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Time spent in sedentary posture is associated with waist circumference and cardiovascular risk

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Abstract

Background

The relationship between metabolic risk and time spent sitting, standing and stepping has not been well established. The present study aimed to determine associations of objectively measured time spent siting, standing and stepping, with coronary heart disease (CHD) risk.

Methods

A cross-sectional study of healthy non-smoking Glasgow postal workers, n=111 (55 office-workers, 5 women, and 56 walking/delivery-workers, 10 women), who wore activPAL physical activity monitors for seven days. Cardiovascular risks were assessed by metabolic syndrome categorisation and 10-y PROCAM risk.

Results

Mean(SD) age was 40(8) years, BMI 26.9(3.9)kg/m^2 and waist circumference 95.4(11.9)cm. Mean(SD) HDL-cholesterol 1.33(0.31), LDL-cholesterol 3.11(0.87), triglycerides 1.23(0.64)mmol/l and 10-y PROCAM risk 1.8(1.7)%. Participants spent mean(SD) 9.1(1.8)h/d sedentary, 7.6(1.2)h/d sleeping, 3.9(1.1)h/d standing and 3.3(0.9)h/d stepping, accumulating 14,708(4,984)steps/d in 61(25) sit-to-stand transitions per day. In univariate regressions - adjusting for age, sex, family history of CHD, shift worked, job type and socio-economic status - waist circumference (p=0.005), fasting triglycerides (p=0.002), HDL-cholesterol (p=0.001) and PROCAM-risk (p=0.047) were detrimentally associated with sedentary time. These associations remained significant after further adjustment for sleep, standing and stepping in stepwise regression models. However, after further adjustment for waist circumference, the associations

were not significant. Compared to those without the metabolic syndrome, participants with the metabolic syndrome were significantly less active – fewer steps, shorter stepping duration and longer time sitting. Those with no metabolic syndrome features walked >15,000 steps/day, or spent >7h/day upright.

Conclusion

Longer time spent in sedentary posture is significantly associated with higher CHD risk and larger waist circumference.

Introduction

Sedentary occupation and overall behaviour is now the norm in modern societies. Technological advancements in Western economies have reduced the energy requirements of daily living, with populations spending more hours sitting, at work, in transport and during leisure-time.[1] There is little evidence to suggest that reduced occupational physical activity leads to compensatory increases during leisure-time, or *vice versa*.[2-5] Studies from Europe, US and Australia find that adults spend half of work days sitting (average 4.2 h/d) and about 2.9 h/d of leisure-time sitting.[6-8]

An increasing body of literature suggests that sitting time, independent of physical activity levels, promotes cardiovascular disease.[9,10] Both self-report and objective data have shown that time spent sedentary has an independent detrimental association with coronary and diabetes-related metabolic risk factors, such as waist circumference, blood glucose, insulin and triglycerides and HDL-cholesterol.[11-16] Healy et al.[15] found that accelerometer-determined time spent inactive was significantly associated with waist circumference, blood lipid and glucose profiles. Another recent study found that while physical activity log and recall methods failed to show any clear relationship, accelerometer-measured objective activity was directly related to 10-y Framingham coronary risk.[17]

There is a paucity of evidence on the relationship between objectively measured sedentary behaviour patterns, such as sitting/lying and upright postures, and cardiovascular risk. In a Dutch cross-sectional study van der Berg et al.[18] found that, an additional hour of time spent sedentary posture was associated with a 22% greater odds for type 2 diabetes and a 39% greater odds for the metabolic syndrome. Other studies have used accelerometer counts as a proxy[14,15] but low acceleration counts also include periods of quiet standing or standing still which is metabolically different from sitting. In both animal and human studies, sitting, unlike standing, is associated with reduced skeletal muscle lipoprotein lipase activity and detrimental changes in lipid profile.[1-21] The present study examined the associations between CHD risk and time spent in objectively-measured postures (sitting, lying and standing) and of stepping.

Methods

A cross-sectional study of postal workers was undertaken to relate time spent sedentary (sitting/ lying) and stepping to CHD risk factors in apparently healthy individuals. The study aimed to include a range of different physical activity profiles, involving both mainly sedentary office-bound postal workers and more active delivery staff.

Study Participants

Recruitment was carried out by local advertisement, with no incentives offered, from the Royal Mail Group in Greater Glasgow, Scotland. The employees (n = 5,335; 90.2% men) worked in

four shifts: full-day (9am to 5pm), early (5am to 1pm) and late (1pm to 9 pm) and night (9pm to 5am) with two days off work, including Sunday, each week. Only apparently healthy, non-smokers, with no personal history of myocardial infarction, stroke, CHD, hypertension or diabetes mellitus were included. None of the participants was on any lipid, blood pressure or glucose lowering medication. All volunteers, 59 delivery (5 women) and 59 office staff (10 women) aged 22 to 60 years, were invited to the study and data collection took place between September 2006 and September 2007.

