ORIGINAL ARTICLE

An office-place stepping device to promote workplace physical activity

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Objective: It was proposed that an office-place stepping device is associated with significant and substantial increases in energy expenditure compared to sitting energy expenditure. The objective was to assess the effect of using an office-place stepping device on the energy expenditure of lean and obese office workers.
Methods: The office-place stepping device is an inexpensive, near-silent, low-impact device that can be housed under a standard desk and plugged into an office PC for self-monitoring. Energy expenditure was measured in lean and obese subjects using the stepping device and during rest, sitting and walking. 19 subjects (27±9 years, 85±23 kg): 9 lean (BMI<25 kg/m^2) and 10 obese (BMI>29 kg/m^2) attended the experimental office facility. Energy expenditure was measured at rest, while seated in an office chair, standing, walking on a treadmill and while using the office-place stepping device.
Results: The office-place stepping device was associated with an increase in energy expenditure above sitting in an office chair by 289±102 kcal/hour ($p<0.001$). The increase in energy expenditure was greater for obese (335±99 kcal/hour) than for lean subjects (235±80 kcal/hour; $p=0.03$). The increments in energy expenditure were similar to exercise-style walking.
Conclusion: The office-place stepping device could be an approach for office workers to increase their energy expenditure. If the stepping device was used to replace sitting by 2 hours per day and if other components of energy balance were constant, weight loss of 20 kg/year could occur.

Two-thirds of the population are overweight and obesity affects a third of the UK and US populations.[1–3] The aetiology of obesity is complex but it is generally agreed that low levels of physical activity are important in the pathogenesis of obesity.[4] In particular, obese individuals have a tendency to be seated for more than 2.5 hours per day more than lean individuals and, as a consequence, their non-exercise activity thermogenesis (NEAT) is low.[5]

Over the last 20 years the predominant mode of working has become computer-based in developed/high-income countries.[6] This has resulted in many people spending their work day sitting.[7 8] We are interested in exploring measures to reverse sedentariness while preserving productivity.

One potential tool to help reverse office-based sitting is to use automated walking belts (treadmills). However, efficient and silent treadmills are expensive and require substantial space. Another widely examined strategy to promote workplace activity is to encourage walking at work. The problem with this is that it necessitates an employee to leave their desk. We therefore examined the utility of a device that could promote walking-equivalent energy expenditure but at a lower cost and on a smaller floor area than a treadmill while allowing an employee to remain at their desk.

We modified an inexpensive hydraulic (low-impact) stepping device that can be housed under a standard desk. We measured the energy expenditure of using the office-place stepping device and compared these values to sitting in a standard office chair. Our hypothesis was that the office-place stepping device is associated with significant and substantial increases in energy expenditure compared to sitting energy expenditure. We also wanted to compare the energy expenditure associated with using the office-place stepping device with that for walking exercise since walking is the principal component of the NEAT-deficit in obesity. In addition, we examined the potential energetic differences for stepper use and other activities between lean and obese individuals, since we envisage that such approaches would facilitate weight management.

METHODS AND SUBJECTS

Description of the office-place stepping device

The stepping device we modified was the Discovery Electronic Mini Stepper with hydraulic Resistance Tubes #719377 (Discovery, Florence, Kentucky, USA). The modified unit has a mass of 8.9 kg (19.6 lb), dimensions of 50L×34W×17H cm and a cost of £60 ($120) (fig 1). The office-place stepping device is easily movable, can be housed under a desk (fig 1) and transported in a standard overnight case. The frame of the device is made of steel and it has non-skid rubber foot pedals. We incorporated into the device an accelerometer-containing, micro-electronic system that detects the motion of when the stepper is in use. The accelerometer is a tri-axial micro electro mechanical systems accelerometer (Kionix Inc, Ithaca, NY, USA) that is equipped with USB functionality that enables the sensor to interface with a personal computer (PC) via a standard USB cable. The software then enables the user to monitor the use of the office-place stepping device from a PC.

Our notion of the stepper's use is that it is placed under a desk (fig 1) and pulled out at opportune times, for example, during a telephone call, while reviewing a paper document, during a work break or while talking with a colleague.

