that met our inclusion criteria.

The mean age of the participants was 33 ± 11 years, range 19–74 years, 60% were men, mean BMI was $24\,kg/m^2$ with a mean body weight of 65 ± 15 kg.

None of the studies met all the 25 criteria listed in the customised quality assessment tool. Nineteen had excellent quality, 11 had good quality and the rest had fair quality (Table 1). All of the included studies used indirect calorimetry to measure the amount of EE in sitting and standing.

The mean EE while standing was 1.47 ± 0.33 kcal/min, range 0.952–2.32 kcal/min, while the mean EE of sitting was 1.29 ± 0.24 kcal/min, range 0.85–1.8 kcal/min. The mean difference in EE between standing and standing was 0.15 kcal/min (95% confidence interval (CI) 0.12–0.17) (Figure 3).

In seven studies, the EE of sitting and standing was reported separately for men and women. Subgroup analysis of these studies showed a difference in EE between sitting and standing of 0.1 kcal/min among women that had borderline statistically significance (95% CI 0.0–0.21), while the EE between sitting and standing in men was significantly different (0.19 kcal/min, 95% CI 0.05–0.33) (Figure 4).

We conducted a subgroup analysis to test the difference in EE between sitting and standing by study design. The lowest difference in EE between sitting and standing was found in observational studies (0.11 kcal/min, 95% CI 0.08–0.14), while the greatest difference was reported in randomised trials (0.18 kcal/min, 95% CI 0.11–0.25). Heterogeneity was significant for all subgroup analyses based on the study design; however, the I^2 statistic to test for subgroup difference was 45%, suggesting that the study design could be a possible source of heterogeneity that was observed in the overall meta-analysis (Figure 5).

A subgroup analysis was performed to test the effect of the quality of studies on the overall heterogeneity. The highest difference in EE between sitting and standing was demonstrated in studies with good quality (Figure 6). Another subgroup analysis focused on studies using sit–stand workstations in their experiment and compared the result with those not using sit–stand workstations in their design. The result of the comparison showed the difference between sitting and standing while working is 0.04 kcal/min, higher than the difference between sitting and standing motionless (0.18 kcal/min, 95% CI 0.07–0.29 vs. 0.14 kcal/min, 95% CI 0.11–0.16) (Figure 7).

Discussion

The precise effect of substituting sitting with standing on daily EE and on weight loss has been debated.

Table 1. Description of the studies included in the systematic review and meta-analysis.

	First author	Year of publication	Participants (N) (female, N, %)	Age (mean ± SD)	BMI (mean)	Study design	Setting			Location	Quality score	Subgroup analysis
							Participants	Situation during sitting and standing	Outcomes			
1	Bandyopadhyay[50]	1980	11 (0, 0)	19.04 ± 2.4	18.26	Observational	Two groups of healthy athlete and non-athlete participants	Sitting resting, standing resting	Energy intake, energy expenditure in lying, sitting, standing, walking and playing, intake of protein, fat and carbohydrate	India	8	None
2	Banerjee[51]	1959	11 (2, 18.2)	29.36	21.35	Observational	Healthy research workers	Sitting resting, standing resting	Energy expenditure in lying, sitting, standing, walking and ascending and descending the stairs	India	22.5	None
3	Banerjee[52]	1959	7 (0, 0)	26.14	18.68	Observational	Healthy male workers	Sitting resting, standing resting	Energy expenditure during lying, sitting, standing and walking	India	8	None
4	Banerjee[53]	1961	7 (7, 100)	19.86	19.32	Observational	Healthy undergraduate girl students	Sitting resting, standing resting	Energy intake and expenditure in lying, sitting, standing, walking, ascending stairs and descending stairs	India	9	None
5	Banerjee[54]	1972	20 (10, 50)		21	Non-randomised trial	Healthy athlete and non-athlete participants	Sitting resting and standing	Energy expenditure in lying, sitting, standing, walking and running	China	10	By gender
6	Bleiberg[55]	1980	27 (27, 100)	30.6 ± 2.5	20.53	Observational	Healthy sedentary farmers	Sitting resting, standing resting	Energy expenditure in lying, sitting, standing, walking, sowing, thinning out and replanting, hoeing, grinding grain a millstone, pounding, fetching water from the wall and swamp, washing clothes, stirring sorghum or miller porridge	Burkina Faso	5	None
7	Brun[56]	1979	45 (0, 0)	37		Observational	Healthy male agricultural workers	Sitting resting, standing resting	Energy expenditure of lying, sitting, standing, walking and agricultural activities.	Iran	3	None
8	Brun[57]	1981	30 (0, 0)	36.6 ± 2.2	20.24	Observational	Healthy male farmers	Sitting and standing	Energy expenditure in resting activities, daily life activities, at the market, housework, handicrafts at home, farming, hunting, animal husbandry, teaching religion or making clothes	Burkina Faso	4	None

(continued)

Table 1. Continued

							Setting					
	First author	Year of publication	Participants (*N*) (female, *N*, %)	Age (mean ± SD)	BMI (mean)	Study design	Participants	Situation during sitting and standing	Outcomes	Location	Quality score	Subgroup analysis
9	Buckley[36]	2013	10 (8, 80)			Non-randomised trial	Healthy participants	Sitting and standing while working with computers using sit–stand workstations	Energy expenditure and post-prandial glucose levels in sitting and standing positions	USA	18	None
10	Cole[37]	1987	20 (0, 0)	24 ± 3.2	21	Observational	Healthy male students	Sitting and standing	Energy intake and expenditure in lying, sitting, standing, walking at normal pace, personal necessities, climbing stairs	Nigeria	6	None
11	Cox[35]	2011	31 (22, 71)	37 ± 2.5		Randomised trial	Healthy adult participants	Sitting and standing and reading a note using sit–stand workstation	Oxygen consumption, energy expenditure, heart rate, speech quality and dyspnea	USA	14	None
12	Creasy[32]	2016	74 (43, 61)	24.3 ± 3.6	24.3	Randomised trial	Healthy participants	Sitting and watching TV, standing and watching TV	Energy expenditure in sitting, standing and walking	USA	15	None
13	De Guzman[58]	1978	20 (10, 50)	26.15	19.63	Observational	Male and female clerk-typists	Sitting resting, standing resting	Energy intake, energy expenditure in different occupational and non-occupational activities and also daily energy expenditure	Philippines	6.5	By gender
14	De Guzman[59]	1984	18 (9, 50)	32.5	21.6	Observational	Male and female healthy participants	Sitting resting, standing resting	Calorie intake, Daily energy expenditure Energy expenditure during sitting, standing and walking and also different occupational activities of rice farmers	Philippines	11.5	By gender
15	Edholm[60]	1955	12 (0, 0)	19.46	21.34	Observational	Male cadets	Sitting and standing	Food and calorie intake, daily energy expenditure and energy expenditure of lying, sitting, standing, marching, running, climbing stairs, dressing, and different games	UK	3	None
16	Edmundson[61]	1989	16 (8, 50)	30.69 ± 4.1	17.74	Observational	Healthy Hindu villagers	Sitting and standing	Energy expenditure of lying, sitting, standing, and 13 other work tasks for Indian farmers, energy intake, and nutrient patterns	India	5	None

