Medicine & Science IN Sports & Exercise
The Official Journal of the American College of Sports Medicine
www.acsm-msse.org

. . . Published ahead of Print

The Energy Cost of Sitting versus Standing Naturally in Man

James A. Betts[1], Harry A. Smith[1], Drusus A. Johnson-Bonson[1], Tom I. Ellis[1], Joseph Dagnall[1], Aaron Hengist[1], Harriet Carroll[1], Dylan Thompson[1], Javier T. Gonzalez[1], and Gregg H. Afman[2]

[1]Department for Health, University of Bath, Bath, United Kingdom
[2]Department of Kinesiology, Westmont College, CA

Accepted for Publication: 26 October 2018

Medicine & Science in Sports & Exercise, Publish Ahead of Print
DOI: 10.1249/MSS.0000000000001841

The Energy Cost of Sitting versus Standing Naturally in Man

James A. Betts[1], Harry A. Smith[1], Drusus A. Johnson-Bonson[1], Tom I. Ellis[1], Joseph Dagnall[1], Aaron Hengist[1], Harriet Carroll[1], Dylan Thompson[1], Javier T. Gonzalez[1], and Gregg H. Afman[2]

[1]Department for Health, University of Bath, Bath, United Kingdom

[2]Department of Kinesiology, Westmont College, CA

Corresponding author:

Dr James A. Betts PhD FACSM
Department for Health, University of Bath
Bath, BA2 7AY, United Kingdom
E-mail: J.Betts@bath.ac.uk

The authors declare that they have no conflict of interest in relation to this work – no external funding or support was provided for this work. The results of the present study do not constitute endorsement by ACSM. The results presented are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

Abstract

PURPOSE: Prolonged sitting is a major health concern, targeted via government policy and the proliferation of height-adjustable workstations and wearable technologies to encourage standing. Such interventions have the potential to influence energy balance and thus facilitate effective management of body/fat mass. It is therefore remarkable that the energy cost of sitting *versus* standing *naturally* remains unknown. **METHODS:** Metabolic requirements were quantified via indirect calorimetry from expired gases in 46 healthy men and women (age 27±12 y, mass 79.3±14.7 kg, body mass index 24.7±3.1 $kg \cdot m^{-2}$, waist:hip 0.81±0.06) under basal conditions (i.e. resting metabolic rate; RMR) and then, in a randomized and counterbalanced sequence, during lying, sitting and standing. Critically, no restrictions were placed on natural/spontaneous bodily movements (i.e. fidgeting) to reveal the fundamental contrast between sitting and standing *in situ* whilst maintaining a comfortable posture. **RESULTS:** The mean [95% CI] increment in energy expenditure was 0.18 [0.06 to 0.31] $kJ \cdot min^{-1}$ from RMR to lying, 0.15 [0.03 to 0.27] $kJ \cdot min^{-1}$ from lying to sitting and 0.65 [0.53 to 0.77] $kJ \cdot min^{-1}$ from sitting to standing. An ancillary observation was that the energy cost of each posture above basal metabolic requirements exhibited marked inter-individual variance, which was inversely correlated with resting heart rate for all postures (r=-0.5 [-0.7 to -0.1]) and positively correlated with self-reported physical activity levels for lying (r=0.4 [0.1 to 0.7]) and standing (r=0.6 [0.3 to 0.8]). **CONCLUSION**: Interventions designed to reduce sitting typically encourage 30-120 $min \cdot d^{-1}$ more standing *in situ* (rather than perambulation), so the 12 % difference from sitting to standing reported here does not represent an effective strategy for the treatment of obesity (i.e. weight-loss) but could potentially attenuate any continued escalation of the on-going obesity epidemic at a population level. **Keywords:** Metabolic rate, Energy Balance, Posture, Fidgeting

Introduction

Traditional approaches to both the primary prevention and management of obesity have typically involved diet and/or physical exercise (e.g. brisk walking), yet non-exercise activity thermogenesis (NEAT) plays a central role in our predisposition towards weight gain (1). Specifically, the behaviors of daily life outside structured exercise typically account for the majority of energy expended above resting metabolic rate (RMR). Furthermore, NEAT exhibits greater inter-individual variability and dictates total energy requirements more than any other component of energy expenditure (2). Therefore, alongside conscious efforts to diet and exercise, a promising contemporary approach to obesity management may be to subtly influence lifestyle choices that reduce sedentary time and/or encourage spontaneous behaviors to accelerate metabolism.

The most basic behavioral change with the potential to achieve this objective is simply to modify posture or body position (e.g. reduce time spent sitting). Indeed, obese as opposed to lean adults spend 2-3 hours more time seated rather than standing each day (3) and such sedentary behavior is associated with increased risk of type II diabetes, cardiovascular disease and all-cause mortality (4). The aforementioned pilot study also provided an early suggestion that individuals with obesity might therefore increase energy expenditure by ≈1.5 $kJ \cdot d^{-1}$ (≈350 $kcal \cdot d^{-1}$) merely by adopting the posture allocation of their lean counterparts (3). If supported by further work, that possibility may then justify the recent proliferation of height-adjustable workstations and wearable technologies designed to monitor and interrupt prolonged periods of physical inactivity. It is therefore remarkable that the difference in energy cost between sitting and standing *naturally* has never been measured.

Sheer biomechanical efficiency dictates that more physical work is required for humans to stand than to sit and metabolic studies have indeed verified this under conditions in which participants remain completely motionless (i.e. without fidgeting). For example, such studies in which participants have bodily movements somewhat restricted have reported a 5-17 % increment in energy cost from sitting to standing of 0.17-0.92 $kJ \cdot min^{-1}$ (5-13). At the other end of the spectrum, those basic science studies are complemented by ecologically valid comparisons of various daily tasks completed either seated or with perambulation when not seated (5, 10, 14-21), which reveal increments anywhere up to 33% above sitting depending on the intensity of the specific daily task in question. However, spontaneous movements such as fidgeting are not ordinarily restricted in free-living humans, nor can inferences be drawn regarding the metabolic cost of posture allocation *per se* if specific daily activities are prescribed and sitting is compared with walking. The primary aim of the present experiment is therefore to document the fundamental contrast between sitting and standing *in situ* whilst naturally maintaining a comfortable posture.

Methods

Approach to the Research Question

The novelty and importance of this work therefore stems from three key features of the research design: a) participants were allowed to fidget naturally rather than either having bodily movements restricted or having specific activities or tasks prescribed; b) measurement of RMR enabled the energy cost of each posture to be normalized for basal metabolic requirements and thus account for differences in body size (hence inter-individual variance can be largely attributed to spontaneous bodily movements such as fidgeting); and c) a sample size larger than

related previous investigations provides the most confident estimate to date of the true difference in energy expenditure between typical bodily postures even if had there been little influence of allowing participants to fidget. The combination of these independently important factors provides the first ever indication of the difference in energy expenditure that may reasonably be expected by the many individuals endeavoring to stand more and sit less in accordance with current health recommendations.