Protocol

Participants wore a physical activity monitor (activPAL, PAL Technologies Ltd, Glasgow, UK) for seven days, had weight, height and blood pressure measured, and provided fasting blood samples. Seven participants (3 male delivery and 4 male office workers) refused to provide blood samples, thus the final sample for analysis was 111, 56 delivery workers (5 women) and 55 office workers (10 women). The study aims and protocol were explained and informed written consent obtained, following approval from the Ethics Committee of Glasgow Caledonian University. Socio-demographic data, including age, home address postcode and family history of CHD, were obtained. From postcodes, national tables[22] were used to provide the Scottish Index of Multiple Deprivation (SIMD) score for each participant, as a measure of socioeconomic status, rated from 1 (least deprived) to 5 (most deprived). Weight, height and waist circumference were measured according to the WHO protocol[23]. Fasting serum concentrations were measured of glucose (by hexokinase method), adiponectin (R&D Elisa) and lipids namely, triglycerides, total cholesterol,

LDL cholesterol and HDL cholesterol (by automated analyser) in quality controlled NHS laboratory.

Coronary risk was assessed using the PROCAM.[24] This risk calculator generates 10-year CHD risk, for men aged 35-65y and women aged 45-65y, based on sex, age, family history of CHD, cigarette smoking, systolic blood pressure, fasting HDL-cholesterol, LDL-cholesterol, triglycerides and fasting glucose concentration. The ages of 67 men and 6 women fell within the ranges appropriate for this risk calculator. As a second indication of CHD risk and of diabetes risk, participants were classified as having metabolic syndrome, or not, using both the NCEP criteria[25] and IDF criteria[26]: fasting serum triglycerides ≥1.7 mmol/l, glucose ≥5.6 mmol/l, HDL-cholesterol ≤1.03 mmol/l for men or ≤1.30 mmol/l for women, waist circumference ≥102cm for men or ≥88cm for women, and blood pressure ≥130/85 mmHg.

Physical activity recording

Physical activity and sedentary behaviour were recorded for seven consecutive days using the activPAL monitor to provide time spent stepping, standing and sitting/lying as well as steps, mean stepping rate and number of sit-to-stand transitions per day. In addition, though the activPAL does not differentiate sleeping (lying posture) from sitting posture, time spent sleeping was extracted from the activPAL raw output. This was defined as prolonged periods (>2 hours) of continuous inactivity during sleeping hours. Sleeping hours were simply night hours for those who worked day shifts and day hours for the two participants who worked night shifts. Sleep

duration was subtracted from total sedentary time to obtain waking hours' sedentary time, referred to as sedentary time in this manuscript. Both short and long sleep durations have been reported to be associated with higher risk of CHD.[27]

The activPAL was worn on the mid anterior thigh using adhesive tape according to the manufacturer's guidance and throughout seven days except during activities that risk it being in contact with water, e.g. bathing or swimming. Participants were asked to note down any non-wear periods in the food diary that they also completed as part of the wider study (not relevant to the current study) and these were checked with each participant at the debrief session. The inter-device reliability (ICC = 0.99) and accuracy (95.9% agreement with direct observation) of the activPAL for reporting time spent sedentary, standing and walking have been reported previously.[28] The inter-device reliability (0.99) and accuracy (≥98.99%, depending on walking speed) for step count and stepping rate have also been reported.[29] Stepping rate (cadence) is reported by the activPAL as number of steps per minute during stepping time. Data were accepted for inclusion with a minimum of three 24-hour periods, including a non-work day, as recommended by others.[30]

Data analyses

Age, SIMD values (1 to 5), family history of CHD, job type (delivery or office worker) and work-shifts were obtained. Outcome variables for physical activity were daily time (h) spent sedentary, standing and stepping, step count, average stepping rate and daily sit-to-stand

transitions. The outcome measures included BMI, waist circumference, systolic and diastolic pressure, fasting lipids (triglycerides, total cholesterol, LDL, HDL cholesterol), fasting glucose, and adiponectin. The 10-year PROCAM CHD risk score was generated from age, blood pressure, fasting HDL and LDL cholesterol, triglycerides and glucose.[24] The presence of the metabolic syndrome (derived from levels of fasting glucose, triglycerides, HDL cholesterol, blood pressure and waist circumference) was also obtained.