(continued)

Table 1. Continued

	First author	Year of publication	Participants (N) (female, N, %)	Age (mean ± SD)	BMI (mean)	Study design	Setting: Participants	Setting: Situation during sitting and standing	Setting: Outcomes	Location	Quality score	Subgroup analysis
17	Fountaine[62]	2016	18 (8, 44)	22.3 ± 1.4		Non-randomised trial	Active and healthy college students	Sitting resting, standing resting	Oxygen consumption and energy expenditure in sitting, standing and sit/step position	USA	20	None
18	Gao[63]	2017	18 (18, 100)	49.4 ± 7.9	23.4	Randomised trial	Healthy female participants with a heightened diabetes risk	Sitting and standing and working with computer and reading using sit–stand workstation	Energy expenditure in sitting and standing, metabolic markers including glucose, insulin, triglycerides, glycerol, Free fatty acids and cortisol in sitting and standing	Finland	20.5	None
19	Garry[64]	1952	20 (0, 0)	34	23.15	Observational	Miners and clerks	Sitting and standing	Daily energy expenditure and intake, energy expenditure in sitting, standing, walking, loading coal, girdering or timbering, jawing coal	Scotland	4	None
20	Geissler[65]	1985	43 (0, 0)	26.8 ± 2.6	23	Non-randomised trial	Female carpet weavers and villagers	Sitting resting, standing resting	Daily energy expenditure, energy expenditure in sitting, standing, walking, house works, carpet waiving	UK	13.5	By race
21	Hawari[66]	2016	10 (0, 0)	33 ± 13	28.3	Randomised trial	Normoglycaemic overweight/ obese men	Sitting resting, standing resting	Energy expenditure in prolonged sitting and standing and intermittent sitting and standing, fasting and postprandial glucose, insulin, and triglyceride	UK	10	None
22	Iwaok[67]	1998	46 (0, 0)	36.3 ± 8.1	23.4	Non-randomised trial	Adult men with intellectual disability and normal control men	Sitting resting, standing resting	Energy expenditure of basal, supine, sitting, standing and walking	Japan	18	By intellectual situation
23	Judice[68]	2016	50 (25, 50)	35.2 ± 13	25	Randomised trial	Healthy participants	Sitting resting, standing resting	Energy expenditure in resting, sitting, standing, sit/stand transition	Portugal	19	By gender
24	Kanade[69]	2001	64 (40, 62.5)	32.8 ± 8.4	21.86	Non-randomised trial	Healthy members of staff and students from research institute	Sitting resting, standing resting	Energy expenditure in resting, sitting, standing	India	16.5	By gender and race

(continued)

Table 1. Continued

	First author	Year of publication	Participants (*N*) (female, *N*, %)	Age (mean ± SD)	BMI (mean)	Study design	Setting: Participants	Setting: Situation during sitting and standing	Setting: Outcomes	Location	Quality score	Subgroup analysis
25	Katzmarzyk[70]	1994	47 (12, 25.5)	27	23.2	Non-randomised trial	Adults from two indigenous Siberian populations, the Evenki and Keto	Sitting resting, standing resting	Body composition, resting metabolic rate, energy expenditure of lying, sitting and standing	Russia	5	By gender
26	Lante[71]	2010	46 (20, 43.5)	29.66	26.74	Non-randomised trial	Adults with and without intellectual disabilities	Sitting and resting, standing while completing an assembly task	Energy expenditure in sitting, standing and walking	Australia	18	By gender and intellectual situation
27	Levine[72]	2000	24 (17, 70.8)	38 ± 11	27	Non-randomised trial	Healthy participants	Sitting resting, standing resting	Energy expenditure in sitting, standing and walking	USA	21	None
28	Levine[22]	2007	15 (14, 93)	43 ± 7.5	32	Non-randomised trial	Sedentary individuals with obesity	Sitting and standing and working with computer using sit–stand workstations	Energy expenditure in sitting, standing and walking	USA	18.5	None
29	Mansoubi[38]	2015	51 (26, 50.1)	32.95 ± 9.9	27.36	Randomised trial	normal weight and obese participants	Sitting and watching TV, standing resting	Energy expenditure in sitting, standing and walking	UK	19	None
30	McAlpine[73]	2007	19 (8, 42.1)	27 ± 9	28	Non-randomised trial	Healthy, sedentary volunteers	Sitting resting, standing resting	Energy expenditure in lying, sitting, standing and stepping	USA	25	By weight
31	Miles-Chan[45]	2013	22 (12, 54.5)	24 ± 1	22	Non-randomised trial	Non-smoker young, healthy adult subjects	Sitting resting, standing resting	Energy expenditure in sitting and standing	Switzerland	24.5	By gender
32	Monnard[74]	2017	35 (0, 0)	27 ± 1	23	Non-randomised trial	Young, healthy men	Sitting resting, standing resting	Energy expenditure in sitting and standing and in 4 different races: European, Chinese, Indian, and African	Switzerland	23.5	None
33	Ohwada[75]	2005	46 (0, 0)	36.3 ± 8.1	23.3	Non-randomised trial	Healthy men with and without mental retardation	Sitting resting, standing resting	0xygen consumption, heart rate, and body movement, basal metabolic rate (BMR} and resting metabolic rate in the different positions	Japan	19	By intellectual situation
34	Pulsford[76]	2017	25 (0, 0)	40.2 ± 12.2	26.1	Randomised trial	Healthy non-smoker men	Sitting resting, standing resting	Energy expenditure in sitting, standing and walking, cardiometabolic biomarkers (fasting glucose, glucose, insulin, HOMA, triglyceride, cholesterol, HDL, LDL) Urea, creatinine, ALT, AST in 3 different positions.	UK	19.5	None

(continued)