Subjects

Healthy, sedentary volunteers (n = 19; 27±9 years, 85±23 kg) were recruited; nine were lean (BMI<25 kg/m^2) and 10 were obese (BMI>29 kg/m^2). Subjects were excluded if they smoked, were pregnant, had any acute or chronic illness, had unsteady body weight (>2 kg fluctuation over the 6 months prior to study), had a medical history of thyroid dysfunction or

Abbreviations: NEAT, non-exercise activity thermogenesis; PC, personal computer

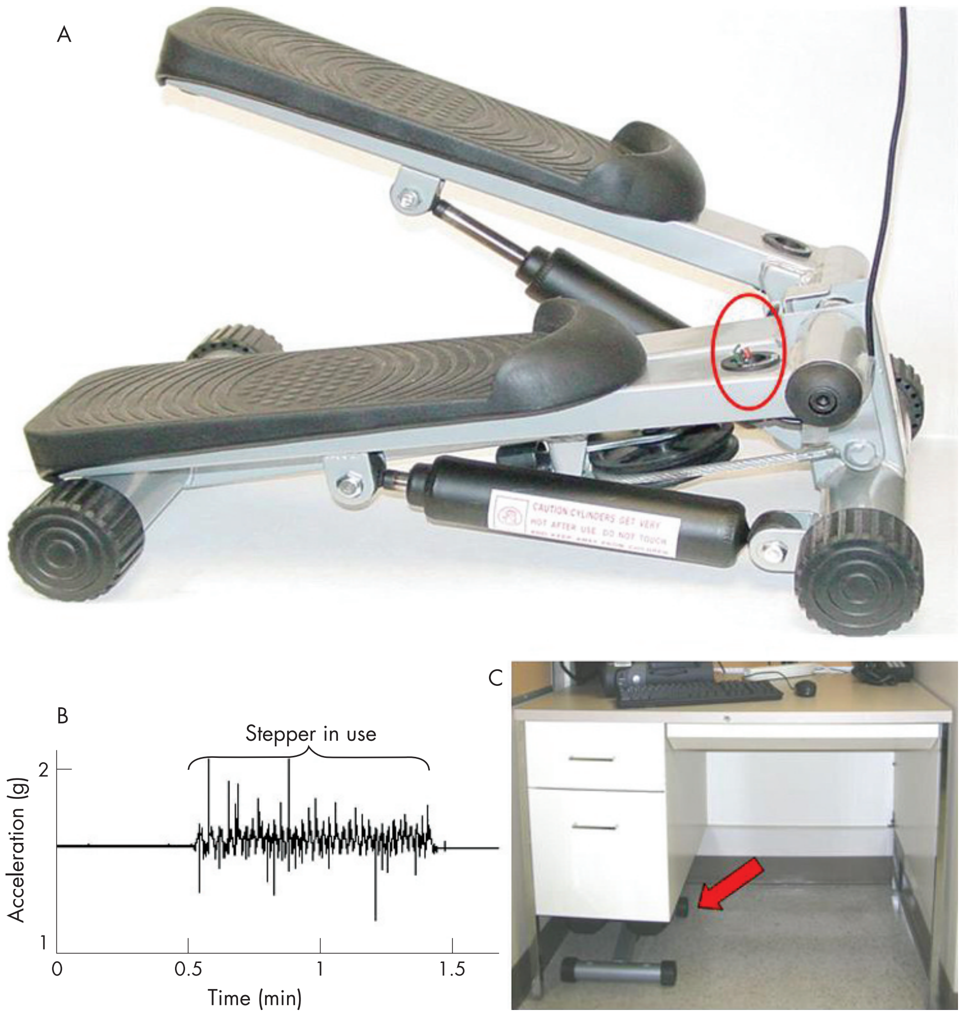

Figure 1 (A) The office-place stepping device. The red oval shows the tri-axial accelerometer-based step-detection module that connects to a standard PC. (B) The output from the sensing module. (C) The unit placed under a desk (arrow).

were taking medications capable of altering metabolic rate. Subjects provided informed written consent and the Mayo Institutional Review Board approved the study.

