Treadmill workstations in office workers who are overweight or obese: a randomised controlled trial

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Summary

Background Treadmill workstations that enable office workers to walk on a treadmill while working at their computers might increase physical activity in offices, but long-term effects are unknown. We therefore investigated whether treadmill workstations in offices increased daily walking time.

Methods We did a randomised controlled trial of healthy office workers who were either overweight or obese. We recruited participants from 13 different companies, which comprised 17 offices, in Umeå, Sweden. We included people who were aged 40–67 years, had sedentary work tasks, and had a body-mass index (BMI) between 25 kg/m² and 40 kg/m². After the baseline measurement, we stratified participants by their BMI (25–30 kg/m² and >30 to 40 kg/m²); subsequently, an external statistician randomly assigned these participants (1:1) to either the intervention group (who received treadmill workstations for optional use) or the control group (who continued to work at their sit–stand desks as usual). Participants in the intervention group received reminders in boosting emails sent out to them at four occasions during the study period. Researchers were masked to group assignment until after analysis of the primary outcome. After the baseline measurement, participants were not masked to group belongings. The primary outcome was total daily walking time at weekdays and weekends, measured at baseline, 2 months, 6 months, 10 months, and 13 months with the accelerometer activPAL (PAL Technologies, Glasgow, UK), which was worn on the thigh of participants for 24 h a day for 7 consecutive days. We used an intention-to-treat approach for our analyses. This trial is registered with ClinicalTrials.gov, number NCT01997970, and is closed to new participants.

Findings Between Nov 1, 2013, and June 30, 2014, a total of 80 participants were recruited and enrolled (n=40 in both the intervention and control groups). Daily walking time during total time awake at weekdays increased between baseline and 13 months by 18 min (95% CI 9 to 26) in the intervention group and 1 min (–7 to 9) in the control group (difference 22 min [95% CI 7 to 37], $p_{interaction}=0\cdot00045$); for weekend walking, the change from baseline to 13 months was 5 min (–8 to 18) in the intervention group and 8 min (–5 to 21) in the control group (difference –1 min [–19 to 17]; $p_{interaction}=0\cdot00045$). Neither measure met our predetermined primary outcome of 30 min difference in total walking time between the intervention and control group, so the primary outcome of the trial was not met. One adverse event was reported in a participant who accidently stepped on their Achilles tendon.

Interpretation In a sedentary work environment, treadmill workstations result in a statistically significant but smaller-than-expected increase in daily walking time. Future studies need to investigate how increasing physical activity at work might have potentially compensatory effects on non-work activity.

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Introduction

In recent decades, occupational tasks have become more sedentary, requiring less physical activity than in the past.[1] Sedentary behaviour—defined as any waking behaviour with energy expenditure of 1·5 metabolic equivalents or less while in a sitting, lying, or reclining posture[2]—is a risk factor for several conditions, including cardiovascular diseases, type 2 diabetes, and cancer,[3] as well as increased all-cause mortality.[4]

Because office workers generally spend up to 82% of their working hours seated,[5] they are a key target group for interventions aiming to identify feasible long-lasting ways to reduce sitting time at work with potential health benefits. Active workstations can enable office workers to be more active while working, potentially reducing sedentary time and increasing physical activity.[6–9] For example, a treadmill workstation designed for use at a sit–stand desk enables walking while working on a computer and performing normal work tasks. Notably, previous studies[6–9] have shown mixed results regarding anthropometric measurements and metabolic parameters. However, existing studies of active workstations lack a randomised study design or have short follow-up periods, or both.[6–9] The far-reaching and population-wide implications of a sedentary lifestyle warrant large randomised controlled trials with long

Research in context

Evidence before this study

Before commencement of this study, we searched PubMed for articles published up to Sept 1, 2013, investigating long-term effects (>6 months) of treadmill workstation installation in offices, and published in English. We used the search terms "active workstation", "treadmill", "workplace", and "sedentary lifestyle" in various combinations. We identified only two long-term studies that suggested treadmill workstations might increase physical activity in offices. However, these studies had a non-randomised study design, and thus the quality of evidence was deemed low.

Added value of this study

This study is the largest and the first randomised controlled trial to investigate the long-term effects of treadmill workstations on daily physical activity and sedentary behaviour. Using two different accelerometers with different applied time filters, we were able to record physical activity and sedentary behaviour during the total day, including both at work and outside of work. Our present results showed that the intervention group significantly increased their daily walking time during working hours, but the effect was smaller than we expected to observe, and some measures of physical activity in the intervention group were reduced.

Implications of all the available evidence

Sparse data are available regarding the effects of active workstations from large studies using a randomised controlled design and a long follow-up period. Recent reviews have highlighted the need for studies with larger samples and longer follow-up durations, and with objective measurement of activity at work and outside of work. Our study provides evidence that treadmill workstations are one feasible way to increase activity in environments that are normally sedentary. Future studies are warranted to further investigate the causes and extent of potential compensatory effects of workplace interventions on non-work activity.

follow-up times to investigate patterns of physical activity and sedentary time throughout the day at work, but also outside of work to evaluate any potential compensatory effects like time spent sitting or time in moderate-to-vigorous physical activity.[10,11]

In this study, we aimed to evaluate the long-term effects of treadmill workstation installation at offices on physical activity at weekdays and weekends, and during work and non-work time on weekdays. Our primary hypothesis was that the intervention of treadmill workstations in office environments would increase daily walking time compared with a control group. Our secondary hypotheses were that the intervention group would show increased daily standing time, decreased daily sitting time, and increased daily light-intensity physical activity compared with the control group. We further hypothesised that the increased activity and decreased sedentary time would have positive effects on anthropometric measures, body composition, metabolic function, stress, depression, and anxiety, and that no changes in moderate-to-vigorous physical activity would be observed.

Methods

Study design and participants

We did a randomised controlled trial in accordance to the CONSORT guidelines.[12] Participants were recruited from 13 different companies (17 offices) in Umeå, Sweden. Data were collected at the University Hospital in Umeå, and ethical approval was granted by the Regional Ethical Review Board in Umeå. The intervention and data collection methods used in this study are described in detail elsewhere,[13] but a brief description is given in this Article.

All participants were office workers with mainly sedentary work tasks, were aged 40–67 years, and had a body-mass index (BMI) between 25 kg/m² and 40 kg/m². The inclusion of participants who were either overweight or obese was based on an epidemiological study,[14] showing a higher health risk with prolonged sitting time in those who were overweight or obese than in individuals with a normal weight. All participants had a sit–stand desk as their ordinary workstation. We excluded those with type 1 and type 2 diabetes, stress-related exhaustion disorder, moderate or severe depression or anxiety (as assessed with the Hospital Anxiety and Depression Scale questionnaire), severe kidney disease, severe cardiovascular disease, severe gastrointestinal or lung disease, untreated thyroid disease (determined by bloosd test by study investigators), a previous cardiovascular event such as transient ischaemic attack or stroke, more than 6% weight loss during the past 6 months, engagement in extensive aerobic exercise training, or musculoskeletal pain making treadmill walking difficult. Pregnant women and people with more than 1 day of travel per workweek or with plans to leave the organisation during the study period were also excluded. To be included, participants needed to be in their office at least 4 days per week, including not working from home more than 1 day per week. For part-time workers, we asked for their working hours and analysed the activity data according to that. If they were out of the office 1 day per week due to part-time work, we analysed that day as a non-work day. All participants gave oral and written informed consent to participate.

