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Section: Original Research

Article Title: Alternating Sitting and Standing Increases the Workplace Energy Expenditure of Overweight Adults

Authors: Alicia Ann Thorp¹, Bronwyn A. Kingwell², Coralie English³, Louise Hammond¹, Parneet Sethi⁴, Neville Owen⁴, and David W. Dunstan⁴

Affiliations: ¹Neurovascular Hypertension and Kidney Disease; ²Metabolic and Vascular Physiology Laboratory; Baker IDI Heart and Diabetes Institute, Melbourne, VIC, Australia. ³International Centre for Allied Health Evidence (iCAHE) and the Sansom Institute, University of South Australia, Adelaide, SW, Australia. ⁴Physical Activity and Behavioural Epidemiology Laboratories, Baker IDI Heart and Diabetes Institute, Melbourne, VIC, Australia.

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ABSTRACT

Background: To determine whether alternating bouts of sitting and standing at work influences daily workplace energy expenditure (EE). **Methods:** 23 overweight/obese office workers (mean $\pm$ SD; age: 48.2 ± 7.9 yrs, BMI: 29.6 ± 4.0 kg/m²) undertook two, 5-day experimental conditions in an equal, randomised order. Participants wore a ‘metabolic armband’ (SenseWear Armband Mini) to estimate daily workplace EE (KJ/8 hours) while working in a: 1) seated work posture (SIT condition); or, 2) alternating between a standing and seated work posture every 30-min using a sit-stand workstation (STAND-SIT condition). To assess the validity of the metabolic armband, a criterion measure of acute EE (KJ/min; indirect calorimetry) was performed on day 4 of each condition. **Results:** Standing to work acutely increased EE by 0.7 [0.3, 1.0] KJ/min (13%), relative to sitting ($p=0.002$). Compared to indirect calorimetry, the metabolic armband provided a valid estimate of EE while standing to work (mean bias: 0.1 [-0.3, 0.4] KJ/min) but modestly overestimated EE while sitting ($p=0.005$). Daily workplace EE was greatest during the STAND-SIT condition (mean condition difference [95% CI]: 76 [8, 144] KJ/8-hour workday, $p=0.03$). **Conclusions:** Intermittent standing at work can modestly increase daily workplace EE compared to seated work in overweight/obese office workers.

Keywords: work posture, sit-stand workstation, office workers, SenseWear Mini, indirect calorimetry

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INTRODUCTION

Globally, the prevalence of obesity has reached epidemic proportions, with an estimated 1 billion adults overweight and 300 million defined as being clinically obese¹. While the etiology of obesity is complex, modern sedentary lifestyles, with repeated exposure to prolonged sitting are argued to be a contributor to the growing obesity epidemic². The preponderance of sitting-based occupations, along with the availability of labour-saving devices that contribute to reduced daily energy expenditure (EE)³ has seen the workplace emerge as a key setting for interventions to reduce adults' sitting time in order to reduce obesity risk^{4,5}.

Observational evidence that breaking up sedentary time (such as standing up from a seated position or ambulating) is associated with a lower BMI and smaller waist circumference^{6,7}, coupled with findings that workers from predominantly standing occupations have a lower risk of overweight/obesity compared to those who mainly sit⁸, has led to the development of workplace initiatives designed to minimize sitting time by increasing standing during the workday. The use of sit-stand workstations, which allow workers to shift between a seated and standing work posture have shown promise in several field studies to reduce workplace sitting (via increased standing) in office workers⁹⁻¹¹.

Standing to work is postulated to promote EE through an increase in heart rate and muscular activity required to support an upright posture^{12,13}. However, few research studies have elucidated the energetic cost of working in an upright posture¹³⁻¹⁵; with those that have done so showing a 6-14% increase in EE (KJ/min) over a conventional seated work posture. Most of these acute laboratory studies have been performed in young, lean, healthy adults^{13,14} and it is possible that promoting standing breaks at work may yield an even greater absolute energy benefit in overweight/obese, sedentary adults who have more body weight, specifically fat mass,

to support in an upright posture¹⁶. Indeed, extrapolation of data from a recent study in young adults¹⁴ suggests that replacing 50% of workplace sitting time with standing across a standard 8-hour workday may yield an additional 352 KJ/day, which could have distinct benefits for preventing weight gain in working adults¹⁷.