Participants

Forty-six women (n=17 and men (n=29) who self-identified as metabolically healthy participated in this experiment (participant characteristics in **Table 1**). Thirty-six participants were recruited from the South-West of the United Kingdom and tested at the University of Bath, whereas the other 10 were recruited from the locality of Santa Barbara in California and tested at Westmont College, both to supplement the sample size and to independently verify observations in a second laboratory. All participants were provided with an information sheet highlighting the nature of the investigation and the potential risks involved, prior to providing both written and verbal consent. This research was approved by the University of Bath Research Ethics Approval Committee for Health (REACH) reference EP 12/13 87 and the use of all data collected conformed to the Data Protection Act 1998.

Experimental Design

All participants underwent metabolic testing via gold-standard indirect calorimetry from gaseous exchange (22, 23) firstly to establish RMR and subsequently to assess energy expenditure over a 20-minute period whilst lying, sitting and standing, with the sequence of these postures applied in randomized and counterbalanced order.

Critically, whereas participants were asked to remain motionless according to best practice for measurement of RMR (24), they were free to make subtle adjustments to position to maintain a comfortable posture during all 3 randomized conditions. Participants were not provided with any specific task to complete but rather viewed a non-emotive nature documentary on television (David Attenborough: Frozen Planet, 2011), with the screen positioned comfortably and standardized across all body positions (0.84 m from the floor at an angle of 90° and 1.87 m from the participant's eye across all conditions). The lying condition had participants supine in a medical bed (Huntleigh Healthcare, Nesbit Evans, UK) with the base 0.5 m from the floor and the headrest inclined at 60°; the sitting condition had participants remain seated in a lightly-padded 4-legged chair with 14° back incline and armrests (Torasen Kyos Ks3a, UK), the height of the seat (48.5 cm) enabled all participants to comfortably maintain foot contact with the floor throughout; the standing condition had participants in comfortable footwear remaining *in situ* on a point marked on the floor (i.e. no perambulation) but otherwise without any restrictions on fidgeting in any condition (i.e. weight-shifting or other posture maintaining behaviors).

Preliminary Measures

Participants arrived at the laboratory between 0800 and 0900 h following an overnight fast (≥ 8 hours) and having refrained from heavy exercise, ingestion of caffeine or alcohol in the 24 hour period prior to the trial, consistent with best practice guidelines for measuring RMR (24). Post-void body mass was recorded to the nearest 0.1 kg using weighing scales (Weylux, UK) and height was measured to the nearest 0.01 m using a Stadiometer (Holtain Ltd, UK). Waist and hip circumferences were measured to the nearest 0.1 cm, as described by World Health Organisation guidelines, using a tension correcting anthropomorphic tape measure (Miniflex, Rabone Chesterman, England), to give a representation of abdominal adiposity. Participants completed the International Physical Activity

Questionnaire (IPAQ) long-form (i.e. 27 questions assessing the duration and frequency of daily activities of known intensities over the past 7 days) using the revised 2005 continuous scoring protocol to give a validated estimation of habitual weekly physical activity (expressed as MET-minutes·week^{-1}; http://www.ipaq.ki.se/; 25).

Sampling & Analysis

Expired gas samples were collected at the University of Bath over at least 20 minutes via a mouthpiece connected to tubing with a unidirectional valve (Hans Rudolph, MO, USA) either directed into four consecutive 200 L Douglas bags (each 5-min sample accepted as stable when within 100 kcal day^{-1} with the average of the lowest three samples reported as RMR). Similarly, expired breath samples were monitored continuously at Westmont College over at least 10 minutes to verify stable values (Vacu-Med Vista MX), with the average of all 30 s periods reported. Heart rate was recorded over the last 10 min of the RMR collection using a Polar HR monitor (Kempele, Finland). A Servomex 1440 Gas Analyser (UK) was used to measure oxygen and carbon dioxide concentrations of ambient air and known volumes of expired gas collected in Douglas bags. This Servomex was calibrated on the morning of each trial using two gases of known concentrations, zero gas (Nitrogen 100%) and a mixed gas (7.95% Carbon Dioxide, 15.98% Oxygen and 76.07% Nitrogen). Gas samples of ambient air were measured proximally to the participants' mouthpiece during each expired gas sample collection, in accordance with the recommendation by Betts & Thompson (2012), to give a representation of inspired air composition (26). The volume of expired air was measured by evacuating the Douglas Bag using a dry gas meter (Havard Apparatus, Kent, UK) with the temperature of the expired air measured using a CheckTemp1C (Hanna Instruments). Rates of oxygen utilization ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) were used to calculate energy expenditure and total carbohydrate and fat oxidation rates were estimated using stoichiometric equations (27).

Statistical Analysis

Data are expressed as the mean change between conditions with 95% confidence intervals. A normal distribution was verified using the Shapiro-Wilk test and thus Pearson correlation coefficients were calculated between energy expenditure and resting heart rate and physical activity levels. Given the relatively low demands placed on participants in terms of time and effort, the required sample size was determined by pilot testing of the first 10 volunteers. Even this small sub-set provided adequate statistical power to detect clear increases in energy expenditure with all three postural allocations but we chose to the other 36 participants not only verify the existence of effects (including those smaller than indicated by our pilot work) but moreover to increase confidence in our estimate of the true *magnitude* of change with each posture, along with generating a more representative sample that also enables consideration of the spread of individual data. All statistical analyses were performed using the IBM Statistical Package for Social Scientists (SPSS) v21.0 (SPSS Inc., Chicago, IL).

Results

Differences in the absolute rate of energy expenditure ($kJ \cdot min^{-1}$) between conditions are illustrated for each individual on **Figure 1**. At a group level, mean (SD) RMR was 4.92 (1.21) $kJ \cdot min^{-1}$ (i.e. adhering to best practice for basal measures; motionless), but once permitted to fidget naturally in maintaining a comfortable posture energy expenditure increased to 5.10 (1.34) $kJ \cdot min^{-1}$ when lying (3.7 % above basal), 5.25 (1.31) $kJ \cdot min^{-1}$ when sitting (6.6 % above basal) and 5.90 (1.39) $kJ \cdot min^{-1}$ when standing (19.7 % above basal).