Table 1. Continued

	First author	Year of publication	Participants (N) (female, N, %)	Age (mean ± SD)	BMI (mean)	Study design	Setting: Participants	Setting: Situation during sitting and standing	Setting: Outcomes	Location	Quality score	Subgroup analysis
35	Reiff[77]	2012	20 (10, 50)	22. ± 1.9	23.48	Randomised trial	Healthy, young adults	Sitting and standing	The volume of oxygen consumed, carbon dioxide produced, minute ventilation and energy expenditure	USA	16	None
36	Roemmich[78]	2016	24 (11, 45.8)	38.3 ± 7.7	26.2	Randomised trial	Healthy sedentary adults	Sitting and word processing on computer, standing and word processing on computer using sit–stand workstation	Energy expenditure during sitting and standing, free-choice of the participants' standing time and their willingness to standing after the trial	USA	15	None
37	Speck[79]	2011	13 (8, 62)	44.2 ± 8.5	27.2	Non-randomised trial	Overweight sedentary participants	Sitting and working with computer, standing and working with computer using sit–stand workstation	Energy expenditure in sitting and standing	USA	4	None
38	Steeves[80]	2011	23 (12, 52.2)	27.9 ± 7	26.6	Non-randomised trial	Normal weight, overweight and obese participants	Sitting resting, standing resting	Energy expenditure in resting, sitting, standing, stepping in place and walking on treadmill	USA	22	None
39	Strickland[81]	1990	22 (0, 0)	23.7 ± 0.7	23.25	Non-randomised trial	Healthy Gurkha and British soldiers	Sitting resting, standing resting	Energy expenditure in lying, sitting, standing and stepping	UK	24.5	None
40	Thompson[82]	1997	40 (40, 100)	66 ± 3	30.22	Non-randomised trial	Obese postmenopausal women	Sitting resting, standing resting	Basal metabolic rate and energy expenditure in resting, sitting, standing and walking	USA	19	None
41	Thorp[25]	2016	17 (6, 35.3)	48.2 ± 8	29.6	Randomised trial	Middle-aged overweight adults	Sitting and working with computer, standing and working with computer using sit–stand workstation	Daily energy expenditure, resting metabolic rate and energy expenditure in sitting and standing	Australia	20	None
42	Verschuren[33]	2016	27 (11, 40.7)	61 ± 11.7	26.58	Observational	Inpatients and outpatients of stroke rehabilitation programme	Sitting resting, standing resting	Energy expenditure of sitting and standing	Netherlands	17	None

(continued)

Table 1. Continued

							Setting					
	First author	Year of publication	Participants (N) (female, N, %)	Age (mean ± SD)	BMI (mean)	Study design	Participants	Situation during sitting and standing	Outcomes	Location	Quality score	Subgroup analysis
43	Visser[83]	1995	12 (12, 100)	74 ± 3	25.6	Observational	Healthy non-smoker women	Sitting and resting, standing	Daily energy expenditure, resting metabolic rate and energy expenditure in lying, sitting, standing, walking or cycling and recreational activities	Netherlands	23.5	None
44	Viteri[84]	1971	18 (0, 0)	29.72 ± 11.7	23.44	Observational	Healthy farmers	Sitting and standing	Basal metabolic rate, energy expenditure, respiratory parameters, and pulse rate in sitting, standing and different categories of agricultural works	USA	6	None
45	Whybrow[85]	2013	14 (7, 50)	38.9 ± 10.4	25.7	Non-randomised trial	Healthy non-smoker adults	Sitting resting, standing resting	Heart rate and energy expenditure in lying, sitting, standing, walking and cycling	UK	12	None
46	Wygand[86]	2016	15 (7, 46.7)	22.4 ± 1.7	24.7	Non-randomised trial	Healthy participants	Sitting and working, standing and working using sit–stand workstation	Energy expenditure in sitting and standing	USA		None

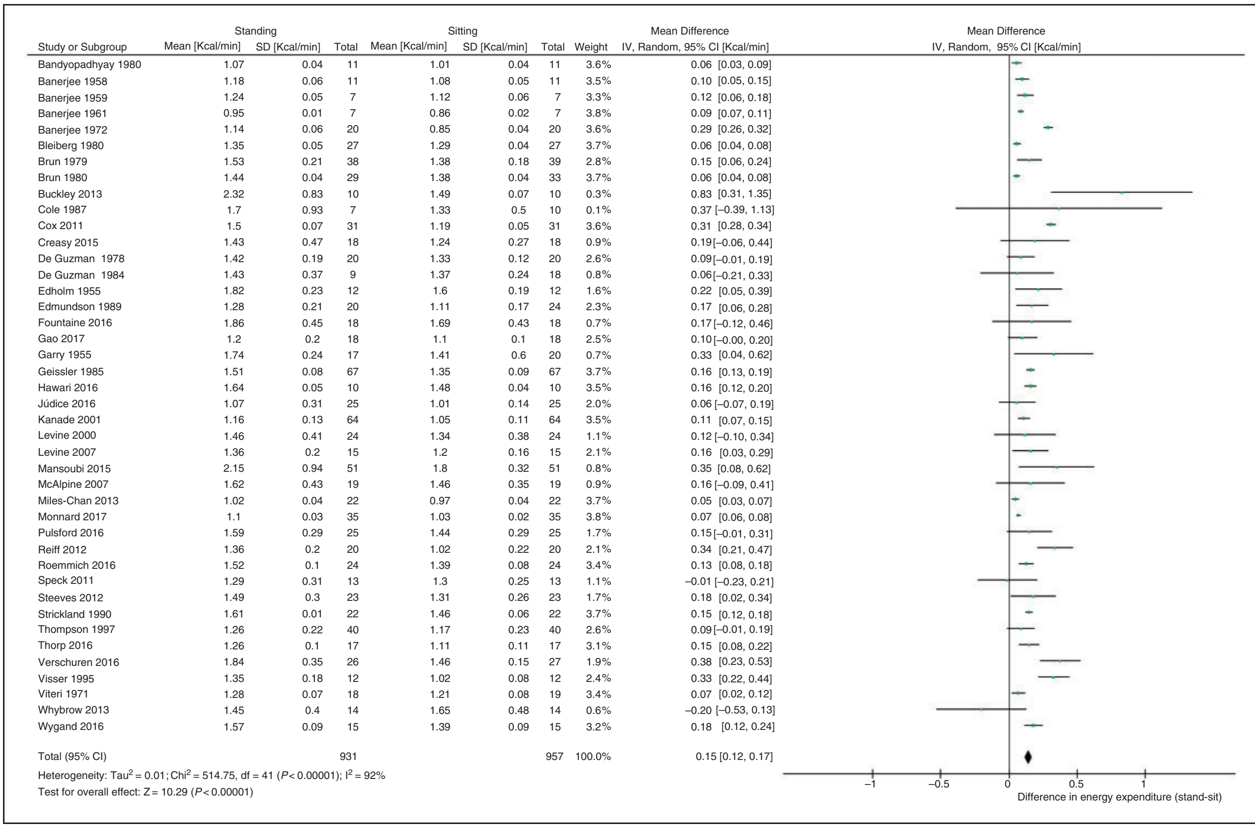

Figure 3. Forest plot of mean difference in energy expenditure (kcal/min) between sitting and standing.