Despite the emerging popularity of sit-stand workstations, their effectiveness to routinely break up prolonged sitting with standing and increase workplace EE remains unknown. This is possibly because assessment of workplace EE with criterion measures such as doubly labeled water is expensive and open-circuit indirect calorimetry is not feasible over an extended time period. The SenseWear Armband (SWA) Mini (version 7.0, BodyMedia® Inc., Pittsburgh, PA) is a small multi-sensor monitor worn on the upper arm that has been shown to provide a valid estimate of daily EE under free-living conditions¹⁸. However, its validity as an estimate of EE during seated and standing work activities against a criterion measure remain unclear.

We recently reported on the effect of introducing intermittent standing bouts every 30-minutes across the workday on markers of cardio-metabolic health in a cohort of 23 overweight/obese office workers¹⁹. In this same cohort of office workers we performed a nested sub-study design to: 1) examine the effect on EE of introducing, intermittent bouts of standing across the workday using a sit-stand workstation; and, 2) examine the validity of the metabolic armband (SWA Mini, version 7.0) to measure EE while sitting and standing at work.

MATERIALS AND METHODS

Participants

Seventeen men and six women completed the nested sub-study as part of a larger randomized (1:1), controlled cross-over laboratory trial (Sit or Stand @ Work Study) between 29 August 2011 and 3 May 2013. Eligibility criteria and a detailed description of the main study

have been provided elsewhere¹⁹. Briefly, middle-aged adults (mean $\pm$ SD age: 48.2 ± 8.0 years), who were overweight (mean BMI: 29.6 ± 4.1 kg/m²) and employed full-time in a deskbound occupation (sit ≥ 4 hours/workday) were recruited to undertake two, 5-day experimental conditions (Monday-Friday), separated by a minimum 7-day washout period. Participants who reported musculoskeletal impairment or injury were excluded from the study. All provided written informed consent prior to their inclusion in the study. Any details that might disclose the identity of the participants involved in the study have been omitted. All participants received financial compensation for their involvement. The study was approved by the Alfred Hospital Human Research Ethics Committee and followed in accordance with the principles of the Declaration of Helsinki. The main study is registered with the Australian New Zealand Clinical Trials Registry (ACTRN12611000632998).

Study Overview

Participants reported to the temperature-controlled (22-24° Celsius) laboratory each morning between 7:00-9:30am in a fasted state (≥ 10 hours) to perform their usual, predominately computer-based, work tasks for 8-hours/day in: 1) a desk-bound (seated) posture (*SIT condition*) or; 2) while alternating between a standing and seated work posture every 30-minutes using an electric, sit-stand workstation (model 1600x 800 mm, Linak Australia) to achieve 4-hours of standing and 4-hours of seated work time (*STAND-SIT condition*).

As part of the nested sub-study, mean daily workplace EE (KJ/8-hour workday) during each experimental condition was estimated using a metabolic armband (SWA Mini, version 7.0) worn by participants. As previously described¹⁹, to control for the thermic effect of food, all meals provided during work hours were standardized for macronutrient content between conditions.

On day 4 of each experimental condition, a criterion measure of acute EE (KJ/min) using open-circuit indirect calorimetry was performed during the first 30-minutes of the workday. Participants were instructed to abstain from alcohol and caffeine and to avoid engaging in structured moderate-to-vigorous physical activity for 24-hours prior to the test. They also consumed (at ~1900) a standardized evening meal that provided 30% of their estimated daily energy requirements (based on gender, age and a sedentary activity level) to minimize fluctuations in their fasting metabolic rate on the morning of the test. Two women with regular menses underwent each experimental condition during the follicular phase of their menstrual cycle (determined by date of onset of their last menses) to avoid fluctuations in their basal metabolic rate²⁰.

SenseWear Armband Mini

The SWA Mini is a small, wireless multi-sensor armband that uses generalized proprietary algorithms to integrate information from several measured parameters (tri-axial accelerometry, heat flux, galvanic skin response, skin temperature, near-body temperature) and descriptive characteristics (gender, age, height, weight, smoking status, dominant hand) to estimate minute-by-minute EE (KJ/min).