The data were tested for normality and summary data were produced using SPSS version 18.0. Univariate associations were explored and multivariable linear regressions undertaken to model the relationship between sedentary time and CHD risk. Adjustment for age, sex, SIMD, family history of CHD, job type and shift (model 1). Job type was considered because self-selection into job type cannot be ruled out. Similarly, as shift patterns may affect sleep patterns, this was included in the model. In addition, further stepwise adjustments were made for sleep duration (model 2), then standing (model 3), stepping in replacing standing (model 4), both standing and stepping (model 5). These stepwise adjustments showed that including stepping time in model 5 did lead to improvement in the R^2 value for any of five outcome variable but rather a drop in R^2 was observed in model 4. We believe this was due to the observed strong correlation between sitting, standing and stepping $r = 0.34–0.61$, $p < 0.001$). One approach would have been to employ compositional data analysis. However, rather than fitting compositional data that are not clinically meaningful, stepping time was excluded in the final model (model 6) where additional adjustments were also made for waist circumference. It is thought that body size may have bidirectional relationship with sedentary behaviour, and thereby predict the behaviour.[31]

Adjusting for the same variables as above, binary logistic regression was modelled to determine the odds of the metabolic syndrome from the physical activity parameters. The associations were explored in the whole sample and for the 67 men only. Separate analyses were not undertaken for the 15 women.

Results

All 111 participants completed the full 7d study. Fifteen participants worked full day shifts, 92 early shift, three late shift and only one worked night shift. A third (32 men; 4 women) had first-degree family histories of CHD. The distribution of the participants by SIMD was as follows: n = 13, 20, 17, 23 and 38 for SIMD 1, 2, 3, 4 and 5 respectively. During the study, the shift patterns of the participants were full-day (n = 15), early (n = 92), late (n = 4). The summary statistics of the study participants are shown in Table 1. For the 73 participants aged between 35-65y (men, n=67) and 45-65y (women, n=6), among whom PROCAM could be applied, 10y PROCAM risk ranged from 0.1-12.0%, mean 1.9(SD 1.7)%.

In exploratory univariate analyses, waist circumference (correlation coefficient, r = 0.28, p =0.002), fasting triglycerides (r = 0.30, p = 0.002), HDL cholesterol (r = -0.38, p < 0.0001) and 10-y PROCAM risk (r = 0.33, p =0.004) were significantly and adversely associated with

sedentary. Waist circumference ($r = -0.23$, $p = 0.014$), fasting triglycerides ($r = -0.22$, $p = 0.018$), HDL cholesterol ($r = 0.24$, $p < 0.01$) and 10-y PROCAM risk ($r = -0.37$, $p = 0.001$) were significantly and favourably associated with stepping time. In these non-adjusted correlations, 10-y PROCAM risk showed an inverse significant ($r = -0.25$, $p = 0.031$) association with daily step count, and serum adiponectin levels showed an inverse significant association with sedentary time ($r = -0.24$, $p = 0.012$) and a positive significant association with standing time ($r = 0.93$, $p = 0.002$). Standing time also had a significant positive association with HDL cholesterol ($r = 0.36$, $p = 0.0001$) and a significant inverse association with waist circumference ($r = 0.20$, $p = 0.033$). Physical activity and sedentary behaviour were not significantly associated with BMI, blood pressure, serum glucose or LDL cholesterol. None of the risk factors was significantly associated with stepping rate or number of sit-to-stand transitions.

After adjusting for age, sex, SIMD, family history of CHD, job type and shift worked, greater waist circumference, higher serum triglycerides and lower HDL cholesterol were significantly ($p < 0.05$) associated with longer time spent sedentary (model 1 in table 2). These associations remained significant after adjustments were made for sleep (model 2), then standing (model 3), stepping (model 4) and then both standing and stepping in addition to sleep (model 5). After further adjustment for waist circumference (model 6), the associations of sedentary time with triglycerides and HDL cholesterol were no longer significant. Sedentary time appears to be better predictor of waist circumference, serum triglycerides and HDL cholesterol than stepping, standing and sleeping durations (models 3 and 4). However, this association was no longer significant after further adjusting for waist circumference (model 6). No significant association

was observed between physical activity behaviour and serum adiponectin in the adjusted analyses. The variables together explained (R^2) 18.5% of variance in serum triglycerides, 30% for HDL cholesterol, 23% for adiponectin, 22% for waist circumference and 48% for 10-year PROCAM risk (model 5 in table 2). Sleep duration was a strong positive predictor of serum HDL cholesterol, even after adjusting for waist circumference. No significant associations were found between physical activity behaviour and BMI or LDL cholesterol. Analysis for men alone did not change the overall findings.