Randomisation and masking

We stratified participants according to their BMI (25–30 kg/m² and >30 to 40 kg/m²) after the baseline measurement. Subsequently, an external statistician randomly assigned participants (1:1) to either the intervention group or control group, using a computer-based list. After randomisation, the external statistician had no further involvement in this study. The researchers responsible for outcome assessment and data analysis were all masked to the group assignment until after primary outcome analysis. After baseline, when participants were randomly assigned to the groups, they were not masked to study group assignment.

Procedures

After randomisation, all participants in both groups received a health consultation that included a dialogue with a trained nurse regarding general physical activity and diet recommendations based on the guidelines used in the Västerbotten County Council, Sweden.[15] All participants also received information about some of the screening and baseline measurements.[13] Recorded demographic data included age, sex, number of children, educational level, marital status, office type, and employment sector, which were assessed by questionnaires at baseline. Self-reported physical exercise was assessed using the question "How many days during the past 3 months have you exercised in workout clothes, with the purpose of improving your fitness and/or to feel good?", which was answered on a five-point ordinal scale ranging from more than three times per week to never. Self-rated health was assessed using the question "In general, would you say your health is...", which was also answered on a five-point ordinal scale ranging from excellent to poor.[16]

Sedentary behaviour and physical activity outcomes were analysed at baseline and at 2, 6, 10, and 13 months. Two different accelerometers were used to enable measurement of both sedentary behaviour and physical activity at different intensity levels. The first, an activPAL3 or activPAL3 micro-activity monitor (default settings; PAL Technologies, Glasgow, UK), was worn by participants on their thigh for 24 h a day for 7 consecutive days. Outcome measures were calculated for the total time awake on weekdays and weekends, and for work time and non-work time on weekdays on the basis of event output from the activPAL monitor, using a custom Excel macro (HSC PAL analysis software; version 2.19s). Applying the filter for total time, a measurement day was included if it showed at least 10 h of wear time, at least 500 steps, and 95% or less of the time awake in sitting or standing behaviour.[17] For work and non-work time, a measurement day was included if it showed at least 4 h of wear time,[18] at least 250 steps, and 95% or less of the time spent in sitting or standing behaviour.

Participants also wore the Actigraph wGT3x-BT (ActiGraph, Pensacola, FL, USA) around the waist during all waking hours for 14 consecutive days at baseline and at 2, 6, 10 and 13 months follow-up, during the same time when they were also wearing the activPAL. Calculations for the Actigraph data were only done for total daily wear time based on the algorithm-defined wear times. The data from the Actigraph were downloaded to the Actilife software (version v.6.13.3) with a 60 s epoch length. Physical activity cutoff points were determined using a modified version of the Freedson Adult VM3 (2011) algorithm,[19] which was based on vector magnitude. Light-intensity physical activity was defined as 201–2689 counts per min and moderate-to-vigorous physical activity as 2690 counts per min or more. For the Actigraph, a measurement day was included if it showed at least 10 h of wear time.[20] If a measurement period included less than 4 valid days (3 work days and 1 non-work day) with either the activPAL or the Actigraph, the measurement was excluded from the analysis of data from that device.[20] Detailed instructions about how to wear both monitors are reported elsewhere,[13] and further details regarding accelerometer data processing are available in the appendix.

See **Online** for appendix

Anthropometric, body composition, and metabolic measurements, energy intake, salivary cortisol, subjective stress and energy, and depression or anxiety were analysed at baseline and at 6 and 13 months. Weight, height, waist and hip circumference, sagittal abdominal diameter, blood pressure, and resting heart rate were measured using standardised methods.[13] Body composition was measured using dual x-ray absorptiometry with a lunar prodigy x-ray tube housing assembly (Brand BX-1 L, Model 8743; GE Medical Systems, Madison, WI, USA), as previously described.[13] Blood samples were collected after overnight fasting, before taking any medications, for measurements of lipids, glycated haemoglobin A_{1c} (HbA_{1c}), C-reactive protein, liver enzymes, fasting glucose, and fasting insulin concentrations. Insulin resistance was estimated by the Homeostasis Model Assessment for insulin resistance index, using the formula:[21]

$$\text{Insulin resistance} = \frac{(G_0 \times I_0)}{22 \cdot 5}$$

for which G_0 is fasting glucose and I_0 is fasting insulin. Dietary intake was assessed using a self-reported food record for 4 consecutive days (three weekdays and one weekend day). Portion sizes were estimated using a food-portion picture book containing known portion weights.[22] Reported dietary intake was converted to energy intake using the nutritional analysis software Dietist XP (version 3.2), which is based on the Swedish National Food Administration's food database. We did the analyses using the mean value per timepoint from the 4 days of measurement. Measurements of salivary cortisol, stress and energy, and depression and anxiety are described in the appendix.

The participants randomly assigned to the control group continued to work as usual at their office desk. Those randomly assigned to the intervention group received a portable treadmill workstation (Walkplace AB, Spånga,