On day 1 of each condition, the SWA Mini was initialized using participants' individual data (gender, age, smoking status, handedness) and height and weight measures taken upon arrival to the laboratory. As recommended by the manufacturer, the SWA Mini was positioned on the upper posterior aspect of participants' left arm and worn for a period of 10-minutes to allow for equilibration to skin temperature prior to commencing the condition. The start and finish time of each workday was recorded; with the metabolic armband remaining on the participant's arm until the completion of each 8-hour workday (except for day 5 which was only

4-hours in duration). Data from the SWA Mini were processed using the latest proprietary algorithms and software (algorithm V5.2, software V.7.0) with mean daily workplace EE (KJ/ 8-hour workday) calculated from data collected during the first 4-workdays (8-hours/day) of each experimental condition.

Indirect Calorimetry

A TrueOne 2400 metabolic cart (Model QMC, PARVOmedics, Sandy, UT) was used on Day 4 of each condition to measure minute-by-minute EE (KJ/min) over a 30-minute period while participants completed computer-based work tasks in either a seated (*SIT condition*) or standing (*STAND-SIT condition*) work posture.

On arrival to the laboratory, participants had their height and weight measured, followed by a 10-minute rest period. The metabolic cart was calibrated against a reference gas (16.02% oxygen and 0.98% carbon dioxide) and a two-way breathing facemask (Hans Rudolph 7450 Series Silicone V2™ Oro-Nasal Mask, Kansas, US) attached to the metabolic cart by 2.7m, 35mm leak-proof tubing was securely fitted to the participant using an adjustable head strap.

Breath-by-breath oxygen consumption (L/min), carbon dioxide production (L/min) and ventilation (L/min) measures, standardized for room temperature, barometric pressure and humidity were analyzed at 1-minute intervals; with the system automatically recalibrating every 5-minutes. The first 10-minutes of data were discarded to ensure collection of data during steady-state respiration. Minute-by-minute EE (KJ/min) during each work posture was then calculated from oxygen consumption (VO_2) and carbon dioxide production (VCO_2) using the Weir equation²¹ during the last 20-minutes of data collection.

Anthropometrics

Weight and height were measured to the nearest 0.1 kg and 0.1 cm respectively, while wearing light clothing and no shoes using a portable digital scale set with adjustable height rod (Charder Medical MS-3400 digital 300kg x 100g, Charder Electronic, Taiwan). BMI was calculated from height and weight measures ($\text{BMI} = \text{kg/m}^2$).

Statistical Analyses

Analyses were performed using SPSS (Version 19.0) and STATA 12.0 for Windows (StataCorp LP). Statistical significance was set at a probability level of 0.05. Data are reported as mean [95% CI] unless otherwise indicated. Two-way repeated measures ANOVA with condition as the within-subject factor and gender as the between-subject factor was used to examine between-condition differences in measures of acute (KJ/min) and daily workplace (KJ/8-hour workday) EE. Data collected during Days 1-4 of each experimental condition was used to calculate mean daily workplace EE. The effect of gender on condition differences was assessed by including a condition*gender interaction term in the model. No significant effects of gender were found; therefore men and women were combined for all analyses.

Additional analyses were performed to examine the agreement between measures of acute EE (KJ/min) while sitting or standing at work by indirect calorimetry and the SWA Mini during the same 20-minute testing period on day 4. Pearson correlation coefficients were calculated to evaluate the overall measurement agreement between the two methods during sitting and standing to work. The Bland-Altman method was also used to assess the level of agreement between the two methods and to quantify the amount and direction of bias as well as the upper and lower limits of agreement ($\text{bias} \pm 2 \text{ SD of the difference}$). Paired t-tests were used to examine differences in mean estimates of acute EE (KJ/min) between methods. Mean absolute

percentage error was calculated during sitting and standing at work to reflect the true error in estimation of the SWA Mini compared to the criterion measure (indirect calorimetry).

RESULTS

Participants were predominately men (74%), overweight (65%), Caucasian (87%), married (91%) and employed in an office-based role (74%). All 23 underwent measurements of indirect calorimetry. However, three participants with implausible ventilation data (minute ventilation (L/min) < 2 SD from group's mean), indicating an ineffective facemask seal or leak during the indirect calorimetry test, were excluded from analyses. Due to the limited availability of the SWA Mini, only 18 (12 men, 6 women) wore the metabolic armband during both experimental conditions. One man was excluded from analyses due to invalid data (acute EE values $\pm$ 2 SD from group's mean).