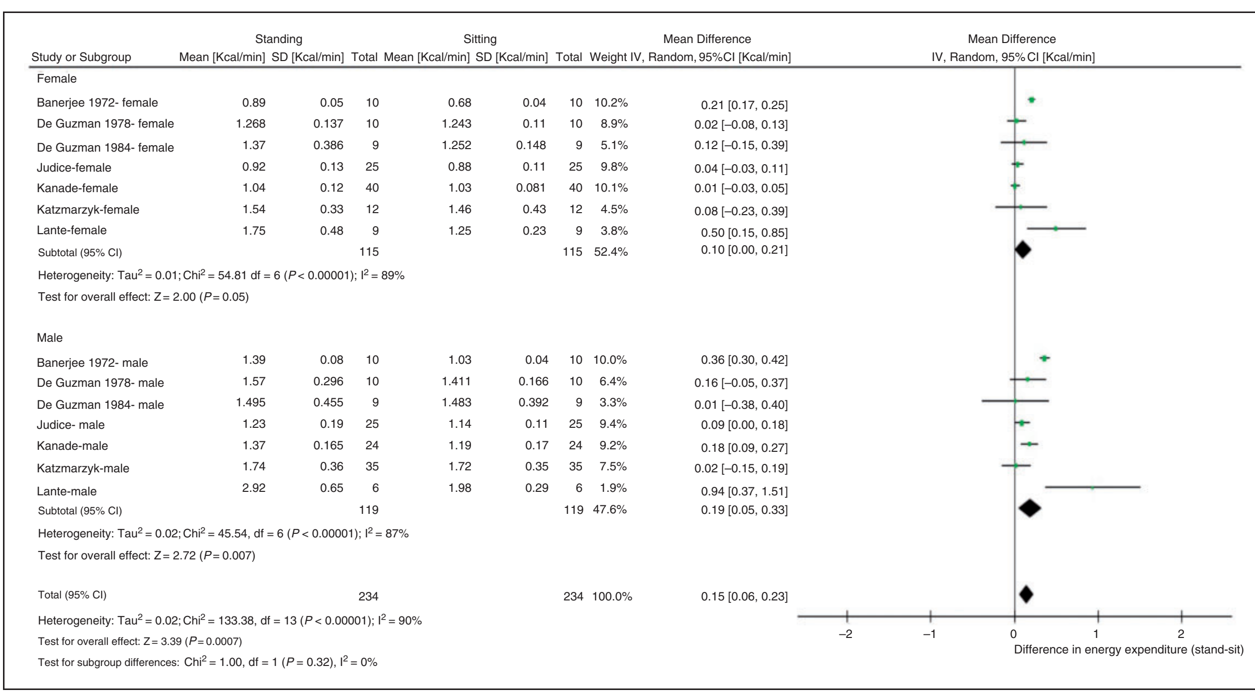

Figure 4. Forest plot of mean difference in energy expenditure (kcal/min) between sitting and standing by gender.

Study or Subgroup	Standing Mean [Kcal/min]	Standing SD [Kcal/min]	Standing Total	Sitting Mean [Kcal/min]	Sitting SD [Kcal/min]	Sitting Total	Weight	Mean Difference IV, Random, 95% CI [Kcal/min]
Observational								
Bandyopadhyay 1980	1.07	0.041	11	1.01	0.039	11	3.6%	0.06 [0.03, 0.09]
Banerjee 1958	1.18	0.064	11	1.076	0.053	11	3.4%	0.10 [0.05, 0.15]
Banerjee 1959	1.232	0.052	7	1.116	0.058	7	3.2%	0.12 [0.06, 0.17]
Banerjee 1961	0.952	0.011	7	0.862	0.023	7	3.7%	0.09 [0.07, 0.11]
Bleiberg 1980	1.35	0.047	27	1.29	0.045	27	3.7%	0.06 [0.04, 0.08]
Brun 1979	1.53	0.21	38	1.38	0.18	39	2.8%	0.15 [0.06, 0.24]
Brun 1980	1.44	0.045	29	1.38	0.043	33	3.7%	0.06 [0.04, 0.08]
Cole 1987	1.7	0.93	7	1.33	0.5	10	0.1%	0.37 [–0.39, 1.13]
De Guzman 1978	1.42	0.19	20	1.33	0.124	20	2.6%	0.09 [–0.01, 0.19]
De Guzman 1984	1.43	0.37	9	1.37	0.24	18	0.9%	0.06 [–0.21, 0.33]
Edholm 1955	1.82	0.23	12	1.6	0.19	12	1.6%	0.22 [0.05, 0.39]
Edmundson 1989	1.28	0.213	20	1.11	0.17	24	2.3%	0.17 [0.05, 0.29]
Garry 1955	1.74	0.24	17	1.41	0.6	20	0.8%	0.33 [0.04, 0.62]
Verschuren 2016	1.84	0.35	26	1.46	0.15	27	1.9%	0.38 [0.23, 0.53]
Visser 1995	1.35	0.18	12	1.025	0.08	12	2.4%	0.33 [0.21, 0.44]
Viteri 1971	1.28	0.07	18	1.21	0.08	19	3.4%	0.07 [0.02, 0.12]
Subtotal (95% CI)			271			297	39.8%	0.11 [0.08, 0.14]
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 56.49$, df = 15 ($P < 0.00001$); $I^2 = 73\%$								
Test for overall effect: $Z = 7.89$ ($P < 0.00001$)								
NRT								
Banerjee 1972	1.14	0.06	20	0.85	0.04	20	3.6%	0.29 [0.26, 0.32]
Buckley 2013	2.32	0.83	10	1.49	0.662	10	0.2%	0.83 [0.17, 1.49]
Fountaine 2016	1.86	0.45	18	1.69	0.43	18	0.8%	0.17 [–0.12, 0.46]
Geissler 1985	1.51	0.08	67	1.35	0.09	67	3.6%	0.16 [0.13, 0.19]
Kanade 2001	1.164	0.135	64	1.05	0.11	64	3.5%	0.11 [0.07, 0.16]
Levine 2000	1.46	0.41	24	1.34	0.38	24	1.1%	0.12 [–0.10, 0.34]
Levine 2007	1.36	0.2	15	1.2	0.16	15	2.1%	0.16 [0.03, 0.29]
McAlpine 2007	1.62	0.43	19	1.46	0.35	19	0.9%	0.16 [–0.09, 0.41]
Miles-Chan 2013	1.02	0.04	22	0.97	0.04	22	3.7%	0.05 [0.03, 0.07]
Monnard 2017	1.1	0.03	35	1.03	0.02	35	3.7%	0.07 [0.06, 0.08]
Speck 2011	1.287	0.31	13	1.296	0.25	13	1.2%	–0.01 [–0.23, 0.21]
Steeves 2012	1.49	0.3	23	1.31	0.26	23	1.7%	0.18 [0.02, 0.34]
Strickland 1990	1.61	0.006	22	1.46	0.06	22	3.7%	0.15 [0.02, 0.18]
Thompson 1997	1.26	0.22	40	1.17	0.23	40	2.6%	0.09 [–0.01, 0.19]
Whybrow 2013	1.45	0.4	14	1.65	0.48	14	0.6%	0.20 [–0.53, 0.13]
Wygand 2016	1.57	0.09	15	1.39	0.09	15	3.1%	0.18 [0.12, 0.24]
Subtotal (95% CI)			421			421	35.9%	0.14 [0.09, 0.18]
Heterogeneity: $Tau^2 = 0.01$; $Chi^2 = 228.08$, df = 15 ($P < 0.00001$); $I^2 = 93\%$								
Test for overall effect: $Z = 5.49$ ($P < 0.00001$)								
RT								
Cox 2011	1.5	0.07	31	1.19	0.05	31	3.6%	0.31 [0.28, 0.34]
Creasy 2015	1.43	0.475	18	1.244	0.27	18	0.9%	0.19 [–0.07, 0.44]
Gao 2017	1.2	0.2	18	1.1	0.1	18	2.5%	0.10 [–0.00, 0.20]
Hawari 2016	1.64	0.05	10	1.48	0.04	10	3.5%	0.16 [0.12, 0.20]
Júdice 2016	1.075	0.31	25	1.01	0.14	25	2.0%	0.06 [–0.07, 0.20]
Mansoubi 2015	2.15	0.94	51	1.8	0.32	51	0.8%	0.35 [0.08, 0.62]
Pulsford 2016	1.2	0.2	18	1.1	0.1	18	2.5%	0.10 [–0.00, 0.20]
Reiff 2012	1.36	0.2	20	1.02	0.22	20	2.1%	0.34 [0.21, 0.47]
Roemmich 2016	1.52	0.1	24	1.39	0.08	24	3.3%	0.13 [0.08, 0.18]
Thorp 2016	1.26	0.1	17	1.11	0.11	17	3.0%	0.15 [0.08, 0.22]
Subtotal (95% CI)			232			232	24.3%	0.18 [0.11, 0.25]
Heterogeneity: $Tau^2 = 0.01$; $Chi^2 = 77.91$, df = 9 ($P < 0.00001$); $I^2 = 88\%$								
Test for overall effect: $Z = 5.08$ ($P < 0.00001$)								
Total (95% CI)			924			950	100.0%	0.14 [0.12, 0.17]
Heterogeneity: $Tau^2 = 0.01$; $Chi^2 = 505,55$ df = 41 ($P < 0.00001$); $I^2 = 92\%$								
Test for overall effect: $Z = 10.08$ ($P < 0.00001$)								
Test for subgroup differences: $Chi^2 = 3.64$, df = 2 ($P = 0.16$), $I^2 = 45.0\%$								