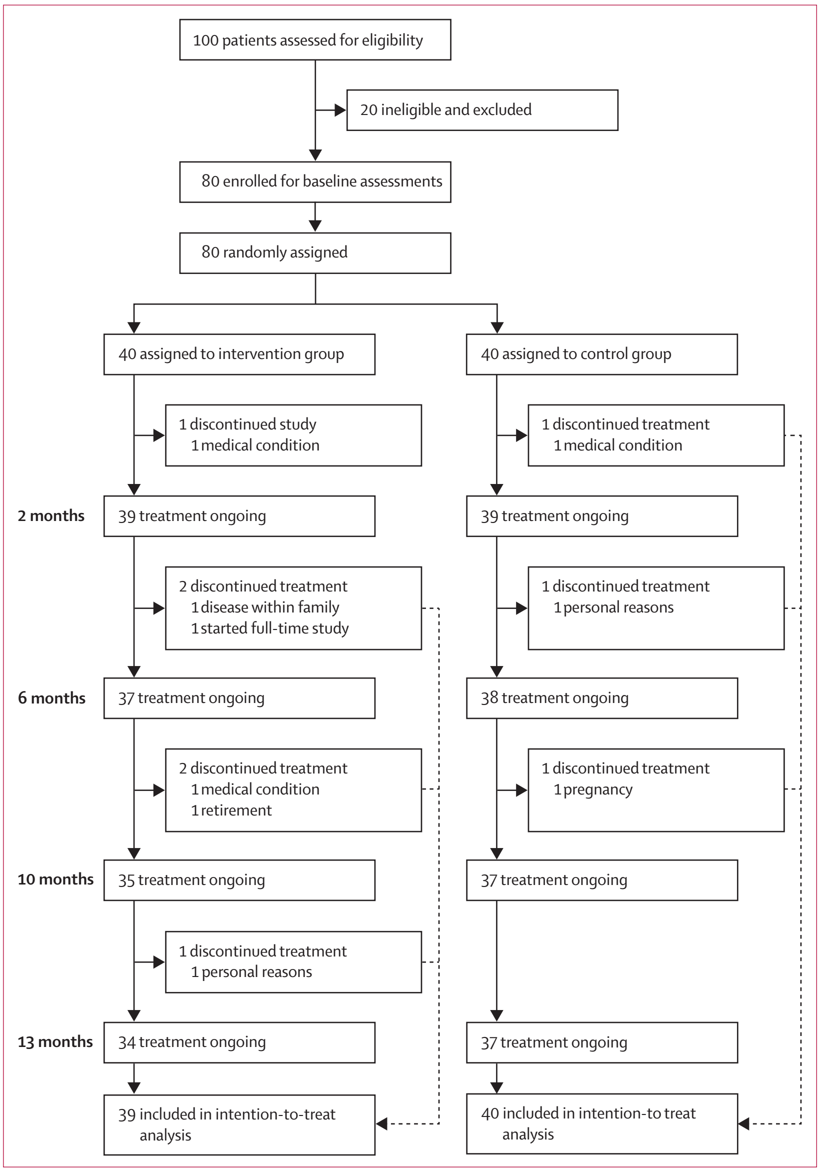

Figure 1: Trial profile

Sweden), which was installed in their usual space at their everyday sit–stand desk. The unit's maximum speed was 8 km/h. The participants were instructed to use the treadmill at a self-chosen walking speed (not running) for at least 1 h per day, but preferably more if possible. The 1 h per day recommendation was based on what was assumed to work for most participants, according to their work tasks. The participants could allocate their daily time on the treadmill as they wished, and individually choose which work tasks to do on the treadmill. At four timepoints during the study (after 5–6 weeks, 19–20 weeks, 31 weeks, and 50 weeks), the participants in the intervention group received emails from the research team, including information about the health risks of sedentary behaviour and reminders to use the treadmill as much as possible. These email communications are available on request from the authors.

Outcomes

The primary outcome was total daily walking time at weekdays and weekends, measured by the activPAL accelerometer; we hypothesised that the intervention would result in an increase of 30 min of walking per day. Other secondary outcomes measured with the activPAL were number of steps, daily standing time, and daily sitting time on weekdays and weekend days. Because the way that sedentary time is accumulated is an important health factor,[23] we also investigated sedentary patterns. Secondary outcomes measured with the activPAL therefore included the number of total breaks, short breaks (<3 min), and long breaks (>20 min); mean sitting period; longest sitting period; time in prolonged sitting (>30 min); and number of walking and standing events. Secondary outcomes related to physical activity intensity levels, measured by the Actigraph accelerometer, were time in light-intensity physical activity and moderate-to-vigorous physical activity; and time in moderate-to-vigorous physical activity bouts of more than 10 min on weekdays and weekend days.

Additional secondary outcomes included anthropometric measurements (weight, BMI, waist and hip circumference, sagittal abdominal diameter, systolic and diastolic blood pressure, and resting heart rate), body composition parameters (fat mass, lean mass, and android and gynoid fat mass), indicators of metabolic function (concentrations of HbA_{1c}, fasting glucose and insulin, apolipoprotein B, apolipoprotein A, triglycerides, and cholesterol concentrations), salivary cortisol measurements, and self-reported stress, energy, and depression and anxiety. Other outcome measurements collected in the study, including cognitive function, functional MRI, and interview data,[13] will be reported separately elsewhere. Details of adverse events were also collected at 13 months, in which participants in the intervention group were asked whether they had any accidents or injuries, or both, related to the use of the treadmill during the study period and to describe the accident or injury if so.

Statistical analysis

Power was calculated for the primary outcome variable (daily walking time) with a 2×2 non-directional fixed effects analysis of variance. On the basis of earlier studies, stratifying the BMI between 25–30 kg/m² and >30–40 kg/m² would include two levels with 30 cases per level, respectively. With anticipated dropouts, it was estimated that 40 participants in each group were needed to achieve a significant between-group difference in doing 30 min of walking per day with 85% power and a significance level of 0·05, with an effect size (*f*) of 0·40.[6,8,13]

Linear mixed models with maximum likelihood and a model of variance components were used for data analysis of the sedentary behaviour, physical activity, anthropometric, body composition, metabolic, and dietary intake outcomes. Estimated means and pairwise comparisons of marginal means, together with 95% CIs, were obtained to describe between-group differences at the different timepoints and within-groups changes at the different timepoints relative to baseline. The model for total time included group (intervention or control), timepoint (baseline, 2 months, 6 months, 10 months, and 13 months), day of week (weekday or weekend), and sex (man or woman) as fixed effects for the analysis of three-way interactions between group, timepoint, and day of week. The models for work and non-work time, energy intake, and body measurements included group, timepoint, and sex as fixed effects for analysis of two-way interactions including group and timepoint. All models included age at baseline as a covariate, and participants as a random intercept. These data were analysed according to the intention-to-treat principle with use of SPSS (version 24). This study is registered with ClinicalTrials.gov, number NCT01997970.

Role of the funding source

The funder of this study had no role in the study design, data collection, data analysis, data interpretation, writing of the report, or decision to submit for publication. All coauthors had access to the raw data if needed. The corresponding author had full access to all study data and had final responsibility for the decision to submit for publication.

Results

Between Nov 1, 2013, and June 30, 2014, a total of 80 participants (n=40 in the intervention group, and n=40 in the control group) were recruited and enrolled into this study (figure 1). Five private companies, three governmental agencies, and five different municipality or county offices were represented in the study. All companies had structured health promotion programmes for their employees, including subsidised gym fees, the possibility to exercise 1 h per week during work hours, or a gym at the office site. Table 1 presents the participants' demographic data at baseline. The various follow-up timepoints done during the study are shown in figure 1, and the appendix presents the number of individuals analysed per timepoint for each measurement. Regarding the primary outcome, we analysed a total of 849 weekdays and 354 weekend days for the intervention group, and 893 weekdays and 374 weekend days for the control group.

During total time awake on weekdays, daily walking time from baseline to 13 months increased by 18 min (95% CI 9 to 26) in the intervention group and 1 min (–7 to 9) in the control group (difference between groups 22 min [7 to 37], $p_{interaction}$=0·00045). For walking at weekends, the change from baseline to 13 months was 5 min (–8 to 18) in the intervention group and 8 min (–5 to 21) in the control group (difference –1 min [–19 to 17], $p_{interaction}$=0·00045). Neither measure met our predetermined primary outcome of change of 30 min difference in total walking time between the intervention and control group, so the primary outcome of the trial was not met.