Daily EE estimated by the SWA Mini

Based on data from 17 participants, there was a small, albeit statistically-significant, 76 KJ (3%) increase in mean daily workplace EE, as measured by the SWA Mini, during the STAND-SIT condition (2790 [2573, 3006] KJ/8-hour workday) compared to the SIT condition (2714 [2526, 2904] KJ/8-hour workday; $p=0.003$). Extrapolation of the data across a standard work week (5 x 8-hours/day) predicted a theoretical mean energy surplus of 380 KJ/week.

No statistically-significant correlations between BMI and daily workplace EE (KJ/8-hour day) measured during the SIT ($r=0.41$, $p=0.11$) or STAND-SIT condition ($r=0.29$, $p=0.41$) were observed.

Acute EE estimated by Indirect Calorimetry

Mean acute EE (KJ/min) and respiration values, as measured by indirect calorimetry, during each experimental condition are presented in Table 1. On average, standing to work resulted in a significant 0.7 KJ/min (or 13%) increase in EE compared to sitting to work (4.7 [4.2, 5.1] vs. 5.3 [4.7, 5.9] KJ/min; $p=0.002$). Extrapolating across an 8-hour workday, replacing 4-hours of sitting with standing would result in a theoretical increase in mean EE of 168 KJ/8-hour workday or 840 KJ/week.

With the exception of the respiratory exchange ratio (RER), which was consistent between conditions ($p=0.47$), all respiration values were significantly higher while standing to work compared to sitting (all $p\leq 0.01$).

Statistically-significant correlations were observed between participants' BMI and acute EE (KJ/min) measured during sitting ($r=0.52$, $p=0.02$) and standing ($r=0.59$, $p=0.006$) to work. However, expressing acute EE relative to participants' total body weight (KJ/kg/min) ameliorated these significant correlations (both $p>0.52$).

Comparison of Acute EE Methodologies (SWA Mini vs. Indirect Calorimetry)

Pearson's correlation coefficients revealed a strong positive correlation between the two methods (SWA Mini vs. indirect calorimetry) when measuring acute EE while standing ($r=0.73$, $p<0.001$) and sitting ($r=0.82$, $p=0.003$) to work.

Compared to our criterion measure of indirect calorimetry, the SWA Mini overestimated EE during seated work by 9.4% (5.2 [4.4, 6.3] vs. 4.7 [3.1, 6.0] KJ/min; $p=0.005$), but was similar when standing to work ($p=0.61$). As expected, the error rate of the SWA Mini (KJ/min) was higher while sitting to work (mean $\pm$ SD: 10.6 ± 14.2 %) compared to standing ($-0.7 \pm$

12.9%), when expressed as the mean absolute percentage error (computed from the mean of individual percentage error rates).

Bland-Altman plots based on data from 14 participants are presented in Figures 1 and 2 and provide a detailed comparison of the agreement between average EE estimates by the two methods while sitting and standing to work. As shown in Figure 1, a moderate agreement between EE estimates by the two methods was observed when sitting to work (mean EE bias of -0.5 [-0.7, -0.2] KJ/min).

When standing to work, the level of agreement between the two methods was strong with a mean bias of only 0.1 [-0.3, 0.4] KJ/min; see Figure 2).

The 95% limits of agreement were wide for EE estimates during both work postures which may be clinically significant.

DISCUSSION

In this sample of overweight/obese office workers, the introduction of routine, 30-minute standing bouts across a standard 8-hour workday using a sit-stand workstation resulted in a mean increase in workplace EE of 76 KJ /workday or an estimated 380 KJ/working week. The small, yet positive, energy benefit we observed when replacing 4-hours of sitting time with 4-hours of standing at work is likely to be even greater than [what we have](#) reported due to the SWA overestimating EE while sitting to work ($P=0.005$). The modest increase that we observed in daily workplace EE measured by the metabolic armband contrasts significantly with EE predictions based on the Physical Activity Compendium, which suggests a benefit of ~1,070 KJ/8-hour workday for an 80 kg man (method assumes 1 MET approximates 1 kcal kg⁻¹h⁻¹) could be achieved by replacing 4-hours of sitting (1.8 MET) with standing (2.3 MET) at work²². It is also considerably lower than the energy benefits predicted from engaging in 1-minute of