Experimental design

The study was conducted at the experimental office facility of the Mayo Clinical Research Center which contains prefabricated office equipment, evaluation equipment and is temperature controlled and silent. The subject was orientated to the procedures and then weighed on a calibrated standing scale (model 644, Seca Corporation, Hanover, Maryland, USA) and height was measured using a standiometer (model 242, Seca Corporation, Hanover, Maryland, USA). Subjects were fasted for >6 hours, had not undertaken exertional activity for >6 hours, had not consumed caffeine for >6 hours nor alcohol for >12 hours prior to the start of the study. Throughout the study, subjects were in thermal comfort (20–23℃).

Energy expenditure was then measured for 20 minutes each under the following conditions:

(a) Lying motionless. Rested (30 minutes), relaxed subjects were in a supine position with head at a 10° tilt. Subjects were supervised and asked (and prompted where necessary) to remain awake and still during the measurement.

(b) Office chair sitting. Subjects were seated on an office chair that supported their back, arms and legs. Subjects were asked to remain relaxed during the measurement.

(c) Standing motionless. Subjects were instructed to stand motionless with arms hanging by their sides and feet spaced 15 cm apart. Subjects were asked to remain relaxed and still during the measurement.

(d) We compared the exothermic effect of the office-place stepping device with treadmill walking which is an alternative approach for promoting workplace walking while remaining at one's desk. Walking energy expenditure was then measured for 15 minutes each at 0.5, 1, 1.5, 2, 2.5 and 3 mph while subjects walked on a calibrated treadmill (True 600, O'Fallon, Missouri, USA). Subjects were asked their preferred speed for "pleasurable, exercise walking". Subjects then rested for 15 minutes.

(e) Subjects used the under-desk stepper at a self-selected speed. After acclimation, all steps taken by the subject were counted over 15 minutes by a trained investigator (DAM).

The order of these activities was fixed and the instructions were standardised. This was because the excursions in energy expenditure associated with rest and sitting cannot be conducted reliably, even after minimal exertion has occurred, and because the energy cost of using the office-place stepping device would affect the measurements of low-speed walking, if it was performed in between walking speeds.

Indirect calorimetry

Measurements of energy expenditure were performed using a high-precision indirect calorimeter (Columbus Instruments, Ohio, USA).[5] The calorimeter was calibrated before each measurement with primary standard span gases (5% CO_2, 25% O_2, balance N_2). Gas flow through the system was modulated to maintain O_2 and CO_2 concentrations within ''physiological comfort''. Data were integrated every 30 seconds and stored in a computer (Dell Optiplex GX240, Dell Computers, Round Rock, Texas, USA; software by Columbus Instruments, Ohio, USA). The system was tested by burning a measured mass of high-purity ethanol (AAPER alcohol and chemical company Shelbyville, Kentucky, USA) using a specialised apparatus (SensorMedics, Yorba Linda, California, USA).

Expired air was collected using a full-face transparent dilution mask (Scott Aviation, Lancaster, NY, USA). The facemask was connected to the calorimeter by 2.74 m of 35 mm diameter leak-proof tubing (Vacumed, Ventura, California, USA). The advantage of this system was that it permits almost complete mobility with minimal agitation. We have found that while wearing this equipment volunteers can complete tasks inside and outside the laboratory such as walking on level ground, climbing stairs in stairwells or working in an office environment.[9] Even in these circumstances highly precise measures of energy expenditure can be made.

Statistical analysis

Mean energy expenditure for each of the five activities was calculated. All values are provided as mean $\pm$ SD. ANOVA (energy expenditure, age, sex and BMI) and post-hoc paired t tests were used to compare paired changes in energy expenditure for the 19 subjects. To evaluate the primary hypothesis, energy expenditure was compared between the stepper device and sitting and the stepper device and the treadmill walking using paired two-tailed t tests. Lean and obese subjects were compared similarly using unpaired t tests. Statistical significance was defined as $p<0.05$.

RESULTS

Of the 19 subjects who were recruited, 9 were lean and 10 were obese (table 1). The office-place stepping device was tolerated well by all subjects; there were no injuries, falls or unsteadiness. For the indirect calorimeter, repeated alcohol burn experiments yielded CO_2 and O_2 recoveries of more than 98%. The SD of the respiratory quotient for the last 15 minutes of these measurements was less than 1% of the mean. Test–retest differences for duplicate measures of basal metabolic rate (BMR) were less than 3%.