	Intervention group (n=40)	Control group (n=40)
Age (years)	52·4 (6·8)	50·3 (6·7)
Sex		
Men	18 (45%)	18 (45%)
Women	22 (55%)	22 (55%)
Number of children	2 (0·9)	2 (0·9)
Education level		
Compulsory	0	2 (5%)
Upper secondary	15 (38%)	15 (38%)
University	18 (45%)	18 (45%)
Other tertiary	7 (18%)	4 (10%)
Missing	0	1 (3%)
Marital status		
Married or living together	38 (95%)	34 (85%)
Living alone or divorced	2 (5%)	5 (13%)
Missing	0	1 (3%)
Self-reported health		
Excellent	1 (3%)	1 (3%)
Very good	16 (40%)	15 (38%)
Good	14 (35%)	20 (50%)
Fair	6 (15%)	3 (8%)
Bad	3 (8%)	0
Missing	0	1 (3%)
Physical exercise		
Never	8 (20%)	6 (15%)
Not regularly	8 (20%)	9 (23%)
Once per week	6 (15%)	6 (15%)
2–3 times per week	14 (35%)	10 (25%)
>3 times per week	4 (10%)	8 (20%)
Missing	0	1 (3%)
Office size		
Cell office (one person per room)	33 (83%)	29 (73%)
Shared room (2–3 people per room)	1 (3%)	3 (8%)
Small landscape (4–9 people per room)	4 (10%)	1 (3%)
Medium-size landscape (10–24 people per room)	2 (5%)	6 (15%)
Missing	0	1 (3%)
Employment		
Private company	12 (30%)	19 (48%)
Government	11 (28%)	10 (25%)
Municipality or county	17 (43%)	11 (28%)

Data are mean (SD) or n (%).

Table 1: **Participants' baseline characteristics**

	Within-group differences		Between-group differences	p value overall test for interaction
	Intervention	Control		
Walking time (min)	..	..	..	0·00045
Baseline value	107 (97 to 117)	102 (92 to 112)	5 (−10 to 20)	..
Difference at 2 months	47 (39 to 56)	11 (3 to 19)	42 (27 to 56)	..
Difference at 6 months	31 (22 to 39)	−4 (−12 to 4)	40 (25 to 55)	..
Difference at 10 months	29 (21 to 38)	−4 (−13 to 4)	39 (23 to 54)	..
Difference at 13 months	18 (9 to 26)	1 (−7 to 9)	22 (7 to 37)	..
Number of steps	..	..	..	0·0033
Baseline value	9183 (8270 to 10097)	8799 (7898 to 9700)	384 (−902 to 1670)	..
Difference at 2 months	3389 (2631 to 4147)	808 (55 to 1562)	2964 (1657 to 4271)	..
Difference at 6 months	2174 (1406 to 2941)	−298 (−1049 to 452)	2856 (1545 to 4167)	..
Difference at 10 months	1904 (1126 to 2683)	−450 (−1212 to 312)	2738 (1415 to 4062)	..
Difference at 13 months	1305 (523 to 2087)	43 (−710 to 796)	1646 (326 to 2966)	..
Standing time (min)	..	..	..	0·021
Baseline value	324 (296 to 352)	351 (324 to 379)	−27 (−67 to 12)	..
Difference at 2 months	20 (1 to 39)	−10 (−28 to 9)	2 (−38 to 42)	..
Difference at 6 months	−11 (−30 to 9)	−8 (−27 to 11)	−30 (−70 to 10)	..
Difference at 10 months	−3 (−23 to 16)	−5 (−24 to 14)	−25 (−66 to 15)	..
Difference at 13 months	−13 (−33 to 7)	−35 (−54 to −17)	−5 (−45 to 35)	..
Sitting time (min)	..	..	..	0·44
Baseline value	577 (545 to 610)	540 (508 to 572)	37 (−9 to 83)	..
Difference at 2 months	−82 (−104 to −59)	−11 (−33 to 12)	−34 (−80 to 12)	..
Difference at 6 months	−36 (−59 to −13)	0·4 (−22 to 23)	1 (−46 to 47)	..
Difference at 10 months	−42 (−65 to −19)	−13 (−36 to 10)	8 (−39 to 55)	..
Difference at 13 months	−22 (−46 to 1)	25 (2 to 47)	−10 (−57 to 37)	..
Light-intensity physical activity (min)	..	..	..	0·0050
Baseline value	340 (319 to 361)	345 (324 to 365)	−5 (−35 to 25)	..
Difference at 2 months	38 (27 to 48)	4 (−7 to 14)	29 (−1 to 59)	..
Difference at 6 months	10 (−1 to 21)	−10 (−21 to 0·4)	15 (−15 to 45)	..
Difference at 10 months	9 (−2 to 19)	−9 (−20 to 1)	13 (−17 to 43)	..
Difference at 13 months	−6 (−17 to 4)	−14 (−25 to −4)	3 (−27 to 33)	..
Moderate-to-vigorous physical activity (min)	..	..	..	0·23
Baseline value	59 (52 to 66)	50 (43 to 57)	9 (−1 to 19)	..
Difference at 2 months	−7 (−11 to −2)	0·3 (−4 to 5)	2 (−8 to 12)	..
Difference at 6 months	−8 (−12 to −3)	−2 (−7 to 3)	4 (−6 to 14)	..
Difference at 10 months	−11 (−15 to −6)	−4 (−9 to 1)	2 (−7 to 12)	..
Difference at 13 months	−13 (−18 to −9)	−6 (−11 to −2)	2 (−8 to 12)	..
Time in moderate-to-vigorous physical activity bouts of >10 min (min)	..	..	..	0·19
Baseline value	22 (18 to 27)	18 (14 to 23)	4 (−3 to 10)	..
Difference at 2 months	−6 (−10 to −2)	−2 (−6 to 2)	−1 (−7 to 6)	..
Difference at 6 months	−5 (−9 to −1)	0·03 (−4 to 4)	−1 (−8 to 5)	..
Difference at 10 months	−5 (−9 to −1)	−1 (−5 to 3)	0·2 (−6 to 7)	..
Difference at 13 months	−5 (−9 to −1)	−3 (−7 to 1)	1 (−5 to 8)	..
Number of breaks	..	..	..	0·14
Baseline value	54 (50 to 59)	54 (50 to 59)	−0·01 (−6 to 6)	..
Difference at 2 months	−8 (−11 to −6)	−0·5 (−3 to 2)	−8 (−14 to −2)	..
Difference at 6 months	−5 (−8 to −2)	−1 (−4 to 1)	−4 (−10 to 3)	..
Difference at 10 months	−4 (−7 to −2)	−3 (−6 to −1)	−1 (−7 to 5)	..
Difference at 13 months	−5 (−7 to −2)	−2 (−5 to 0·3)	−2 (−9 to 4)	..