Higher 10-year PROCAM risk was significantly ($p < 0.05$) associated with sedentary time, adjusting for age, sex, SIMD, family history of CHD, job type and shift worked (model 1 in table 2). This association remained significant after further adjustment for sleep (model 2) but not after adjusting for standing, stepping or waist circumference (models 3-6). Sedentary time explains (R^2 change) 2% of the variance in 10-year PROCAM risk, 2% in waist circumference, 1% in serum HDL and 4% in serum triglycerides (table 2). The association of sedentary time with PROCAM risk (Figure 1) appears to be curvilinear, such that greater deterioration of risk is associated with longer time spent sedentary. However, the introduction of a quadratic term (square of sedentary time) in the model did not yield a significant association ($R^2 = 0.01$, 95% CI: -0.01 - 0.03). One additional hour per day sitting was associated with 0.18% (95% CI 0.01–0.36%) greater 10-year PROCAM risk.

Thirteen study participants had the metabolic syndrome, as defined by NCEP.[32] Compared to those without the metabolic syndrome, participants with the metabolic syndrome were significantly less active, with lower step count, slower stepping rate, shorter stepping duration and longer time spent sedentary (table 3). Twenty participants satisfied the IDF consensus criteria for metabolic syndrome.[26] These participants similarly spent more time in a sedentary posture and walked less than those without metabolic syndrome (table 3). Those participants with no metabolic syndrome features walked ≥3.5 hour/day, >15,000 steps/day, or spent >7h/day upright.

The logistic regression model was used to explore the association between physical activity time and the development of the metabolic syndrome. After adjusting for age, sex, family history of CHD, job type, shift worked, socioeconomic status and shift worked, no significant association was found between time in posture and activity with the development of the metabolic syndrome.

Discussion

The present study set out to relate objectively measured time spent in sedentary posture, standing and stepping to a comprehensive list of cardiovascular and diabetes-related risk factors. The data indicate that sedentary behaviour is associated with coronary and diabetes risk as reflected by metabolic syndrome, with elevated waist circumference, elevated serum triglycerides, and lowered serum HDL cholesterol. After adjusting for socio-demographic variables, sleep and physical activity (stepping and standing), time spent sedentary was positively associated with

coronary risk, as determined by PROCAM. This association has been quantified to demonstrate the level of risk (the β coefficient or odds ratio) associated with sedentary behaviour.

These findings, if proven to be a causal relationship, may offer support for a health promotion intervention in the workplace, to reduce sitting and increase time spent in an upright posture. Animal studies have shown that preventing ambulatory activity of the hind limb over 24 hours could lead to a reduction in plasma HDL-cholesterol by 22% and lipoprotein lipase activity (the hormone responsible for triglyceride catabolism) by 90% to 95%.[19,33] LPL activity in limb muscles is dependent on local contractile activity. Sedentary behaviour therefore promotes CHD independently from lack of moderate-vigorous physical activity, and as demonstrated previously[4], adults do not necessarily compensate sedentary posture at work with upright posture after work. Reducing sedentary behaviour by spending more time upright, thereby engaging limb and trunk muscles, is a simple protective mechanism to reduce CVD. The metabolic cost of upright posture is approximately 33-40% higher than that of sitting posture.[34,35] It is recognised that one recent small study[36] of energy expenditure of some activities (lasting ≤ 15min duration) found no significant difference in energy expenditure between sitting and standing. Mansoubi et al. [37,] on the other hand, suggest reclassifying some sitting-based activities as non-sedentary because they may involve energy expenditures > 1.5 METs, the cut-off for sedentary behaviour by definition.[38] It is our view that participation in such activities are not a common occurrence. It is rather unusual to engage in sitting activities that expend more energy than standing activities. However, fitting more upright time into busy workdays on a habitual basis is an easy message, and is potentially acceptable. Encouraging leisure time physical activity is of course valuable, but

tends to result in erratic and poorly sustained improvements.[39-41] Efforts to increase participation in moderate-to-vigorous physical activity are complementary with that of reducing sedentary behaviour.

Previous research using pedometers has related step counts to risks. In the present study, using the activPAL which is more accurate and reliable than pedometers in measuring steps[29], we found that waist circumference and 10-y PROCAM risk were associated with step count in unadjusted data, but not after adjustments. The presence of the metabolic syndrome was significantly associated with daily step count. Though the number of cases of the metabolic syndrome was relatively small, the findings corroborate previous results. Schofield et al.[42] reported that Australian adolescent girls who achieved less than 10,000 steps/day were significantly more likely to have two or more CHD risk factors. We have further shown that CHD risk has stronger associations with time spent stepping and in sedentary posture than with step count.