Figure 2 illustrates these same group contrasts but with data expressed relative to basal energy requirements, thus adjusting individual responses for variance in metabolic requirements

due largely to differences in total tissue mass. The inter-individual differences in response on this figure therefore provide a better reflection of the extent of small postural changes such as fidgeting within each individual. The mean [95% CI] increments between conditions were 0.18 [0.06 to 0.31] kJ·min^{-1} from RMR to lying, 0.15 [0.03 to 0.27] kJ·min^{-1} from lying to sitting and 0.65 [0.53 to 0.77] kJ·min^{-1} from sitting to standing (thus a 2.8 % change from lying to sitting and 12.3 % change from sitting to standing).

Mean (SD) resting heat rate was 60 (9) beats·min^{-1} (measured during RMR) and this parameter exhibited a moderate inverse correlation with the extent of the increment in energy expenditure above basal metabolic requirements in all conditions (i.e. lying r=-0.47 [-0.70 to -0.13]; sitting r=-0.45 [-0.70 to -0.12]; and standing r=-0.41 [-0.67 to -0.07]; **Figure 3**). Similarly, mean (SD) self-reported physical activity levels were 3291 (1946) MET-minutes·week^{-1}, where one MET is equivalent to a standard metabolic rate of 1.0 kcal·kg^{-1}·h^{-1} (28), and exhibited moderate positive correlations with the extent of the increment in energy expenditure above basal metabolic requirements when lying (r=0.4 [0.1 to 0.7]) and standing (r=0.6 [0.3 to 0.8]), with a less clear relationship apparent for sitting (r=0.26 [-0.10 to 0.56]; **Figure 4**).

Discussion

The primary aim of this experiment was to isolate the effect of natural body position on energy expenditure. The observed increment in energy expenditure of 12 % (0.65 [0.53 to 0.77] kJ·min^{-1}) from sitting to standing warrants discussion on four counts. First and foremost, it is inherently important from a basic science perspective to have now established the fundamental difference in energy cost between sitting and standing *naturally*. This difference is broadly

similar to the 5-17 % (0.17-0.92 $kJ \cdot min^{-1}$) increment observed when participants remain motionless and/or bodily movements are completely restricted (5-13); whereas there is a wide range of estimates up to a 33 % increment when participants emulate daily activities either seated or allowing for perambulation when standing (5, 10, 14-21), with the magnitude of change understandably dependent on the specific tasks prescribed in each study. For example, participants in the pilot study by Levine *et al* (*5*) answered telephones, ambled around the laboratory and pretended to interact with pets, which increased energy expenditure by 26 % (2.1 $kJ \cdot min^{-1}$) from sitting to standing. We did not ask participants to emulate any daily activities and so document here that the fundamental contrast between postures without any restriction on fidgeting is less than half that earlier estimate. Interestingly, the 2011 Compendium of Physical Activities estimates the energy cost of quietly watching television whilst lying supine to be 1 MET and whilst sitting to be 1.3-1.5 MET, whereas standing quietly (e.g. standing in line) is 1.3-1.8 MET (the upper limit of the range for sitting and standing allows for fidgeting). When expressed in such terms as a multiple of resting metabolic rate, the findings of the present study understandably agree with the negligible energy cost of lying (1.04 MET) but reveal lower absolute energy costs for sitting (1.07 MET) and standing (1.20) despite the fact fidgeting was not restricted, although the increment does broadly fall within the reported range (28). Similarly, consistent with the recent study by Miles-Chan (6), an energy cost of 1.5 MET was only exceeded by a minority of participants when standing and by none when seated or lying, supporting the proposal that this intensity may represent an appropriate threshold for a standardised definition of sedentary behaviors (29).

The second major point of discussion relates to the *treatment* of obesity (i.e. weight-*loss*). The observed difference of 0.65 $kJ \cdot min^{-1}$ (9.3 $kcal \cdot hour^{-1}$) between sitting and standing is unlikely to result in clinically meaningful reductions in body fatness. Workplace interventions to reduce sitting typically increase standing time by 30-120 $min \cdot d^{-1}$ (30) and the energy density of adipose tissue is *circa* 7.1 $kcal \cdot g^{-1}$ (i.e. 30 kJ, p.301; 31). Therefore, the direct energy deficit imposed by prescribed standing for even two full additional hours everyday would only equate to *circa* 130 kcal per week (less than the energy content of 20 g adipose tissue) and so falls far short of the rate of weight-loss generally considered worthwhile, safe and sustainable (e.g. 0.5-1.0 kg per week).

Thirdly however, the observed difference of 0.65 $kJ \cdot min^{-1}$ (9.3 $kcal \cdot hour^{-1}$) between sitting and standing may still be meaningful in relation to the on-going and rising incidence of obesity, which has been attributed to a sustained daily positive energy balance of just 30 $kJ \cdot d^{-1}$ (7.2 $kcal \cdot d^{-1}$; 32). Importantly, to maintain this small surplus over the last 3-4 decades purely via changes in diet would have required a more substantial increase in energy intake of *circa* 900 $kJ \cdot d^{-1}$ (>200 $kcal \cdot d^{-1}$) in order to slightly exceed the elevated energy requirement necessarily associated with accumulating tissue mass (32). Therefore, while the relatively minor energy cost of standing for an extra hour each day would be insufficient to offset the average increase in energy intake seen since the late 1970s, a subtle societal shift to favour standing naturally for longer each day does have the potential to slow or even halt further progress of the escalating obesity epidemic at a population level (i.e. our already high rates of obesity would at least not continue rising so rapidly (33) - assuming that standing itself does not elicit other compensatory responses).

A fourth and final major discussion point when considering the primary outcome of this experiment is the potential for the increased muscular work of one posture over another to impart health benefits irrespective of any difference in energy balance or therefore obesity (34). It remains debatable whether the low-level physical exertion of simply standing *in situ* is sufficient to improve metabolic health (35). Whilst merely not being in a seated position may encourage unprompted engagement in more energetic physical activities (e.g. perambulation), a recent 12-month workplace intervention to reduce prolonged sitting time revealed that people in fact mostly substitute sitting only with standing *in situ* (as was studied in the current experiment), yet long-term improvements in cardiometabolic health biomarkers (e.g. fasted insulin concentrations) are dependent on greater engagement in ambulatory activities (36). Equally, even if the majority of time is to be spent in a seated position and therefore energy balance not greatly affected, regularly interrupting prolonged sitting with activity breaks can still be beneficial for metabolic and cardiovascular health (37-39).