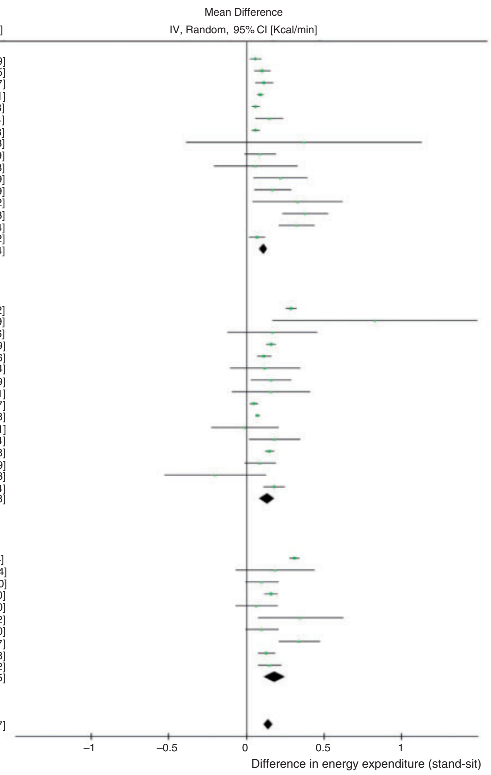

Figure 5. Forest plot of mean difference in energy expenditure (kcal/min) between sitting and standing by study design. NRT: non-randomised trials; RT: randomised trials.