walking every hour at work (247 KJ/8-hour workday)²³. Despite the magnitude of the EE benefit reported in our study being small, it could still have important implications for weight management with predictions a negative energy balance as little as 63 KJ/day can contribute to long-term weight gain in 50% of adults¹⁷. Theoretically, in the absence of changes in diet, weight and physical activity, if an overweight adult used a sit-stand workstation to adopt a standing posture for half of their workday (i.e. 4-hours per workday), over a year based on our findings, an additional 19,760 KJ could be expended. In the present study, absolute acute EE (KJ/min) during standing to work was shown to be positively correlated with participants' BMI. However, relative acute EE (KJ/kg/min) was not, which would suggest that overweight/obese adults do not experience greater energy benefits from working in an upright posture than normal weight adults. Interestingly, no correlation was observed between daily workplace EE (measured by SWA Mini) and BMI during the STAND-SIT condition. Future studies that include a longer follow up period are thus needed to elucidate the potential protective role of sit-stand workstations in helping to prevent long-term weight gain and ascertain whether the energy benefits from standing intermittently at work are more pronounced in overweight/obese adults than healthy, lean adults.

To our knowledge, this is the first study to have used the SWA Mini (version 7.0) to measure daily workplace EE. There has only been one other controlled laboratory study performed in children (aged 7-10 years) that has measured EE while sitting or standing at a school desk²⁴. The study, which used an older model SWA to measure changes in EE, showed standing for 30-minutes to complete school tasks acutely increased EE by 0.3 KJ/min or 13% ($p < 0.001$) compared to sitting. This is comparable in magnitude to the acute energy benefit we observed using indirect calorimetry when standing to work (relative to seated work).

Concurrent use of the SWA Mini during the indirect calorimetry measurement provided a unique opportunity to compare the level of agreement between these two methods. Examination of the graphical plots revealed a strong agreement (mean bias of 0.1 KJ/min) between methods when measuring EE while standing to work; with a tendency for the SWA Mini to modestly overestimate EE when sitting to work (mean bias of -0.5 KJ/min). While the variance attributable to systematic bias between the SWA Mini and indirect calorimetry was similar (data not shown), the wide limits of agreement revealed moderate individual (random) error for EE measures during both sitting and standing to work, which may be important clinically when using the SWA Mini to estimate EE during sedentary/light-intensity activities (i.e sitting and standing).

Our observation that the SWA Mini (version 7.0) modestly overestimated EE during sitting to work is consistent with other studies that used older models to measure EE during sedentary behaviours^{25,26}. It is possible that the observed modest energy benefit of 76 KJ per 8-hour workday reported in favour of the STAND-SIT condition has been diluted by the overestimation of EE when undertaking seated work. Extrapolation of our own acute EE estimates by indirect calorimetry suggests that standing for 50% of the workday (~4-hours) could expend an additional 168 KJ/ 8-hour workday which is significantly higher (a 121% increase) than estimates derived by the metabolic armband. While the SWA Mini's tendency to overestimate EE while sitting to work is small from a quantitative standpoint, we should still interpret our results with a certain level of caution as the daily workplace energy benefit estimated by the metabolic armband during the SIT-STAND condition may in fact be greater than reported. An important strength of the study is that workplace EE was measured over an 8-hour period and averaged over 4-consecutive workdays. Most studies that have examined the potential energy benefits of standing whilst working have relied on estimates collected during

brief work periods only (ranging in duration from 7-45 minutes) and extrapolated the acute results to reflect effects over an 8-hour workday¹³⁻¹⁵. Conducting the study in a controlled, laboratory workplace setting also meant we were able to maintain excellent protocol compliance across each experimental condition while mimicking habitual office activity.

A further strength relates to the validation of the SWA Mini (version 7.0) against a criterion measure (indirect calorimetry) during sedentary and low-intensity work tasks in overweight adults. Of the limited number of validity studies that have been performed using the SWA Mini, all have examined either whole-day EE^{18,27} or EE during high-intense activities²⁸. This is also the only study to investigate the acute EE benefits of standing at work in an overweight, middle-aged population at heightened risk for chronic disease. Previous studies that have used indirect calorimetry to report on the energy benefits of height-adjustable/standing desks have generally been limited to lean, young, healthy adults^{13,14}.