Whilst this experiment was not designed to answer questions regarding the factors responsible for inter-individual variability in fidgeting in each posture (questions which have recently been systematically addressed; 6, 7), it is nonetheless interesting to consider the variance in energy expenditure due to fidgeting apparent in the present dataset. As evidenced by the individually paired differences plotted on **Figure 1**, there was a high degree of heterogeneity across the sample in the magnitude and indeed direction of observed responses between postures. This variance is likely to reflect inter-individual differences in the amount of fidgeting/movement that occurred in each body position rather than pure measurement error given the extremely high reliability of properly conducted indirect calorimetry for measuring

oxygen uptake (coefficient of variation 0.05 %; 40). The novelty of reporting this variance stems largely from the fact that the scientific rigor necessary to precisely quantify metabolic rate via indirect calorimetry is most logically and commonly complemented by equally tight standardization of experimental conditions, rather than the unusual combination reported here of precision measurement with purposely uncontrolled conditions (i.e. permitting natural fidgeting).

The importance of reporting inter-individual differences is linked to the possibility that this may explain personal predisposition towards weight-gain/loss. The present data clearly demonstrate inter-individual variance in the observed energy cost between different body positions and so may indicate that certain people have a greater propensity than others to fidget and thus facilitate weight-loss by adopting a given position. However, it is important to consider whether the observed responses would persist if each postural allocation were maintained for a more extended duration than the 20-min monitoring periods investigated in this study but also whether a similar duration of monitoring at other times within the same day and especially over multiple days would yield similar results between postures and/or between participants. Whilst a replicated design over multiple periods would be required to truly identify those with a genuine predisposition towards fidgeting (41), evidence that certain individuals may indeed consistently fidget more than others can be drawn from certain more stable traits which are predictive of that response. For example, resting heart rate exhibited moderate inverse correlations with the change in energy expenditure above RMR (when not permitted to fidget) when naturally lying, sitting or standing (**Figure 3**), whereas moderate positive correlations were apparent for the increment with both lying and standing relative to self-reported physical activity levels (International Physical Activity Questionnaire; **Figure 4**).

Given that a more active lifestyle can improve cardiovascular fitness and that a reduced resting heart rate is an archetypal adaptation to physical training, the above correlations introduce the intriguing prospect that physically fitter individuals also tend to spontaneously expend more energy when naturally maintaining a comfortable posture at rest. One possible explanation is that some individuals are inherently driven to be more active whenever the opportunity arises, thus explaining both the greater propensity to fidget at rest and the more active habitual lifestyle in general. This reasoning is consistent with the hypothesis that engagement in behaviors of daily life outside structured exercise (i.e. NEAT) is regulated by the genetically determined capacity of a personal energy 'tank' whereby, under conditions where locomotion is not possible, more active individuals expend their additional energy reserve via compensatory increases in spontaneous movements such as fidgeting (42).

It is also possible that the apparent relationship between resting heart rate and the change in energy expenditure above rest may be an artefact of some participants being more relaxed during all resting measures (i.e. thus producing a relatively low heart rate and RMR, with the latter driving the ostensibly greater increase from rest). However, several observations are not consistent with that explanation: primarily that the observed resting heart rates do not correlate whatsoever with RMR either in absolute terms (r=0.03, p=0.9) or expressed per kilogram of body mass (r=0.18, p=0.3) but also given that best practice measures were used to ensure all measures of RMR represented a valid and reliable estimate of basal energy requirements (24). Lastly, even assuming some degree of covariance between resting measures of heart rate and metabolic rate, this would not explain the strongest correlation between self-reported physical activity levels and the increase in metabolic rate from rest to standing (r=0.59, p<0.001; **Figure**

4). By this reasoning, individual differences in the magnitude of increase in energy cost above rest is likely to reflect the amount of fidgeting/movement in each posture, which appears to be associated with these proxy measures of physical activity and fitness. However, given both that the measures of physical activity and fitness applied in this study provide only indirect, subjective estimates and that the experiment was not designed specifically to explore inter-individual differences in energy cost, further research is warranted to determine the existence and direction of any causal relationships between these variables (for example, including an exercise test with indirect calorimetry to directly quantify maximal oxygen uptake as a measure of cardiorespiratory fitness and/or with combined accelerometry or doubly/labelled water as objective measures of physical activity levels).

Of relevance to all the preceding discussion regarding the energy cost of sitting versus standing is whether the observed increment of 0.65 $kJ \cdot min^{-1}$ is generalizable across various populations. The data reported here represent a sample of 46 men and women who were generally young and of healthy weight, although our broad inclusion criteria and relatively large total sample does allow for some speculation regarding generalizability. Specifically, those participants with a BMI under (n=25) or over (n=21) 25 $kg \cdot m^{-2}$ exhibited an increment from sitting to standing that was accordingly slightly under (0.61 $kJ \cdot min^{-1}$) or over (0.69 $kJ \cdot min^{-1}$) the group mean, so this crude measure of adiposity does not appear to meaningfully alter interpretation of this study (although it remains to be seen whether a more sophisticated measure of body composition such as dual-energy x-ray absorptiometry may reveal other potential factors predictive of the observed postural/fidgeting responses). Likewise, the small minority of participants (n=6) who were older than the mean group age by more than one standard deviation

(i.e. ≥40 years) increased energy expenditure by 0.74 $kJ \cdot min^{-1}$ from sitting to standing, so further research in an older population may be warranted. Incidentally, as distinguished by the solid versus dotted lines on **Figure 2**, the main finding of his study is entirely consistent between the 36 individuals tested in Bath and the 10 tested in California (i.e. 0.6463 *versus* 0.6461 $kJ \cdot min^{-1}$, respectively), thus lending confidence to the overall finding given the independent verification across multiple laboratories.

In summary, this experiment isolates for the first time the difference in energy cost between sitting and standing *naturally* (i.e. when permitted to spontaneously fidget in order to maintain comfort). This fundamental contrast reveals a 12 % increment in energy expenditure when standing rather than sitting, which is less than half earlier estimates based on conditions in which participants were asked to emulate daily activities either seated or allowing for perambulation when standing. The increment reported here therefore reflects the direct difference in energy expenditure that might reasonably be expected by anyone adopting general recommendations to stand more and sit less (i.e. without any further prescription to engage in specific activities or walking). The fact that this observation is smaller than previously thought may question the value for weight-*loss* of height-adjustable workstations or wearable technologies that indicate when we have been sitting too long because the increased energy cost of mere standing *per se* is grossly inadequate to elicit the large energy deficit needed for effective *treatment* of obesity. Conversely, prompting the simple act of standing rather than sitting naturally for a short time each day could theoretically compensate for the small energy surplus responsible for gradual weight-*gain* at a population level and therefore potentially limit the rising global incidence of obesity.

Acknowledgments

The authors thank the research participants for their time.