In absolute terms as expected, resting energy expenditure was significantly less in the lean than in the obese subjects (table 1). When expressed relative to body weight, resting energy expenditure was significantly greater in the lean than in the obese subjects (table 1). There was a significant positive correlation between weight and resting energy expenditure as expected ($r = 0.78$, $p<0.001$).

Energy expenditure increased significantly with walking with each increment in velocity regardless of whether energy expenditure was expressed in absolute terms or relative to body weight ($p<0.001$ in all cases). There were significant linear relationships between walking speed and energy expenditure for all subjects ($r^2 = 0.99$). Walking energy expenditure, when expressed in absolute terms, was greater for obese than for lean subjects (table 1). When walking energy expenditure was expressed relative to body weight, values for the obese subjects were less than for the lean subjects (table 1).

For the lean subjects, the average self-selected stepping rate was 39 ± 11 steps/minute and for the obese subjects 40 ± 12 steps/minute (NS). For the group as a whole, using the office-place stepping device was associated with an absolute increase in energy expenditure above resting by 300 ± 106 kcal/hour ($p<0.001$) and above sitting in an office chair by 289 ± 102 kcal/hour ($p<0.001$). The effect of using the office-place stepping device on the energy expenditure above resting was greater for obese than for lean subjects (433 ± 109 vs 312 ± 91 kcal/hour; $p = 0.02$) (table 1). Similarly, the effect of using the office-place stepping device on the absolute increase in energy expenditure above sitting in an office chair was significantly greater for those with obesity than for lean subjects (335 ± 99 vs 235 ± 80 kcal/hour; $p = 0.03$) (table 1). When the energy expenditure data for using the stepping-device were expressed relative to body weight, obese and lean subjects showed similar increments in energy expenditure above sitting: 3.3 ± 1.0 vs 3.6 ± 1.0 kcal/kg/hour, respectively (NS) (table 1). Thus, the office-place stepping device was associated with significant and substantial increases in energy expenditure.

After the treadmill walking segment of the protocol was complete, we asked subjects to state which of the speeds they would select for an exercise-style walk. For the lean subjects this was 2.6 ± 0.5 mph and for the obese subjects, 2.9 ± 0.3 mph; this difference was not statistically significant. For the group as a whole, the office-place stepping device was associated with a greater increase in energy expenditure than treadmill walking at the selected exercise speed (fig 2) both for the lean and obese subjects when analysed separately.

DISCUSSION

The obesity epidemic affects all high-income countries as well as middle-income and even low-income countries.[10] This has occurred because of a persistent positive energy balance that may be as little as 100 kcal/day.[8] This energy imbalance reflects nutritional excess plus low levels of physical activity.[7] Low levels of physical activity result from low participation in formal exercise, such as going to the gym,[11] and from low levels of non-exercise habitual activity.[12 13] The energy expended in association with non-exercise activity, NEAT, is low in obesity specifically because walking activity is substantially less (>2 hours/day less) in obese than in lean individuals.[5] Because the majority of the waking weekday is spent at work, it is not surprising that work is the predominant predictor of NEAT.[14] Along with obesity, sedentariness at work is increasing,[15 16] to a great extent because of the common use of desktop computers. By 2010 it is estimated that more than half of the workforce from developed countries will be working behind computers.[6] We are therefore interested in devising and validating devices that promote physical activity in the workplace. To this end, we adapted an inexpensive, near-silent, low-impact, commercially available stepping device that can be housed under the standard work desk and can be plugged into a standard office PC for self-monitoring. Our primary hypothesis was that the office-place stepping device was associated with significant and substantial increases in energy expenditure compared to sitting energy expenditure. We demonstrated that using the office-place stepping device was associated with a significant and substantial increase in energy expenditure compared to sitting energy expenditure. Moreover our volunteers enjoyed using it. Were the stepping device to be used by an overweight office worker to replace 2 hours per day of office sitting and if other components of energy balance were constant, weight loss of 20 kg/year could occur.