While it is important to acknowledge that validation of the SWA Mini (version 7.0) was performed on a small subgroup of participants (n=14) only, the potential inability of the metabolic armband to accurately measure EE during seated work is a notable limitation of the study. Despite a recent system upgrade to a tri-axial accelerometer which is reported to reduce technical error by ~5 %¹⁸, based on our findings, further modifications to the SWA Mini algorithms are required to improve the accuracy of EE estimates during sedentary behaviors which are inherently difficult to measure using arm accelerometry.

Other limitations include the disproportionate number of men to women in the study which meant we were not powered to stratify our results by gender. The absence of measures of heart rate and fat free mass also precluded us from investigating the relationship between these parameters and daily workplace EE.

Sit-stand workstations, which can facilitate intermittent standing during the workday, appear to be useful for inducing modest increases in daily workplace EE in overweight/obese, middle-aged office workers. Specifically, introducing intermittent standing bouts across the workday can yield a mean energy benefit of 76 KJ/8-hour workday, which may have importance for weight maintenance with prolonged, continued use. While the metabolic armband (SWA Mini, version 7.0) showed promise against a criterion measure of EE during light-intensity activity (ie. standing to work) further work is needed to improve its ability to accurately measure EE during sedentary activities (ie. seated work).

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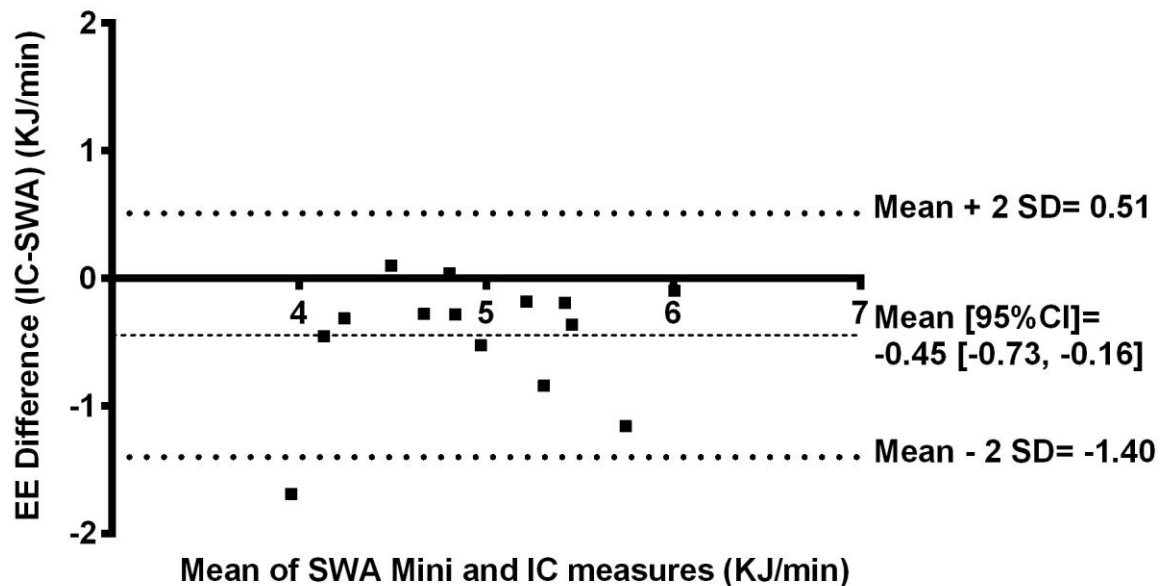
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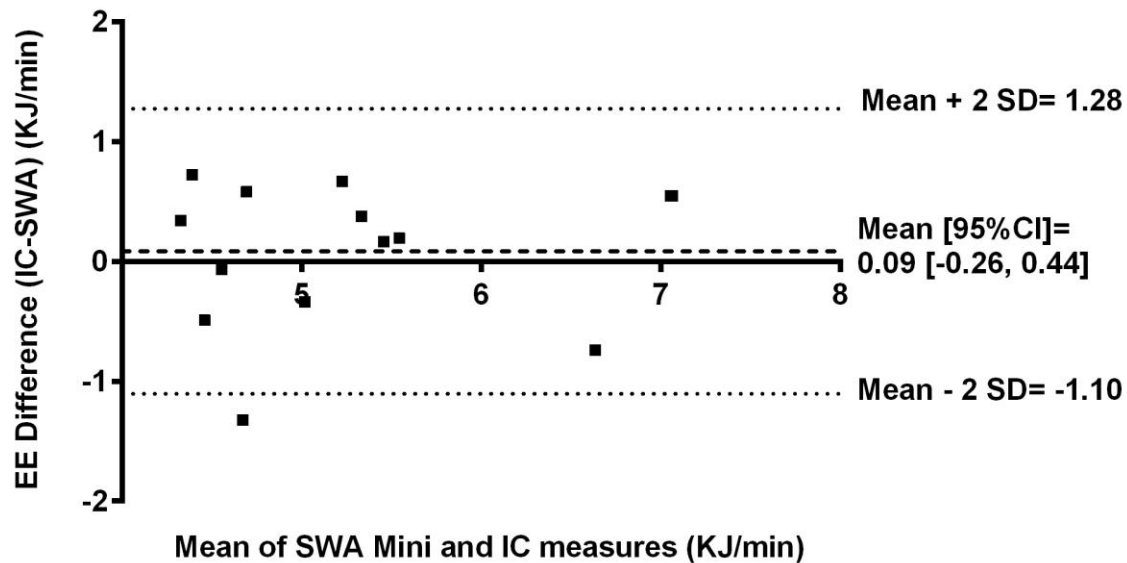
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Figure 1 Bland-Altman bias plot between SenseWear Armband Mini (SWA Mini) estimate and indirect calorimetry (IC: reference standard) measurement of minute-by-minute energy expenditure (KJ/min) during an acute (30-minute) bout of sitting to work in 14 overweight/obese office workers