(Table 2 continues on next page)

	Within-group differences		Between-group differences	p value overall test for interaction
	Intervention	Control		
(Continued from previous page)				
Number of 0–3 min breaks	..	..	..	0·033
Baseline value	28 (25 to 32)	28 (25 to 31)	0·01 (−5 to 5)	..
Difference at 2 months	−7 (−9 to −5)	1 (−1 to 3)	−8 (−13 to −3)	..
Difference at 6 months	−3 (−6 to −1)	1 (−1 to 3)	−4 (−9 to 1)	..
Difference at 10 months	−3 (−5 to −0·4)	−1 (−3 to 1)	−2 (−7 to 3)	..
Difference at 13 months	−3 (−6 to −1)	−0·5 (−3 to 2)	−3 (−8 to 2)	..
Number of >20 min breaks	..	..	..	0·022
Baseline value	5·4 (4·8 to 6·0)	5·8 (5·2 to 6·4)	−0·4 (−1·3 to 0·5)	..
Difference at 2 months	1·4 (0·9 to 1·9)	0·3 (−0·2 to 0·7)	0·7 (−0·1 to 1·6)	..
Difference at 6 months	0·5 (0·05 to 1·0)	−0·3 (−0·8 to 0·1)	0·5 (−0·4 to 1·3)	..
Difference at 10 months	0·7 (0·2 to 1·2)	−0·3 (−0·7 to 0·2)	0·6 (−0·3 to 1·4)	..
Difference at 13 months	0·4 (−0·1 to 0·8)	−0·6 (−1·1 to -0·2)	0·6 (−0·3 to 1·5)	..
Mean sitting period (min)	..	..	..	0·69
Baseline value	11·6 (10·4 to 12·8)	10·7 (9·5 to 11·8)	1·0 (−0·7 to 2·7)	..
Difference at 2 months	0·05 (−0·8 to 0·9)	−0·01 (−0·9 to 0·9)	1·0 (−0·7 to 2·8)	..
Difference at 6 months	0·3 (−0·6 to 1·2)	0·4 (−0·5 to 1·3)	0·9 (−0·8 to 2·6)	..
Difference at 10 months	−0·02 (−0·9 to 0·9)	0·4 (−0·5 to 1·2)	0·6 (−1·1 to 2·4)	..
Difference at 13 months	0·7 (−0·2 to 1·6)	0·9 (0·03 to 1·8)	0·7 (−1·0 to 2·5)	..
Longest sitting period (min)	..	..	..	0·96
Baseline value	87·9 (79·7 to 96·2)	80·5 (72·4 to 88·6)	7·5 (−4·1 to 19·0)	..
Difference at 2 months	−1·1 (−9·6 to 7·4)	−3·2 (−11·7 to 5·2)	9·6 (−2·3 to 21·4)	..
Difference at 6 months	2·5 (−6·1 to 11·1)	6·4 (-2·0 to 14·8)	3·5 (−8·4 to 15·4)	..
Difference at 10 months	−4·9 (−13·6 to 3·8)	1·2 (−7·3 to 9·7)	1·3 (−10·7 to 13·4)	..
Difference at 13 months	−1·0 (−9·7 to 7·8)	6·3 (−2·2 to 14·7)	0·2 (−11·8 to 12·3)	..
Time in prolonged sitting (min)	..	..	..	0·73
Baseline value	244·6 (213·1 to 276·2)	232·6 (201·6 to 263·6)	12·1 (−32·2 to 56·4)	..
Difference at 2 months	−21·2 (−45·5 to 3·1)	−12·7 (−36·8 to 11·3)	3·6 (−41·3 to 48·4)	..
Difference at 6 months	−0·1 (−24·6 to 24·5)	0·8 (−23·2 to 24·7)	11·2 (−33·8 to 56·2)	..
Difference at 10 months	−7·9 (−32·9 to 17·0)	−8·8 (33·1 to 15·5)	12·9 (−32·4 to 58·3)	..
Difference at 13 months	8·9 (−16·1 to 34·0)	16·5 (−7·5 to 40·5)	4·5 (−40·8 to 49·7)	..
Number of walking events	..	..	..	0·019
Baseline value	353 (320 to 385)	348 (316 to 380)	5 (−41 to 51)	..
Difference at 2 months	17 (−5 to 40)	32 (10 to 55)	−11 (−57 to 36)	..
Difference at 6 months	−9 (−32 to 14)	−8 (−30 to 14)	3 (−43 to 50)	..
Difference at 10 months	3 (−20 to 26)	−3 (−25 to 20)	10 (−37 to 57)	..
Difference at 13 months	−6 (−29 to 18)	4 (−18 to 26)	−5 (−52 to 42)	..
Number of standing events	..	..	..	0·015
Baseline value	407 (372 to 442)	402 (368 to 436)	5 (−44 to 54)	..
Difference at 2 months	9 (−14 to 32)	32 (9 to 55)	−19 (−68 to 31)	..
Difference at 6 months	−14 (−37 to 9)	−9 (−32 to 14)	−0·4 (−50 to 49)	..
Difference at 10 months	−2 (−25 to 22)	−6 (−29 to 17)	9 (−41 to 59)	..
Difference at 13 months	−10 (−34 to 13)	2 (−21 to 25)	−7 (−57 to 42)	..
Energy intake (kcal)*	..	..	..	0·31
Baseline value	1946 (1807 to 2086)	1882 (1743 to 2022)	64 (−134 to 262)	..
Difference at 6 months	−171 (−303 to −39)	−92 (−222 to 38)	−15 (−217 to 187)	..
Difference at 13 months	−253 (−388 to −117)	−109 (−238 to 20)	−80 (−284 to 124)	..

Data are estimated mean (95% CI), unless otherwise specified. Within-group differences at all timepoints are compared with the baseline measurement. Between-group differences are at each timepoint. The overall test for interactions include group, time and day of week interactions. *Estimated means are based on the mean value from three weekdays and one weekend day.