Study or Subgroup	Standing Mean [Kcal/min]	Standing SD [Kcal/min]	Standing Total	Sitting Mean [Kcal/min]	Sitting SD [Kcal/min]	Sitting Total	Weight	Mean Difference IV, Random, 95% CI [Kcal/min]
Excellent quality								
Banerjee 1972	1.14	0.06	20	0.85	0.04	20	3.6%	0.29 [0.26, 0.32]
Buckley 2013	2.32	0.83	10	1.49	0.662	10	0.2%	0.83 [0.17, 1.49]
Fountaine 2016	1.86	0.45	18	1.69	0.43	18	0.8%	0.17 [–0.12, 0.46]
Gao 2017	1.2	0.2	18	1.1	0.1	18	2.5%	0.10 [–0.00, 0.20]
Júdice 2016	1.075	0.31	25	1.01	0.14	25	2.0%	0.06 [–0.07, 0.20]
Levine 2000	1.46	0.41	24	1.34	0.38	24	1.1%	0.12 [–0.10, 0.34]
Levine 2007	1.36	0.2	15	1.2	0.16	15	2.1%	0.16 [0.03, 0.29]
Mansoubi 2015	2.15	0.94	51	1.8	0.32	51	0.8%	0.35 [0.08, 0.62]
McAlpine 2007	1.62	0.43	19	1.46	0.35	19	0.9%	0.16 [–0.09, 0.41]
Miles-Chan 2013	1.02	0.04	22	0.97	0.04	22	3.7%	0.05 [0.09, 0.07]
Monnard 2017	1.1	0.03	35	1.03	0.02	35	3.7%	0.07 [0.06, 0.08]
Pulsford 2016	1.2	0.2	18	1.1	0.1	18	2.5%	0.10 [–0.00, 0.20]
Steeves 2012	1.49	0.3	23	1.31	0.26	23	1.7%	0.18 [0.02, 0.34]
Strickland 1990	1.61	0.006	22	1.46	0.06	22	3.7%	0.15 [0.12, 0.18]
Thompson 1997	1.26	0.22	40	1.17	0.23	40	2.6%	0.09 [–0.01, 0.19]
Thorp 2016	1.26	0.1	17	1.11	0.11	17	3.0%	0.15 [0.08, 0.22]
Visser 1995	1.35	0.18	12	1.025	0.08	12	2.4%	0.33 [0.21, 0.44]
Wygand 2016	1.57	0.09	15	1.39	0.09	15	3.1%	0.18 [0.12, 0.24]
Subtotal (95% CI)			404			404	40.4%	0.15 [0.11, 0.20]
Heterogeneity: $Tau^2 = 0.01$; $Chi^2 = 229.17$, df = 17 ($P < 0.00001$); $I^2 = 93\%$								
Test for overall effect: $Z = 6.23$ ($P < 0.00001$)								
Good quality								
Banerjee 1958	1.236	0.052	7	1.116	0.058	7	3.2%	0.12 [0.06, 0.18]
Cox 2011	1.5	0.07	31	1.19	0.05	31	3.6%	0.31 [0.28, 0.34]
Creasy 2015	1.43	0.475	18	1.244	0.27	18	0.9%	0.19 [–0.07, 0.44]
De Guzman 1984	1.43	0.37	9	1.37	0.24	18	0.9%	0.06 [–0.21, 0.33]
Geissler 1985	1.51	0.08	67	1.35	0.09	67	3.6%	0.16 [0.13, 0.19]
Hawari 2016	1.64	0.05	10	1.48	0.04	10	3.5%	0.16 [0.12, 0.20]
Kanade 2001	1.164	0.135	64	1.05	0.11	64	3.5%	0.11 [0.07, 0.16]
Reiff 2012	1.36	0.2	20	1.02	0.22	20	2.1%	0.34 [0.21, 0.47]
Roemmich 2016	1.52	0.1	24	1.39	0.08	24	3.3%	0.13 [0.08, 0.18]
Verschuren 2016	1.84	0.35	26	1.46	0.15	27	1.9%	0.38 [0.23, 0.53]
Whybrow 2013	1.45	0.4	14	1.65	0.48	14	0.6%	–0.20 [–0.53, 0.13]
Subtotal (95% CI)			290			300	27.1%	0.18 [0.12, 0.24]
Heterogeneity: $Tau^2 = 0.01$; $Chi^2 = 107.76$, df = 10 ($P < 0.00001$); $I^2 = 91\%$								
Test for overall effect: $Z = 5.93$ ($P < 0.00001$)								
Fair quality								
Bandyopadhyay 1980	1.07	0.041	11	1.01	0.039	11	3.6%	0.06 [0.03, 0.09]
Banerjee 1958	1.236	0.052	7	1.116	0.058	7	3.2%	0.12 [0.06, 0.18]
Banerjee 1961	0.952	0.011	7	0.862	0.023	7	3.7%	0.09 [0.07, 0.11]
Bleiberg 1980	1.35	0.047	27	1.29	0.045	27	3.7%	0.06 [0.04, 0.08]
Brun 1979	1.53	0.21	38	1.38	0.18	39	2.8%	0.15 [0.06, 0.24]
Brun 1980	1.44	0.045	29	1.38	0.043	33	3.7%	0.06 [0.04, 0.08]
Cole 1987	1.7	0.93	7	1.33	0.5	10	0.1%	0.37 [–0.39, 1.13]
De Guzman 1978	1.42	0.19	20	1.33	0.124	20	2.6%	0.09 [–0.01, 0.19]
Edholm 1955	1.82	0.23	12	1.6	0.19	12	1.6%	0.22 [0.05, 0.39]
Edmundson 1989	1.28	0.213	20	1.11	0.17	24	2.3%	0.17 [0.05, 0.29]
Garry 1955	1.74	0.24	17	1.41	0.6	20	0.8%	0.33 [0.04, 0.62]
Speck 2011	1.287	0.31	13	1.296	0.25	13	1.2%	–0.01 [–0.23, 0.21]
Viteri 1971	1.28	0.07	18	1.21	0.08	19	3.4%	0.07 [0.02, 0.12]
Subtotal (95% CI)			226			242	32.5%	0.08 [0.06, 0.10]
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 21.31$, df = 12 ($P = 0.05$); $I^2 = 44\%$								
Test for overall effect: $Z = 8.46$ ($P < 0.00001$)								
Total (95% CI)			920			946	100.0%	0.14 [0.12, 0.17]
Heterogeneity: $Tau^2 = 0.01$; $Chi^2 = 505.77$, df = 41 ($P < 0.0001$); $I^2 = 92\%$								
Test for overall effect: $Z = 10.10$ ($P < 0.00001$)								
Test for subgroup differences; $Chi^2 = 15.77$, df = 2 ($P = 0.0004$); $I^2 = 87.3\%$								

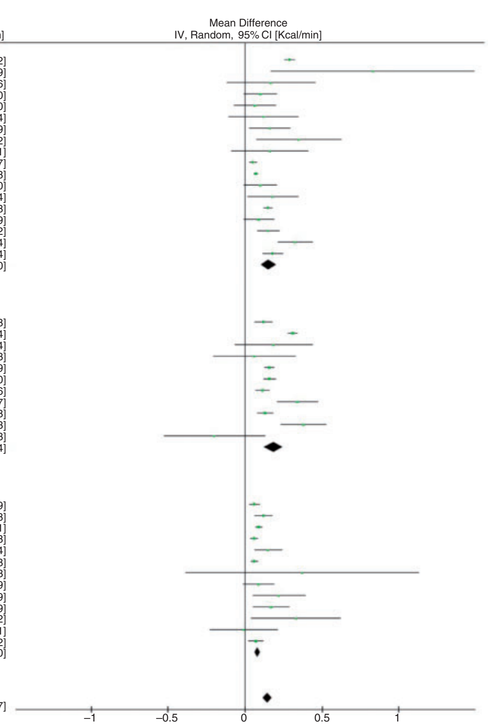

Figure 6. Forest plot of mean difference in energy expenditure (kcal/min) between sitting and standing by studies' quality score.