Conflict of Interest

The authors declare that they have no conflict of interest in relation to this work – no external funding or support was provided for this work.

The results of the present study do not constitute endorsement by ACSM.

The results presented are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

References:

1. Levine JA, Eberhardt NL, Jensen MD. Role of nonexercise activity thermogenesis in resistance to fat gain in humans. Science. 1999;283(5399):212-4. PubMed PMID: 9880251.

2. Thompson D, Batterham AM, Peacock OJ, Western MJ, Booso R. Feedback from physical activity monitors is not compatible with current recommendations: A recalibration study. Prev Med. 2016;91:389-94. doi: 10.1016/j.ypmed.2016.06.017. PubMed PMID: 27330025; PubMed Central PMCID: PMCPMC5061550.

3. Levine JA, Lanningham-Foster LM, McCrady SK, et al. Interindividual variation in posture allocation: possible role in human obesity. Science. 2005;307(5709):584-6. doi: 10.1126/science.1106561. PubMed PMID: 15681386.

4. Proper KI, Singh AS, van Mechelen W, Chinapaw MJ. Sedentary behaviors and health outcomes among adults: a systematic review of prospective studies. Am J Prev Med. 2011;40(2):174-82. doi: 10.1016/j.amepre.2010.10.015. PubMed PMID: 21238866.

5. Levine JA, Schleusner SJ, Jensen MD. Energy expenditure of nonexercise activity. Am J Clin Nutr. 2000;72(6):1451-4. PubMed PMID: 11101470.

6. Miles-Chan JL, Fares EJ, Berkachy R, et al. Standing economy: does the heterogeneity in the energy cost of posture maintenance reside in differential patterns of spontaneous weight-shifting? Eur J Appl Physiol. 2017;117(4):795-807. doi: 10.1007/s00421-017-3563-7. PubMed PMID: 28260201.

7. Miles-Chan JL, Sarafian D, Montani JP, Schutz Y, Dulloo A. Heterogeneity in the energy cost of posture maintenance during standing relative to sitting: phenotyping according to magnitude and time-course. PLoS ONE. 2013;8(5):e65827. Epub 2013/06/07. doi: 10.1371/journal.pone.0065827. PubMed PMID: 23741514; PubMed Central PMCID: PMC3669211.

8. Judice PB, Hamilton MT, Sardinha LB, Zderic TW, Silva AM. What is the metabolic and energy cost of sitting, standing and sit/stand transitions? Eur J Appl Physiol. 2016;116(2):263-73. doi: 10.1007/s00421-015-3279-5. PubMed PMID: 26467968.

9. Creasy SA, Rogers RJ, Byard TD, Kowalsky RJ, Jakicic JM. Energy Expenditure During Acute Periods of Sitting, Standing, and Walking. J Phys Act Health. 2016;13(6):573-8. doi: 10.1123/jpah.2015-0419. PubMed PMID: 26693809.

10. Levine JA, Miller JM. The energy expenditure of using a "walk-and-work" desk for office workers with obesity. Br J Sports Med. 2007;41(9):558-61. doi: 10.1136/bjsm.2006.032755. PubMed PMID: 17504789; PubMed Central PMCID: PMCPMC2465387.

11. McAlpine DA, Manohar CU, McCrady SK, Hensrud D, Levine JA. An office-place stepping device to promote workplace physical activity. Br J Sports Med. 2007;41(12):903-7. doi: 10.1136/bjsm.2006.034900. PubMed PMID: 17513333; PubMed Central PMCID: PMCPMC2658993.

12. Steeves JA, Thompson DL, Bassett DR, Jr. Energy cost of stepping in place while watching television commercials. Med Sci Sports Exerc. 2012;44(2):330-5. doi: 10.1249/MSS.0b013e31822d797e. PubMed PMID: 21760553.

13. Monnard CR, Miles-Chan JL. Energy Cost of Standing in a Multi-Ethnic Cohort: Are Energy-Savers a Minority or the Majority? PLoS ONE. 2017;12(1):e0169478. doi: 10.1371/journal.pone.0169478. PubMed PMID: 28056094; PubMed Central PMCID: PMCPMC5215931.

14. Beers EA, Roemmich JN, Epstein LH, Horvath PJ. Increasing passive energy expenditure during clerical work. Eur J Appl Physiol. 2008;103(3):353-60. doi: 10.1007/s00421-008-0713-y. PubMed PMID: 18351381.

15. Buckley JP, Mellor DD, Morris M, Joseph F. Standing-based office work shows encouraging signs of attenuating post-prandial glycaemic excursion. Occup Environ Med. 2014;71(2):109-11. doi: 10.1136/oemed-2013-101823. PubMed PMID: 24297826.

16. Burns J, Forde C, Dockrell S. Energy Expenditure of Standing Compared to Sitting While Conducting Office Tasks. Hum Factors. 2017:18720817719167. doi: 10.1177/0018720817719167. PubMed PMID: 28719766.

17. Reiff C, Marlatt K, Dengel DR. Difference in caloric expenditure in sitting versus standing desks. J Phys Act Health. 2012;9(7):1009-11. PubMed PMID: 22971879.

18. Speck RM, Schmitz KH. Energy expenditure comparison: a pilot study of standing instead of sitting at work for obesity prevention. Prev Med. 2011;52(3-4):283-4. Epub 2011/02/16. doi: 10.1016/j.ypmed.2011.02.002. PubMed PMID: 21320526.

19. Whybrow S, Ritz P, Horgan GW, Stubbs RJ. An evaluation of the IDEEA activity monitor for estimating energy expenditure. Br J Nutr. 2013;109(1):173-83. doi: 10.1017/S0007114512000645. PubMed PMID: 22464547.

20. Fountaine CJ, Johann J, Skalko C, Liguori GA. Metabolic and Energy Cost of Sitting, Standing, and a Novel Sitting/Stepping Protocol in Recreationally Active College Students. Int J Exerc Sci. 2016;9(2):223-9. PubMed PMID: 27182423; PubMed Central PMCID: PMCPMC4836565.

21. Gibbs BB, Kowalsky RJ, Perdomo SJ, Grier M, Jakicic JM. Energy expenditure of deskwork when sitting, standing or alternating positions. Occup Med (Lond). 2017;67(2):121-7. doi: 10.1093/occmed/kqw115. PubMed PMID: 27515973.

22. Gladden LB, Yates JW, Howley ET. Who needs a bag? Med Sci Sports Exerc. 2012;44(2):288-9. Epub 2012/01/19. doi: 10.1249/MSS.0b013e3182376b93

00005768-201202000-00014 [pii]. PubMed PMID: 22251923.