Table 2: **Total time awake on weekdays**

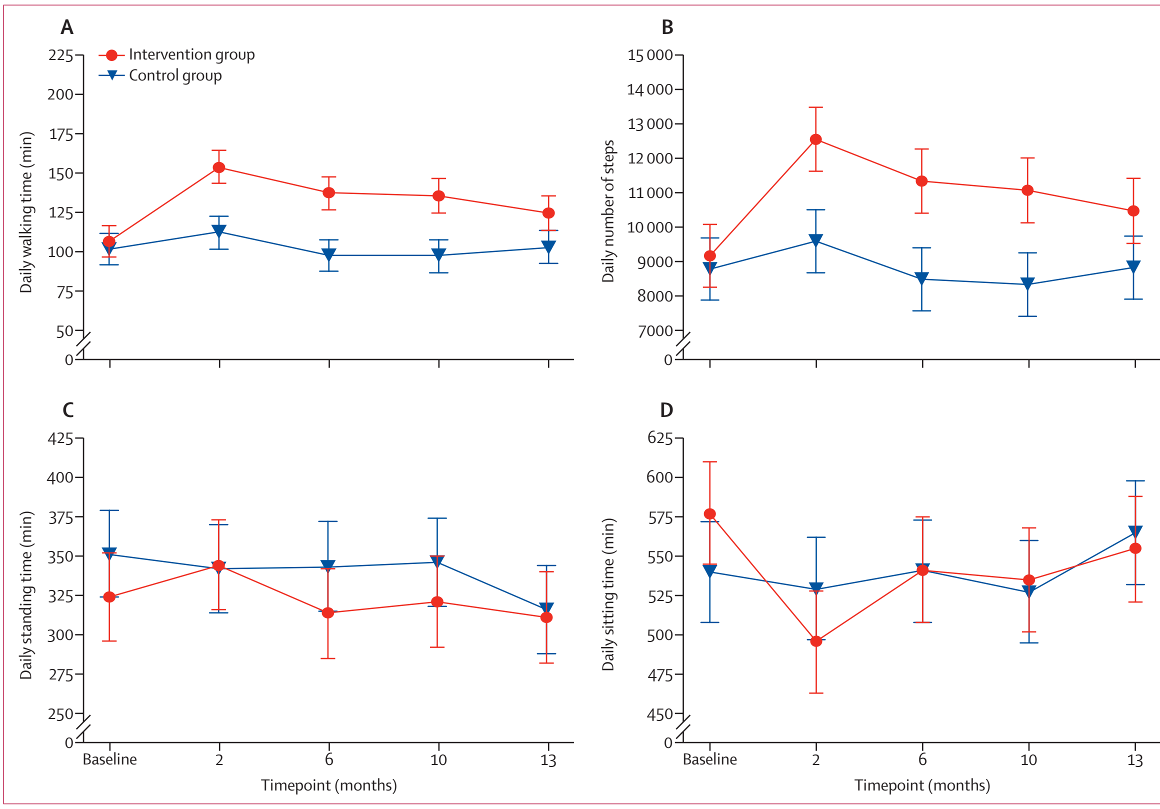

Figure 2: **Estimated means of daily walking time (A), number of steps (B), standing time (C), and sitting time (D) during total time awake on weekdays**
Error bars are 95% CIs. A significant overall test for interaction was found for daily walking time ($p_{interaction}$=0·00045), number of steps ($p_{interaction}$=0·0033) , and standing time ($p_{interaction}$=0·021). No significant effect was found for daily sitting time ($p_{interaction}$=0·44).

Table 2 shows the within-group and between-group differences and the overall test for interaction for total time awake on weekdays; the appendix shows the respective data for the weekends. During total time awake on weekdays, a significant intervention effect was seen between the intervention group and the control group from baseline to 13-month follow-up for daily walking time (figure 2A) and daily number of steps (figure 2B). Although we noted a significant interaction between the control and intervention groups for daily standing time ($p_{interaction}$=0·021), there was no significant difference between baseline and 13 months for the intervention group (–13 min [95% CI –33 to 7]) or between the intervention and control group at 13 months (–5 min [–45 to 35]; figure 2C). No significant intervention effects were observed for daily time spent sitting ($p_{interaction}$=0·44; figure 2D).

An intervention effect was seen for daily light-intensity physical activity during total time awake ($p_{interaction}$=0·0050; figure 3A, 3B), although the difference at 13 months between intervention and control group was significant for weekends only (44 min [95% CI 78 to 11] less light physical activity in the intervention group than the control group). No intervention effect was observed for daily moderate-to-vigorous physical activity on weekdays or weekends ($p_{interaction}$=0·23; figure 3C, 3D): the control group did not significantly decrease their moderate-to-vigorous physical activity at all follow-ups, they decreased significantly at 13 months on weekdays and weekend days. The intervention group decreased at all follow-ups on weekdays and weekend days. (figure 3C and 3D). No significant intervention effect was observed for daily time spent in moderate-to-vigorous physical activity bouts of 10 min or more on both weekdays and weekends (table 2). A significant intervention effect was further observed for the number of short and long breaks, and number of walking and standing events during total time awake on both weekdays and weekends.

During work time, a significant intervention effect was observed for daily walking time, number of steps, standing and sitting time, number of breaks, and for the number of short and long breaks (table 3); however, during non-work time, no significant intervention effects were observed for these respective measures (appendix). Our data showed no major intervention effects on anthropometric measurements, body composition, metabolic functions (appendix), energy intake (table 2), salivary cortisol concentrations, self-reported stress and energy levels, and depression and anxiety scores (appendix). One adverse event was reported, with one participant reported to have accidently stepped on their Achilles tendon, causing tenderness and soreness.

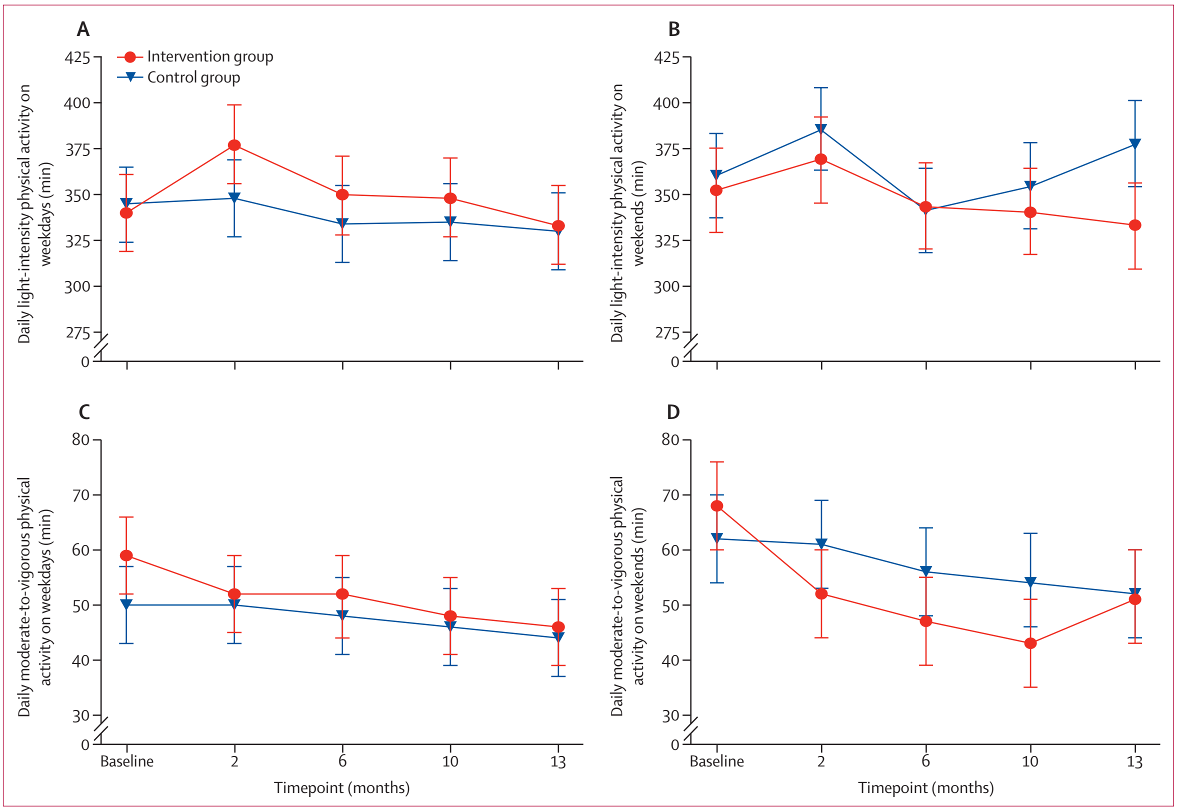

Figure 3: **Physical activity measurements for total time awake on weekdays and weekends**
Error bars are 95% CIs. Estimated mean daily light-intensity physical activity for total time awake on weekdays (A) and weekends (B), and estimated mean daily moderate-to-vigorous physical activity for total time awake on weekdays (C) and weekends (D). A significant overall test for interaction was found for daily light-intensity physical activity on weekdays and weekends (both $p_{interaction}$=0·0050). No significant effect was found for daily moderate-to-vigorous physical activity on weekdays and weekends (both $p_{interaction}$=0·23) .