Footnote for Figure 1 The middle dashed horizontal line corresponds to the mean difference between the methods (SWA Mini-IC), and the upper and lower dotted horizontal lines represent the 95% limits of agreement given by the mean difference $\pm$ 2SD of the difference. The 95% limits of agreements were equal to 0.51 to -1.40 KJ/min

Figure 2 Bland–Altman bias plot between SenseWear Armband Mini (SWA Mini) estimate and indirect calorimetry (IC: reference standard) measurement of minute-by-minute energy expenditure (KJ/min) during an acute (30-minute) bout of standing to work in 14 overweight/obese office workers



Footnote for Figure 2 The middle dashed horizontal line corresponds to the mean difference between the methods (SWA Mini-IC), and the upper and lower dotted horizontal lines represent the 95% limits of agreement given by the mean difference $\pm$ 2SD of the difference. The 95% limits of agreements were equal to 1.28 to -1.10 KJ/min

Table 1 Acute energy expenditure (KJ/min) and respiratory values for 20 participants measured during open-circuit indirect calorimetry while sitting or standing to work

	Sitting to work	Standing to work	Mean Difference	Condition P-value
Ventilation (L/min)	8.52 [7.67, 9.37]	9.65 [8.69, 10.60]	1.13 [0.59, 1.66]	<0.001
VO ₂ (L/min)	0.23 [0.21, 0.26]	0.27 [0.24, 0.29]	0.03 [0.01, 0.05]	0.002
VCO ₂ (L/min)	0.19 [0.17, 0.21]	0.21 [0.19, 0.23]	0.02 [0.01, 0.04]	0.01
RER	0.81 [0.79, 0.83]	0.80 [0.79, 0.81]	-0.01 [-0.2, 0.01]	0.47
EE (METS)	0.79 [0.72, 0.86]	0.90 [0.84, 0.96]	0.11 [0.05, 0.17]	0.002
EE (KJ/min)	4.65 [4.20, 5.11]	5.30 [4.72, 5.88]	0.65 [0.27, 1.02]	0.002

Based on data from n=20 participants (15 men/5 women). Data presented as mean [95%CI]. Measures collected on day 4 of each study condition during first 30 minutes of the 8-hour workday.

VO₂= oxygen consumption. VCO₂= carbon dioxide production. RER= Respiratory Exchange Ratio; expressed as a ratio of VCO₂ to VO₂; METS=Metabolic Equivalent of Task