23. Frayn KN. Calculation of substrate oxidation rates in vivo from gaseous exchange. J Appl Physiol. 1983;55(2):628-34.

24. Compher C, Frankenfield D, Keim N, Roth-Yousey L. Best practice methods to apply to measurement of resting metabolic rate in adults: a systematic review. J Am Diet Assoc. 2006;106(6):881-903. Epub 2006/05/25. doi: S0002-8223(06)00146-5 [pii]

10.1016/j.jada.2006.02.009. PubMed PMID: 16720129.

25. Craig CL, Marshall AL, Sjostrom M, et al. International physical activity questionnaire: 12-country reliability and validity. Med Sci Sports Exerc. 2003;35(8):1381-95. doi: 10.1249/01.MSS.0000078924.61453.FB. PubMed PMID: 12900694.

26. Betts JA, Thompson D. Thinking outside the bag (not necessarily outside the lab). Med Sci Sports Exerc. 2012;44(10):2040.

27. Frayn KN. Calculation of substrate oxidation rates in vivo from gaseous exchange. Journal of applied physiology: respiratory, environmental and exercise physiology. 1983;55(2):628-34. Epub 1983/08/01. PubMed PMID: 6618956.

28. Ainsworth BE, Haskell WL, Herrmann SD, et al. 2011 Compendium of Physical Activities: a second update of codes and MET values. Med Sci Sports Exerc. 2011;43(8):1575-81. doi: 10.1249/MSS.0b013e31821ece12. PubMed PMID: 21681120.

29. Network SBR. Letter to the editor: standardized use of the terms "sedentary" and "sedentary behaviours". Appl Physiol Nutr Metab. 2012;37:540-2.

30. Shrestha N, Kukkonen-Harjula KT, Verbeek JH, Ijaz S, Hermans V, Bhaumik S. Workplace interventions for reducing sitting at work. Cochrane Database Syst Rev. 2016;3:CD010912. doi: 10.1002/14651858.CD010912.pub3. PubMed PMID: 26984326.

31. Frayn K. Metabolic regulation: a human perspective. Oxford, United Kingdom: Blackwell Science; 2003.

32. Hall KD, Sacks G, Chandramohan D, et al. Quantification of the effect of energy imbalance on bodyweight. Lancet. 2011;378(9793):826-37. Epub 2011/08/30. doi: S0140-6736(11)60812-X [pii]

10.1016/S0140-6736(11)60812-X. PubMed PMID: 21872751.

33. Hales CM, Fryar CD, Carroll MD, Freedman DS, Ogden CL. Trends in Obesity and Severe Obesity Prevalence in US Youth and Adults by Sex and Age, 2007-2008 to 2015-2016. JAMA. 2018;319(16):1723-5. doi: 10.1001/jama.2018.3060. PubMed PMID: 29570750; PubMed Central PMCID: PMCPMC5876828.

34. LaMonte MJ, Blair SN. Physical activity, cardiorespiratory fitness, and adiposity: contributions to disease risk. Curr Opin Clin Nutr Metab Care. 2006;9(5):540-6. doi: 10.1097/01.mco.0000241662.92642.08. PubMed PMID: 16912548.

35. Edwardson CL, Henson J, Bodicoat DH, et al. Associations of reallocating sitting time into standing or stepping with glucose, insulin and insulin sensitivity: a cross-sectional analysis of adults at risk of type 2 diabetes. BMJ Open. 2017;7(1):e014267. doi: 10.1136/bmjopen-2016-014267. PubMed PMID: 28087555; PubMed Central PMCID: PMCPMC5253585.

36. Winkler EAH, Chastin S, Eakin EG, et al. Cardiometabolic Impact of Changing Sitting, Standing, and Stepping in the Workplace. Med Sci Sports Exerc. 2018;50(3):516-24. doi: 10.1249/MSS.0000000000001453. PubMed PMID: 29166319.

37. Carter SE, Gladwell VF. Effect of breaking up sedentary time with callisthenics on endothelial function. J Sports Sci. 2017;35(15):1508-14. doi: 10.1080/02640414.2016.1223331. PubMed PMID: 27559678.

38. Saunders TJ, Atkinson HF, Burr J, MacEwen B, Skeaff CM, Peddie MC. The Acute Metabolic and Vascular Impact of Interrupting Prolonged Sitting: A Systematic Review and Meta-Analysis. Sports Med. 2018;48(10):2347-66. doi: 10.1007/s40279-018-0963-8. PubMed PMID: 30078066.

39. Chen YC, Betts JA, Walhin JP, Thompson D. Adipose Tissue Responses to Breaking Sitting in Men and Women with Central Adiposity. Med Sci Sports Exerc. 2018;50(10):2049-57. doi: 10.1249/MSS.0000000000001654. PubMed PMID: 29727403.

40. Hopker JG, Jobson SA, Gregson HC, Coleman D, Passfield L. Reliability of cycling gross efficiency using the Douglas bag method. Med Sci Sports Exerc. 2012;44(2):290-6. Epub 2011/07/29. doi: 10.1249/MSS.0b013e31822cb0d2. PubMed PMID: 21796054.

41. Atkinson G, Batterham AM. True and false interindividual differences in the physiological response to an intervention. Exp Physiol. 2015;100(6):577-88. doi: 10.1113/EP085070. PubMed PMID: 25823596.

42. Levine JA. Nonexercise activity thermogenesis (NEAT): environment and biology. Am J Physiol Endocrinol Metab. 2004;286(5):E675-85. doi: 10.1152/ajpendo.00562.2003. PubMed PMID: 15102614.

Figure Legends:

Figure 1: Resting metabolic rate and the increment in energy expenditure when lying, sitting and standing, expressed in absolute terms. Solid lines are those participants tested in Bath and dotted lines are those tested in Santa Barbara.

Figure 2: The increment in energy expenditure when lying, sitting and standing, expressed relative to basal metabolic requirements. Solid lines are those participants tested in Bath and dotted lines are those tested in Santa Barbara.

Figure 3: The association between resting heart rate and the change in energy expenditure above resting metabolic rate when naturally lying, sitting or standing.

Figure 4: The association between habitual physical activity levels and the change in energy expenditure above resting metabolic rate when naturally lying, sitting or standing.