Discussion

A treadmill workstation can enable an office worker to walk on a treadmill while doing their usual work tasks. Our present study is, to our knowledge, the first long-term randomised controlled trial of treadmill workstations that used objective measurements to record both sedentary behaviour and physical activity. Our results showed that the installation of treadmill workstations in offices increased daily walking time among office workers who were overweight or obese compared with participants with a sit–stand desk. The intervention group also took an increased number of steps per day. Some alterations in sedentary behavioural patterns were also seen within the intervention group—notably, more numbers of long breaks (>20 min) and fewer numbers of short breaks (<3 min). This finding was not unexpected, since treadmill installation at the office desk would possibly result in its use for longer periods. Further analyses revealed that the activity change (ie, walking time, number of steps, and number of breaks) in the intervention group mainly occurred during work time.

Looking at many of the outcomes in our study—mainly walking time and number of steps—clear trends over time can be found, in which the increase in walking time within the intervention group was most pronounced in the beginning of the study and then slowly attenuated, although it was still significant at 13 months. This attenuated effect is a common finding in lifestyle intervention studies aiming to increase physical activity.[24] Methods to achieve sustainability with active workstations at offices for extended periods are therefore needed.

We did not reach a difference of 30 min walking time between the groups at 13 months, which our power calculation was based on, using a 2×2 analysis. However, if using our estimated marginal difference of 22 min (f=0·27) at 13 months in a power calculation for a supposed new study with the same repeated-measures design, sample sizes, as well as error and random effect variances, the new study's power would be 0·92. A difference in walking time of 22 min and 1646 number of steps per day equals 110 min more walking time and 8230 more steps per week, which is likely to have a clinically meaningful effect. Notably, a higher number of steps per day has been associated with a lower risk for developing dysglycaemia 5 years later in adults with normal glucose tolerance.[25] Effects of interventions similar to ours could therefore have effects beyond 13 months, and reduce the risk for obesity-related disorders, notably type 2 diabetes, with a potentially major public health impact.

All participants in both groups already had sit–stand desks at the time of recruitment to the study, which is common in Sweden where 68% of office workers who work more than 25% of their work time in an office have such desks.[26] At baseline, both groups showed more than 200 min of daily standing time at work, took about 9000 steps per day, and had a mean moderate-to-vigorous physical activity of 50–60 min on weekdays and

	Within-group differences		Between-group differences	p value overall test for interaction
	Intervention	Control		
Walking time (min)	..	..	..	<0·0001
Baseline	54 (47 to 60)	50 (43 to 56)	4 (–5 to 13)	..
Difference at 2 months	47 (41 to 53)	5 (–1 to 10)	46 (37 to 56)	..
Difference at 6 months	33 (27 to 39)	–2 (–8 to 4)	38 (29 to 48)	..
Difference at 10 months	29 (23 to 35)	–4 (–10 to 2)	37 (27 to 46)	..
Difference at 13 months	15 (9 to 21)	–2 (–8 to 3)	21 (12 to 31)	..
Number of steps	..	..	..	<0·0001
Baseline	4774 (4189 to 5359)	4399 (3822 to 4976)	375 (–449 to 1199)	..
Difference at 2 months	3452 (2944 to 3959)	439 (–66 to 943)	3388 (2550 to 4227)	..
Difference at 6 months	2413 (1899 to 2928)	–67 (–570 to 436)	2855 (2013 to 3698)	..
Difference at 10 months	1924 (1402 to 2447)	–365 (–876 to 146)	2665 (1813 to 3516)	..
Difference at 13 months	1086 (562 to 1611)	–175 (–679 to 330)	1636 (787 to 2485)	..
Standing time (min)	..	..	..	0·0074
Baseline	206 (181 to 231)	230 (205 to 254)	–23 (–59 to 12)	..
Difference at 2 months	15 (–0·4 to 30)	–10 (–25 to 5)	1 (–35 to 36)	..
Difference at 6 months	–12 (–27 to 3)	–1 (–16 to 14)	–35 (–70 to 1)	..
Difference at 10 months	–5 (–20 to 10)	–4 (–19 to 11)	–24 (–60 to 11)	..
Difference at 13 months	–15 (–30 to 1)	–33 (–48 to –18)	–6 (–41 to 30)	..
Sitting time (min)	..	..	..	<0·0001
Baseline	275 (249 to 301)	250 (225 to 275)	25 (–11 to 61)	..
Difference at 2 months	–56 (–72 to –39)	10 (–6 to 27)	–41 (–77 to –4)	..
Difference at 6 months	–22 (–39 to –5)	11 (–6 to 27)	–7 (–44 to 29)	..
Difference at 10 months	–25 (–42 to –8)	9 (–8 to 25)	–9 (–45 to 28)	..
Difference at 13 months	–4 (–21 to 13)	35 (19 to 52)	–15 (–51 to 22)	..
Number of breaks	..	..	..	<0·0001
Baseline	30 (27 to 34)	30 (27 to 33)	1 (–4 to 5)	..
Difference at 2 months	–6 (–8 to –4)	0·3 (–2 to 2)	–6 (–10 to –1)	..
Difference at 6 months	–4 (–6 to –2)	–1 (–3 to 1)	–3 (–7 to 2)	..
Difference at 10 months	–4 (–6 to –2)	–1 (–3 to 1)	–2 (–7 to 2)	..
Difference at 13 months	–3 (–5 to –1)	–2 (–4 to –0·1)	–0·4 (–5 to 4)	..
Number of 0–3 min breaks	..	..	..	<0·0001
Baseline	16 (13 to 19)	15 (13 to 18)	1 (–3 to 5)	..
Difference at 2 months	–5 (–7 to –4)	1 (–0·1 to 3)	–6 (–10 to –2)	..
Difference at 6 months	–3 (–5 to –2)	0·2 (–1 to 2)	–3 (–6 to 1)	..
Difference at 10 months	–3 (–5 to –2)	0·1 (–1 to 2)	–2 (–6 to 1)	..
Difference at 13 months	–2 (–4 to –1)	–0·4 (–2 to 1)	–1 (–5 to 3)	..
Number of >20 min breaks	..	..	..	0·0032
Baseline	3·4 (2·9 to 3·9)	3·6 (3·1 to 4·1)	–0·2 (–0·9 to 0·5)	..
Difference at 2 months	1·1 (0·7 to 1·5)	0·1 (–0·3 to 0·5)	0·8 (0·1 to 1·5)	..
Difference at 6 months	0·3 (–0·1 to 0·7)	–0·1 (–0·4 to 0·3)	0·2 (–0·5 to 0·9)	..
Difference at 10 months	0·6 (0·2 to 1·0)	–0·2 (–0·6 to 0·2)	0·6 (–0·1 to 1·3)	..
Difference at 13 months	0·04 (–0·3 to 0·4)	–0·5 (–0·8 to –0·1)	0·3 (–0·4 to 1·1)	..