Study or Subgroup	Standing Mean [Kcal/min]	Standing SD [Kcal/min]	Standing Total	Sitting Mean [Kcal/min]	Sitting SD [Kcal/min]	Sitting Total	Weight	Mean Difference IV, Random, 95% CI [Kcal/min]
EE difference with sit-stand workstation								
Buckley 2013	2.32	0.83	10	1.49	0.662	10	0.2%	0.83 [0.17, 1.49]
Cox 2011	1.5	0.07	31	1.19	0.05	31	3.8%	0.31 [0.28, 0.34]
Levine 2007	1.36	0.2	15	1.2	0.16	15	2.2%	0.16 [0.03, 0.29]
Roemmich 2016	1.52	0.1	24	1.39	0.08	24	3.5%	0.13 [0.08, 0.18]
Speck 2011	1.287	0.31	13	1.296	0.25	13	1.2%	−0.01 [−0.23, 0.21]
Thorp 2016	1.26	0.1	17	1.11	0.11	17	3.2%	0.15 [0.08, 0.22]
Subtotal (95% CI)			110			110	14.1%	0.18 [0.07, 0.29]
Heterogeneity: $Tau^2 = 0.01$; $Chi^2 = 53.97$, df = 5 ($P < 0.00001$); $I^2 = 91\%$								
Test for overall effect: Z = 3.26 ($P = 0.001$)								
EE difference without sit-stand workstation								
Bandyopadhyay 1980	1.07	0.041	11	1.01	0.039	11	3.8%	0.06 [0.03, 0.09]
Banerjee 1958	1.18	0.064	11	1.076	0.053	11	3.5%	0.010 [0.05, 0.15]
Banerjee 1959	1.236	0.052	7	1.116	0.058	7	3.4%	0.12 [0.06, 0.18]
Banerjee 1961	0.952	0.011	7	0.862	0.023	7	3.9%	0.09 [0.07, 0.11]
Banerjee 1972	1.14	0.06	20	0.85	0.04	20	3.8%	0.29 [0.26, 0.32]
Bleiberg 1980	1.35	0.047	27	1.29	0.045	27	3.8%	0.06 [0.04, 0.08]
Brun 1979	1.53	0.21	38	1.38	0.18	39	2.9%	0.15 [0.06, 0.24]
Brun 1980	1.44	0.045	29	1.38	0.043	33	3.9%	0.06 [0.04, 0.08]
Cole 1987	1.7	0.93	7	1.33	0.5	10	0.1%	0.37 [−0.39, 1.13]
Creasy 2015	1.43	0.475	18	1.244	0.27	18	1.0%	0.19 [−0.07, 0.44]
De Guzman 1978	1.42	0.19	20	1.33	0.124	20	2.7%	0.09 [−0.01, 0.19]
De Guzman 1984	1.43	0.37	9	1.37	0.24	18	0.9%	0.06 [−0.21, 0.33]
Edholm 1955	1.82	0.23	12	1.6	0.19	12	1.7%	0.22 [0.05, 0.39]
Edmundson 1989	1.28	0.213	20	1.11	0.17	24	2.4%	0.17 [0.05, 0.29]
Fountaine 2016	1.86	0.45	18	1.69	0.43	18	0.8%	0.17 [−0.12,0.46]
Garry 1955	1.74	0.24	17	1.41	0.6	20	0.8%	0.33 [0.04, 0.62]
Geissler 1985	1.51	0.08	67	1.35	0.09	67	3.8%	0.16 [0.13, 0.19]
Hawari 2016	1.64	0.05	10	1.48	0.04	10	3.7%	0.16 [0.12, 0.20]
Júdice 2016	1.075	0.31	25	1.01	0.14	25	2.1%	0.06 [−0.07, 0.20]
Kanade 2001	1.164	0.135	64	1.05	0.11	64	3.6%	0.11 [0.07, 0.16]
Levine 2000	1.46	0.41	24	1.34	0.38	24	1.2%	0.12 [−0.10, 0.34]
Mansoubi 2015	2.15	0.94	51	1.8	0.32	51	0.9%	0.35 [0.08, 0.62]
McAlpine 2007	1.62	0.43	19	1.46	0.35	19	1.0%	0.16 [−0.09, 0.41]
Miles-Chan 2013	1.02	0.04	22	0.97	0.04	22	3.8%	0.05 [0.03, 0.07]
Monnard 2017	1.1	0.03	35	1.03	0.02	35	3.9%	0.07 [0.06, 0.08]
Reiff 2012	1.36	0.2	20	1.02	0.22	20	2.2%	0.34 [0.21, 0.47]
Steeves 2012	1.49	0.3	23	1.31	0.26	23	1.8%	0.18 [0.02, 0.34]
Strickland 1990	1.61	0.006	22	1.46	0.06	22	3.8%	0.15 [0.12, 0.18]
Thompson 1997	1.26	0.22	40	1.17	0.23	40	2.7%	0.09 [−0.01, 0.19]
Verschuren 2016	1.84	0.35	26	1.46	0.15	27	2.0%	0.38 [0.23, 0.53]
Visser 1995	1.35	0.18	12	1.025	0.08	12	2.5%	0.33 [0.21, 0.44]
Viteri 1971	1.28	0.17	18	1.21	0.08	19	3.6%	0.07 [0.02, 0.12]
Whybrow 2013	1.45	0.4	14	1.65	0.48	14	0.6%	−0.20 [−0.53, 0.13]
Wygand 2016	1.57	0.09	15	1.39	0.09	15	3.3%	0.18 [0.12, 0.24]
Subtotal (95% CI)			778			804	85.9%	0.14 [0.11, 0.16]
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 317.43$, df = 33 ($P < 0.00001$); $I^2 = 90\%$								
Test for overall effect: Z = 10.08 ($P < 0.00001$)								
Total (95% CI)			888			914	100.0%	0.15 [0.12, 0.18]
Heterogeneity: $Tau^2 = 0.01$; $Chi^2 = 505.59$, df = 39 ($P < 0.00001$); $I^2 = 92\%$								
Test for overall effect: Z = 9.94 ($P < 0.00001$)								
Test for subgroup difference: $Chi^2 = 0.62$, df = 1 ($P = 0.43$), $I^2 = 0\%$								

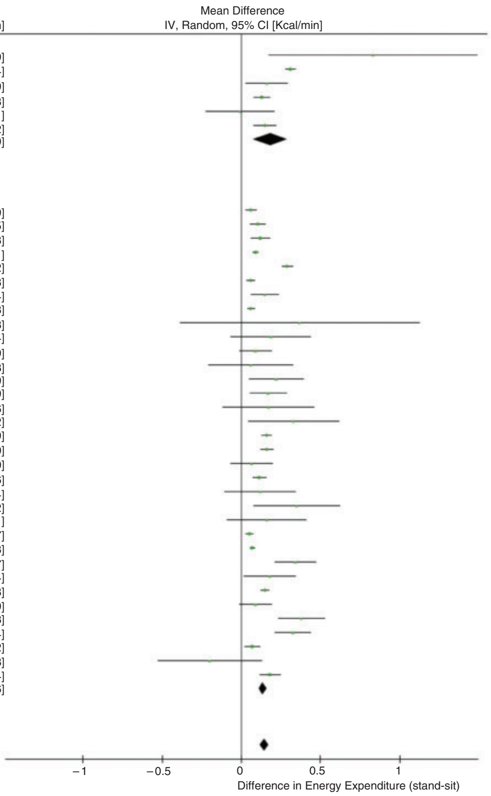

Figure 7. Forest plot of mean difference in energy expenditure (kcal/min) between sitting and standing with and without using sit–stand workstations.