The stepping device we describe is immediately available and so it is tenable that many desk-based office workers could have access to such a device. Obesity is associated with decreased workforce participation[17] and healthcare costs estimated, in the US alone, to be \$100–200 billion/year[18] and so interventions such as this might prove to be cost-effective. Previous workplace strategies to promote physical activity have proven limited either because the activity component is too short in duration

Table 1 Energy expenditures (kcal/hour) for study participants

	Total	Lean	Obese	Lean vs obese
N (women; men)	19 (8:11)	9 (3:6)	10 (5:5)	
Age (years)	27±9	23±4	30±10	NS
Weight (kg)	85±23	66±13	102±14	<0.001
Body mass index (kg/m^2)	28±6.6	22±2.6	34±2.9	<0.001
Energy expenditure (kcal/hr)				
Resting	76±19	68±15	84±19	<0.05
Sitting	88±21	77±16	98±21	0.03
Standing	97±26	86±21	106±27	NS
Walking: 0.5 mph	163±41	146±41	178±38	NS
Walking: 1 mph	205±53	176±47	231±46	0.02
Walking: 1.5 mph	231±57	198±47	262±49	0.01
Walking: 2 mph	262±69	219±50	302±60	0.005
Walking: 2.5 mph	299±77	250±54	339±70	0.005
Walking: 3 mph	338±94	275±59	394±85	0.003
Walking: 3.5 mph	405±117	322±72	480±98	0.001
Stepper	376±116	312±91	433±109	0.02
Energy expenditure/weight (kcal/kg/hr)				
Resting	0.92±0.16	1.02±0.13	0.82±0.13	0.004
Sitting	1.06±0.17	1.17±0.09	0.96±0.17	0.004
Standing	1.16±0.21	1.30±0.13	1.03±0.19	0.003
Walking: 0.5 mph	1.96±0.43	2.20±0.40	1.75±0.34	0.02
Walking: 1 mph	2.44±0.41	2.65±0.46	2.25±0.24	0.03
Walking: 1.5 mph	2.76±0.39	2.98±0.40	2.55±0.25	0.01
Walking: 2 mph	3.11±0.41	3.31±0.40	2.94±0.34	<0.05
Walking: 2.5 mph	3.51±0.50	3.74±0.48	3.30±0.45	NS
Walking: 3 mph	4.00±0.59	4.18±0.56	3.85±0.59	NS
Walking: 3.5 mph	4.78±0.66	4.89±0.64	4.69±0.69	NS
Stepper	4.5±1.07	4.75±1.06	4.26±1.09	NS

Data are expressed as mean±SD. For the energy expenditure–velocity relationships, when energy expenditure is expressed in absolute terms, for the lean subjects, slopes were 60±17, and intercept 103±34 and for the obese subjects, 97±23 (p = 0.001), intercept 117±25 (NS). When expressed relative to weight, the slopes and intercepts for the energy expenditure/weight–velocity relationships were for the lean subjects, slope 0.92±0.21, intercepts 1.54±0.37 and for the obese subjects, slope 0.94±0.17 (NS), intercepts 1.14±0.18 (p = 0.007). The areas under the curve for the walking energy expenditure versus velocity curves were for the lean subjects, 430±105 kcal/mph and 6.5±1.2 kcal/kg/mph and for the obese subjects, 627±116 kcal/mph (p<0.001) and 6.2±0.8 kcal/kg/mph, respectively.

(eg, "climb the stairs" or "walk from the car park") or because the interventions require high levels of workforce commitment (eg, gym programmes).[19–21] The office-stepper device is another approach that could overcome these limitations by changing the mode of the office desk. We envisage, for example, that phone calls or document review could be performed while using

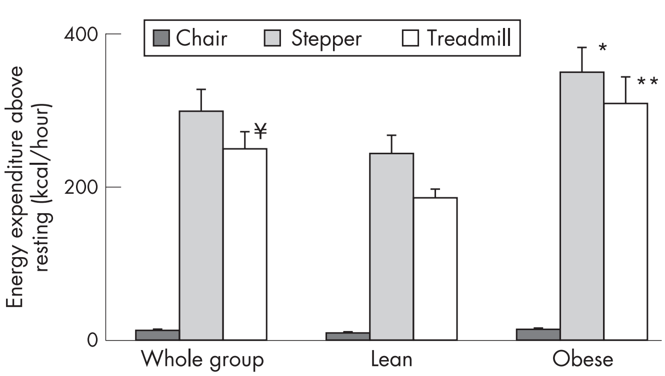

Figure 2 Energy expenditure above resting values for sitting in an office chair, using the office-place stepping device at a self-selected speed and walking on a treadmill at a velocity selected for exercise in 10 obese and 9 lean subjects. Data are displayed as mean±standard error of the mean. For the group as a whole, the increase in energy expenditure compared to sitting was significantly greater for the stepper than for treadmill walking (¥p = 0.03). When lean and obese subjects were compared, the energy expenditure associated with using the stepper was significantly greater for obese subjects than for lean subjects (*p = 0.03); also the energy expenditure associated with using the treadmill was significantly greater for the obese subjects than for the lean subjects (**p = 0.005).