Data are estimated mean (95% CI), unless otherwise specified. Within-group differences at all timepoints are compared with the baseline measurement. Between-group differences are at each timepoint. The overall test for interactions include 2-way interactions between group and time.

Table 3: **Working hours on weekdays**

60–70 min on weekends. These findings suggest the possibility of a negative bias, for which effects on physical activity might be more difficult to show because of a so-called ceiling effect. However, we still observed effects on our primary outcome of daily walking time, indicating that treadmill workstations could be a feasible method to improve daily activity even among relatively active individuals. Treadmill workstations could thus be one step forward to a more active workplace than the use of sit–stand tables alone.

It is important to investigate sedentary and physical activity patterns both at work and outside of work because of the risk of compensatory effects of increasing activity at work.[11] Both groups showed decreased sitting time during non-work time on weekdays; however, only the intervention group still showed a decrease in sitting time at the 13-month follow-up. This finding suggested that the intervention group had a long-term compensatory effect of the intervention on their sitting time outside of work. By contrast, both study groups showed decreased time in moderate-to-vigorous physical activity on both weekdays and weekends, with the largest decrease found in the intervention group on weekends. Additional long-term studies are needed to investigate the reasons for and the extent of potential compensatory effects from reducing sedentary behaviour at work.

Our results showed no major effects on anthropometric measures, body composition, or metabolic functions. These findings might at least partly be due to the decrease in moderate-to-vigorous physical activity that we observed in both groups. In line with our findings, previous short-term or non-randomised studies of treadmill workstations have observed no major effects on body composition, triglycerides, plasma glucose, or insulin,[6–8] but positive effects on weight, waist circumference, HbA_{1c}, total cholesterol, and LDL and HDL cholesterol have been reported.[6,8] In the multicomponent intervention study Stand-up Victoria, which among other things included instalment of sit–stand workstations, the intervention group showed a significantly decreased sitting time and increased standing time,[27] accompanied by moderate decreases in fasting glucose and overall cardiometabolic risk score at 12 months compared with those in the control group. These decreases were mainly due to a worsening of metabolic markers within the control group while the intervention group remained stable over time.[28] Notably, our present study included individuals who were overweight or obese without known major alterations in health status. In future studies, it would therefore be of interest to investigate the metabolic responses to this intervention in more sedentary people or individuals with type 2 diabetes, or both. Furthermore, we did not observe any effects on stress estimates or depression or anxiety, which might also relate to the good health condition in our study group.

The reported decrease in energy intake might be an effect of the health consultation at the start of the intervention, which included dietary recommendations. Notably, self-reported dietary intake data are rather unreliable because of difficulties in assessing portion sizes or reporting less food than was actually consumed. However, the present results are still intriguing and might suggest that the intervention was associated with decreased energy intake.

Strengths of this study included the randomised controlled design, the long-term follow-up period, and the relatively large sample size compared with previous research in this area.[6–9] Another strength was the objective measurement of sedentary behaviour and physical activity using two accelerometers worn on the thigh and around the waist to record putative differences in both body positions and intensity. The thigh-worn accelerometer activPAL enabled thorough investigation of different aspects of sedentary patterns, providing a good overview of how sedentary time was accumulated, whereas the Actigraph, worn around the waist, enabled investigation of different intensity levels of physical activity. Another strength of this study was the analysis of sedentary time and physical activity using different time filters. This analysis enabled investigation of potential compensatory effects during non-work time due to the increased activity at work, which could be of importance since it is the total amount of physical activity that is most important for public health.

Breaking up sitting time has been shown to have important metabolic benefits on blood glucose concentrations in people with type 2 diabetes.[23] However, little is known about whether the instalment of treadmill workstations influences breaks from sitting. By investigating total breaks and dividing them into shorter and longer breaks, we were able to analyse sedentary patterns in more detail. Sedentary behaviour and light-intensity physical activity have a strong inverse relationship to one another, which implies that if time spent in sedentary behaviour is reduced, time spent in light-intensity physical activity is most likely increased.[29] Before objective measurements of physical activity were available, light-intensity physical activity was difficult to measure in a relatively easy and valid way. The impact of light-intensity physical activity on different health parameters has therefore not been thoroughly investigated, and there is a need to further investigate it, in addition to the effects of changes in moderate-to-vigorous physical activity.

Our study also has limitations. Cluster randomisation has been recommended for studies investigating sedentary behaviour in offices.[11] Since all the different companies participating in our study had various health-promoting programmes for their employees, we individually randomised our participants to reduce the risk of bias. This study design generated a larger contamination risk between the participants in the different groups, since a few employees from the same company or the same office landscape ended up in different groups. Participants working in the same company are more likely to talk to each other about the study, and might be encouraging one another, regardless of group allocation. This limitation might explain the increase in light-intensity physical activity seen in the control group at 13 months at weekends. It is also possible that companies and employees who participated in our study were those that were the most motivated participants. Furthermore, several participants in our study had individual offices. This factor might influence the broader generalisability of the treadmill workstations, since it may be more feasible to install them in individual offices than in office landscapes. However, the inclusion of multiple companies from different work sectors should increase the generalisability of our findings. Another limitation is that only participants in the intervention group received the boosting emails, and we cannot say how much these emails influenced the endpoint variables compared with the effects of the treadmill itself. Additionally, we did not collect data related to the implementation of the treadmills in a systematic manner. The design of the treadmills did not allow us to save the data of how much the participants actually used the treadmill. We also cannot exclude a seasonal effect on physical activity. Unfortunately, it was not possible to do the study so that similar amounts of data were collected in each season for all participants starting the study at different timepoints. The adherence to salivary cortisol collection was moderate and some samples were contaminated by blood, resulting in an inadequate power for these analyses.

Overall, this long-term randomised controlled trial showed that treadmill workstations can potentially increase walking time in offices. Human behaviour is influenced by factors on many different levels, with the surrounding environment being one important level.[30] Office environments must facilitate office workers in becoming more active during work to improve public health. Our present results show that treadmill workstations are one feasible way to increase physical activity in normally sedentary environments. Future interventions should combine strategies for increasing physical activity at work and increasing moderate-to-vigorous physical activity.

Contributors

FB, VW, ASt, ASö, C-JB, PW, JAL, and TO planned and designed the study. FB, VW, JO, ASö, and TO recruited participants. FB and VW collected the data. FB processed the accelerometer data with the assistance of PW, FÖ, and TO. FB, JO, EL, and TO processed the anthropometric, body composition, and metabolic data. MW processed the dietary intake data. FB and RR processed the salivary cortisol, stress and energy, and depression and anxiety data. FB, FÖ, and TO did the statistical analyses on all outcomes apart from cortisol, stress and energy, and depression and anxiety, which were done by FB and RR. FB wrote the first draft of the manuscript and the revised versions. All authors participated in data interpretation, commented on subsequent drafts, approved the final manuscript, and agreed to submit for publication.

Declaration of interests

We declare no competing interests.

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