This is the first systematic review and meta-analysis evaluating the difference in EE between sitting and standing in an adult population. Our study demonstrates when putting all the available scientific evidence together, that standing can effectively account for more EE than sitting. The results also show that the difference in EE is more modest than is generally stated in studies or review papers recommending the substitution of sitting with standing.[35–39]

In the subgroup analyses, we found that EE between standing and sitting is about twice as high in men as in women, probably reflecting the effect of greater muscle mass in men on the amount of EE, as EE is proportional to the muscle mass activated while standing. In the subgroup analysis by the study design, the difference in EE between sitting and standing was twice as high in randomised trials as in observational studies. In observational studies, the participants were observed while doing daily activities, whether they were primarily sitting or primarily standing. Thus, investigators had no control over the time participants would spend in each position, and the contamination of exposure (standing vs. sitting) was likely to have interfered with the precision of the calculated difference in EE between standing versus sitting.

The subgroup analysis of studies using a sit–stand workstation and working with computers as part of their design showed that the use of a workstation does not necessarily lead to a higher difference in EE standing versus sitting, compared to just standing. This is probably because the EE of typing is negligible.

In recent years, the role of a sedentary lifestyle on obesity and CVD has been highlighted, and decreasing the sedentary time, independent of MVPA, is considered a target for weight loss and CVD reduction. Several studies have suggested the substitution of sitting with NEAT, and especially with standing, as a way to reduce sedentary time and specifically to prevent or manage obesity.[19–21,40,41]

Levine et al.[20] proposed the concept of NEAT and considered standing as one of the most influential components of NEAT that along with walking and fidgeting-like activities could prevent obesity. The results of this study partially support this theory. On the basis of our results, the substitution of 6 hours of sitting per day with standing would result in an additional 54 kcal in daily EE, predicting a loss of 2.5 kg of body fat mass in one year based on the principle of energy balance. However, whether such a small difference in EE will truly translate into long-term weight loss is yet to be proved, as compensatory mechanisms in basal metabolic rate, increased caloric intake as a result of more muscle activity, or other factors may negate the benefit of spending a few extra calories a day. The limited experimental evidence testing the effect of standing versus sitting on weight loss shows conflicting results. Danquah et al.[42] demonstrated that the substitution of sitting with standing would have positive, albeit very modest, effects on fat loss. The authors showed that the body fat percentage was only 0.61 percentage points lower among participants in the intervention group compared to the control group. Aadahl et al.,[43] on the other hand, reported that with decreasing sitting time by 3% and substituting this time with standing for 6 months, waist circumference would decrease by 1.42 cm. The limited experimental evidence highlights the need for randomised trials using standing time as an intervention, assessing long-term weight loss under controlled and less controlled circumstances.

The physiological basis of the incremental EE difference during standing has been explained by Miller[44] based on the basic rules of thermogenesis. The author describes that the difference in EE between different resting positions of lying, sitting and standing is because of different level of heat production; no work is being accomplished during these positions but a different number and volume of muscles are involved in sitting compared to standing. During standing more muscles are tensed and stretched to fight gravity and bear the weight. This is called 'isometric thermogenesis'. On the other hand, our findings are less substantial than was assumed in previous studies, suggesting that the previous estimates of the effect of standing versus sitting for the management of body weight may need to be reassessed. It is unclear that the acute increase in EE with the postural change from sitting to standing would continue. Miles-Chan et al. have shown that during a 10-minute phase of standing, the expended energy in the second 5 minutes of the phase is about one half of the expended energy in the first 5 minutes.[45] This result may support the theory of adaptation of the muscles during motionless standing that would decrease the amount of EE towards the amount that is observed during sitting.

Although the present study has focused on the changes in EE, the benefits of the substitution of sitting with standing may not be limited to EE. While different observational studies and systematic reviews have shown the undesirable effects of prolonged sitting and sedentary lifestyle on the both CVD risks and outcomes,[12,13,46,47] several studies have suggested beneficial effects of the substitution of sitting with standing on different CVD risk factors. Healy et al. in 2013 showed that replacing sitting time with exclusively standing can decrease fasting blood sugar by approximately 0.34 mmol/dl.[48] Their more recent study in 2017 on different groups of participants and in a different situation confirmed this result.[49] Graves et al. in 2015 also demonstrated the same result for fasting blood sugar,[27] and showed that standing in lieu of sitting can have desirable effects on lowering triglycerides and diastolic blood pressure. These results underscore the potential health benefits of standing instead of sitting, beyond its effects on EE and energy balance, and suggest that recommending standing to replace sitting time may also prevent cardiovascular events. However, epidemiological and experimental studies need to confirm this hypothesis.

The present study has several strengths. As a systematic review and meta-analysis, the results represent evidence coming from different studies, populations and designs. We gathered all the studies ever published asking the same question, and expanded the search to unpublished data, to minimise bias and represent the best available evidence testing the difference in EE between standing versus sitting.

The limitations of this study include the relatively limited quality of the studies included. Most studies were of moderate to fair quality, and no study met all the criteria to be considered of superior quality. We used the trim-and-fill method to assess the effect of this limitation on our meta-analysis results. The difference in EE between sitting and standing in our analysis was significant, but was less than expected and generally perceived. However, considering burning 54 more calories by 6 hours of standing instead of sitting, the long-term effect on weight loss is not trivial, with a possible 10 kg reduction in body fat over 4 years in a 65 kg person. In addition, there are no studies assessing the potential adverse effects of prolonged motionless standing, such as worsening of varicose veins and or peripheral oedema in some people, and also the adaptation of muscles to the new position leading to a decrease in the amount of EE to levels similar to sitting. Also, our results came primarily from white populations, limiting the generalisability to different ethnicities. Information regarding the baseline level of the daily activity of the participants of the included studies was not clarified in their articles; so concluding on the difference in EE between sitting versus standing in people with different levels of daily activities was not possible. The age of the participants varied between 18 and 66 years, and there was a variation between the health status of the participants across different studies. However, given that the aim of the present study was to assess the difference between the EE of sitting and standing, these factors have a trivial effect on the explanation and the accuracy of the results.

In conclusion, the substitution of sitting with standing leads to a modest increase in EE. If applicable to long periods of time (most days of a year), this difference in EE theoretically could be used as a potential solution to ameliorate a sedentary lifestyle so as to prevent weight gain and obesity in the long term.

Author contribution

FLJ and FS contributed to the conception and design of the work. FS, JMI and MS contributed to the acquisition, analysis, or interpretation of data for the work. FS drafted the manuscript. FLJ, TPO, VKS, PJE JRMI and MS critically revised the manuscript. All authors gave final approval and agree to be accountable for all aspects of the work ensuring integrity and accuracy.

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