Figure 1

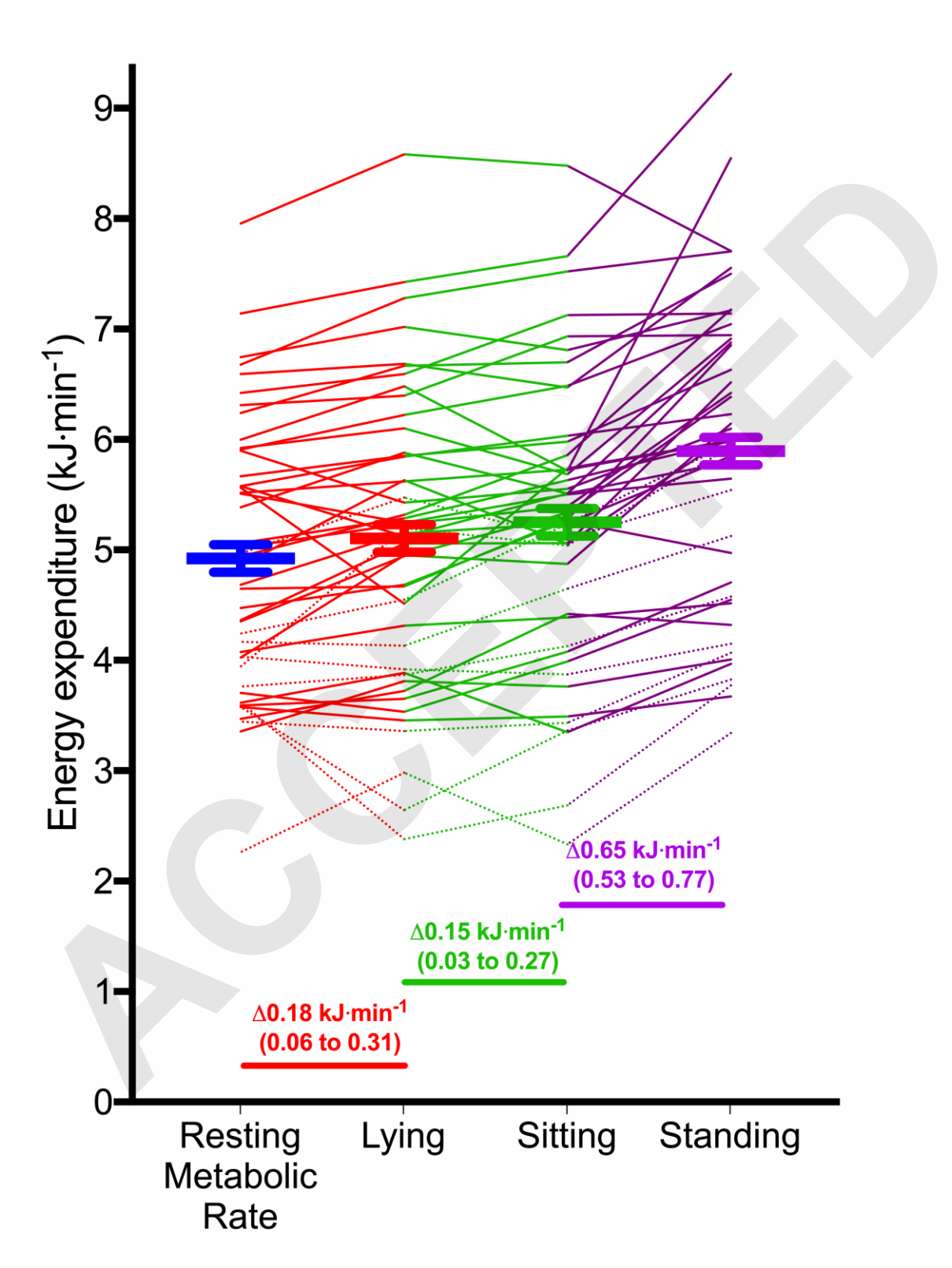

Figure 2

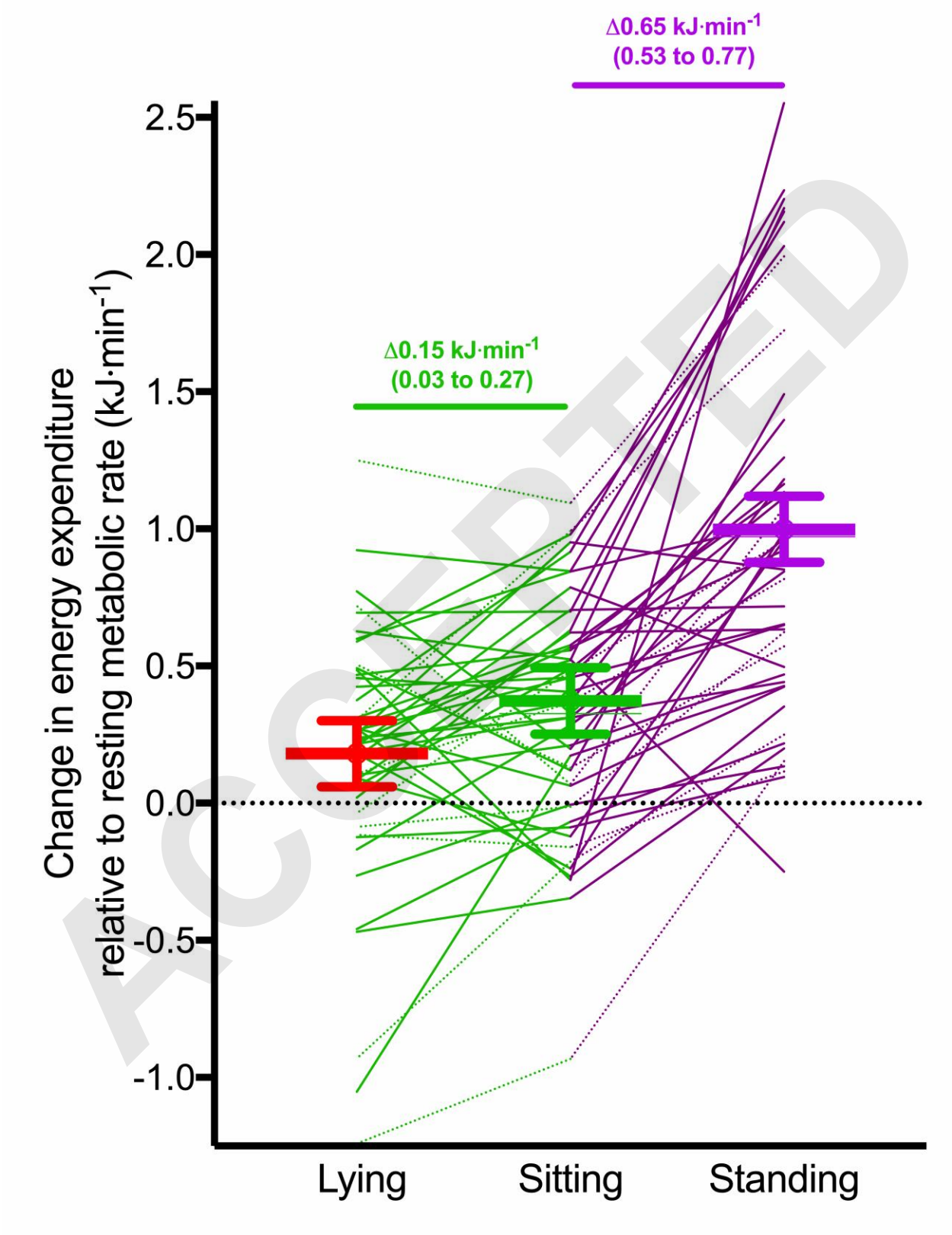

Figure 3

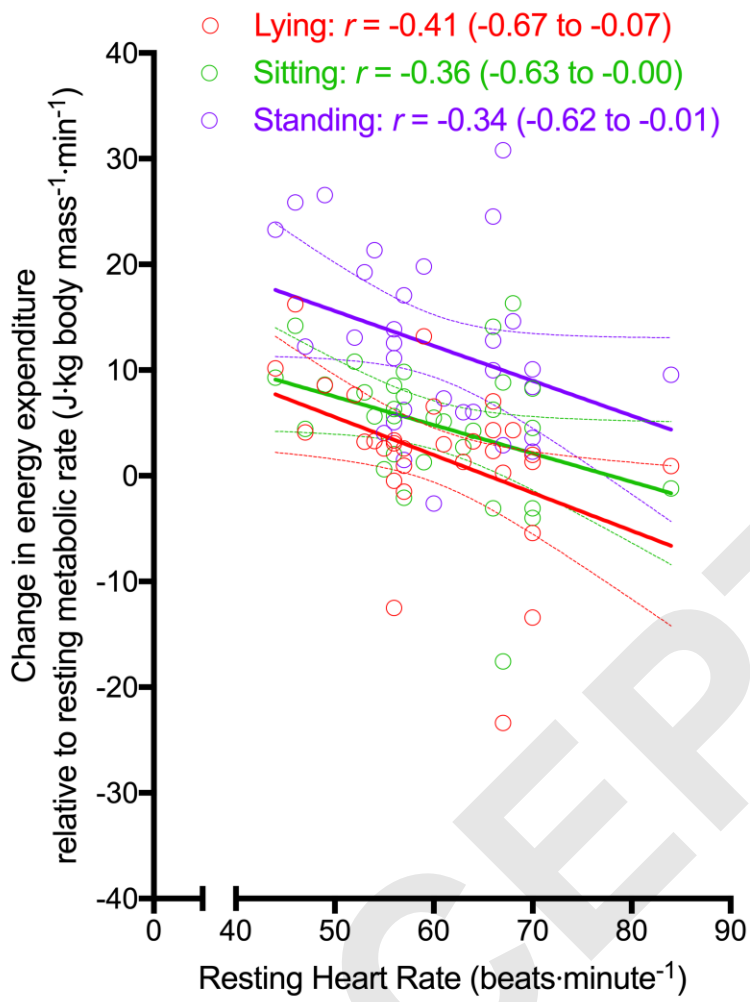

Figure 4

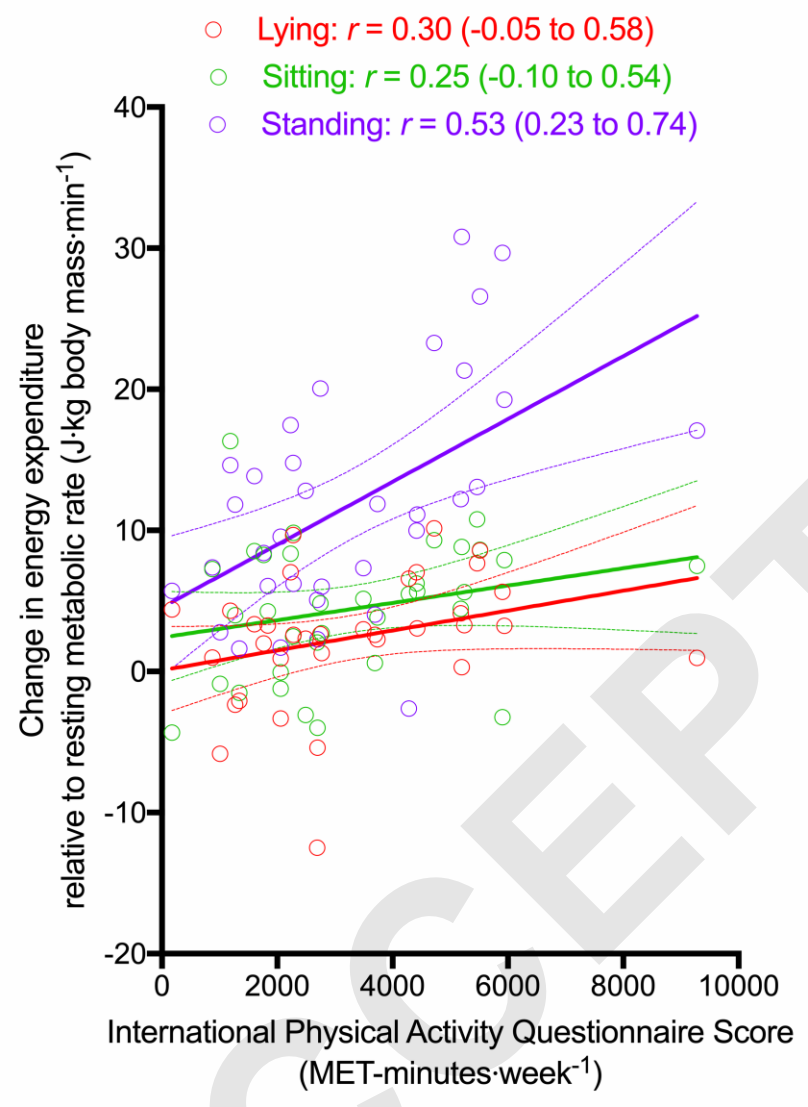

Table 1: Participant characteristics.

Variable	All	Women	Men
n	36	17	29
Age (years)	27 ± 12	32 ± 17	24 ± 8
Height (m)	1.79 ± 0.09	1.71 ± 0.06	1.84 ± 0.07
Mass (kg)	79.3 ± 14.7	67.5 ± 9.3	85.4 ± 9.4
BMI ($kg \cdot m^{-2}$)	24.7 ± 3.1	23.4 ± 2.7	29.4 ± 1.2
Waist:Hip	0.81 ± 0.06	0.77 ± 0.06	3.31 ± 1.14

Data are mean ± SD.