What is already known on this topic?

- More than half of people in high-income countries are obese.
- Obesity is associated with low levels of daily physical activity as well as poor nutritional quality.
- New approaches are desperately needed to promote daytime physical activity.
- Since many people spend the majority of their waking hours at work, there is a growing interest in promoting workplace physical activity.

What this study adds

- We describe the energy expended while using a low-cost stepping device that slides under a standard office desk.
- If a stepping device is used for 1 hour per day instead of sitting, energy expenditure increases by 289±102 kcal/hour.
- Since the stepping device conveniently slides under a desk, it could be used intermittently such as during telephone calls, while reading documents or during meetings.
- Such approaches may help increase daytime physical activity and reverse obesity.

the office-stepper device which is pulled out from under the desk whenever the opportunity arises. In fact the device is sufficiently lightweight that it can be transported to meetings, conferences and seminars to convert these normally sedentary activities into active ones. We are not suggesting that the office-stepper supersede other approaches to promote workplace activity but rather is added to them. Furthermore, we recognise that this and other approaches can only succeed to increase daily activity levels with the support of employers.

An alternative approach, to achieve the same goals as the office-stepping device could be to place treadmills at the desk. However, treadmills are expensive, often noisy and require substantial space, although we note that the preferred exercise walking speeds were similar for the lean and obese subjects suggesting that obese subjects are not placed at a disadvantage when treadmills are made available. For the cost of one treadmill, an office could afford 10–20 under-desk stepping devices. The stepping device we describe here, along with other supportive measures, has the potential to provide several hours of additional walking time each day to office-based workers. Based on these data, this is equivalent to an increased energy expenditure of several hundred kcal per day. We were surprised that use of the stepping device appeared to be equivalent to or even exceed the energy expended for walking-style exercise. This most likely reflects the fact that both activities principally involve displacing the body's weight against gravity.[22] It also suggests that the stepping device could be an inexpensive option for home-based exercise and activity.

There were several limitations to this study. The studies were short in duration and did not extend throughout the work day. For example, it is conceivable that the self-selected stepping paces our volunteers used would slow down if the device was used throughout the work day. However, even if the individuals slowed down to half the pace they selected in these studies, they would still be dissipating 100 kcal/hour above sitting energy expenditure. We suspect that the self-selected stepping pace is unlikely to change throughout the work day because the step rate is determined predominantly by the rate of compression of the step-pistons so that a subsequent step occurs once the piston from the prior step is depressed. Nonetheless, we recognise this as a limitation of our study. Second, there were relatively few subjects in this study, especially if we are suggesting that the stepping device is widely applicable. Although we acknowledge this, we would point out that although the study may appear small, we were able to achieve our objectives and address our hypotheses. Our goal here was to test the feasibility of using the stepping device and also to define the energy expended in its use. A study with greater numbers would be unlikely to change our principal findings although we do recognise that further field-testing and time-and-motion studies will be needed before broad-based office application. Finally, although we demonstrated surprisingly great excursions in energy expenditure, we did not demonstrate long-term weight loss with the use of such a device. Using the office-stepper in weight-loss studies is an immediate next step.

In conclusion, in this paper we described the energy expenditure associated with a simple, inexpensive, low-impact and almost silent office-stepper device that could allow office-based workers to be more active throughout their work day. The stepping device was associated with significant and substantial excursions in energy expenditure above sitting. The increases in energy expenditure were equivalent to taking an exercise-style walk. The increases in energy expenditure (200–300 kcal/hour) and tolerability of the stepping device were compatible for the lean and obese individuals. With population body weight, workplace sedentariness and healthcare costs projected to increase, interventions that allow people to work and yet be active could help reverse obesity. Thus, the office-place stepping device was associated with similar increases in energy expenditure compared to treadmill walking despite being a tenth of the cost and size.

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