A previous cross-sectional study involving 168 subjects reported that greater number of breaks in sedentary time (i.e. 'transitions' to standing posture) had beneficial associations with waist circumference, BMI, triglycerides and 2-hour postprandial glucose.[43] That pattern was not confirmed in the present study; in neither the unadjusted nor the adjusted analyses were sit-to-stand transitions associated with coronary risk. However, unlike this previous study, ours did not include 2-hour postprandial glucose but rather fasting blood glucose only, and this may explain the difference in findings. Importantly, the differences in the findings - in particular the

association with waist circumference, BMI and triglycerides - may also lie in data quality: in the previous study, sedentary time was estimated by actiGraph, setting an arbitrary cut-off (≤100 counts/minute) as a proxy for sedentary time, while actiGraph counts rising above this value were considered transitions out of sedentary behaviour. Secondly, the actiGraph does not differentiate standing still from sitting and lying, and will therefore misclassify a change from standing still to stepping as a break in sedentary time[44]. Standing still is different from sitting in that the former is known to elicit cardio-protective metabolic changes in skeletal muscles.[20,21] The activPAL, used in the present study accurately measures sit-to-stand transitions[27], so our data are likely to be more reliable.

We found no demonstrable relationship between physical activity or sedentary behaviour and blood pressure, the latter being within the normal ranges, although previous studies reported higher blood pressure with longer television watching time[45] and lower energy expenditure.[46] Furthermore, no significant association was found between fasting glucose and the physical activity parameters despite earlier reports of independent association of objectively measured light-intensity physical activity with 2-hour postprandial glucose in other non-diabetic subjects.[45,47] The differences may be due to the differences in the measurement of sedentary behaviour: television watching time, accelerometer counts and heart rate in the previous studies versus time spent sitting and lying in the present study. The difference may also be due the differences in outcome measures: fasting glucose versus 2-hour postprandial glucose. A more recent large study involving 2,497 participants wearing the same activity monitor as in the present study (the activPAL) found higher odds for type 2 diabetes with sedentary behaviour.[18]

The present study adds significant new information to the recent studies and reviews[44-50] which call for valid and reliable quantitative assessment of sedentary behaviour and its relationship with CVD and diabetes. Future studies should endeavour to use similar assessment methods for both sedentary behaviour and the outcome variables.

In man, adiponectin appears to reflect insulin sensitivity but may not be a powerful upstream determinant.[51] We found no significant relationship between adiponectin and physical activity measures, in keeping with prior studies which have yielded differing results.[52-54] Adiponectin levels were, however, significantly associated with waist circumference, reflecting the well-known relationship between insulin sensitivity and obesity.

Strengths and Limitations

Our study has strengths, but also limitations. We used a more intensive measured assessment, which provides more reliable data than conventional step-counters, but this inevitably restricts study numbers and power. We used appropriate statistical methods to avoid over-reporting positive findings, and have not made assertions that invoke beta errors, which could arise from low power. The sample was of white Caucasians, not balanced between the sexes, so conclusions cannot be drawn for other races or for women alone. The main conclusions are based on data adjusted for sex, but while we have no *a priori* reason to suspect sex differences, we have confirmed in sensitivity analyses that the main findings remain for men alone. Though the activPAL does not differentiate sleeping (lying posture) from sitting posture, it was possible to

identify sleep from the raw output, as prolonged periods (>2 hours) of continuous inactivity during sleep hours. Sedentary time is usually reported as a single measure, including sleeping time. Adjusting for sleep as best as we could is therefore a strength of the study.

The study could have benefited from body composition data but due to lack of facilities for these measures. Waist circumference, adjusted for sex and age, is a more robust predictor than BMI of body fat measured by densitometry, and where the range of body fat is narrow a greater waist circumference is a marker of elevated visceral fat mass.[55] In the present study, waist circumference was shown to have significant positive association with sedentary behaviour - the latter explaining 3% of the variance in waist circumference (table 2). After adjusting for waist circumference, the association between sedentary time and 10-year PROCAM risk and with HDL cholesterol were no longer significant, but the association with triglycerides remained significant. It is possible that any effects of sedentary behaviour on CHD risk act through an elevated waist circumference and dyslipidaemia.

The present study reports results from cross-sectional data of healthy participants with relatively low PROCAM-determined CHD risk. Although our data are cross-sectional, our subjects were selected as healthy, so we feel reverse-causality would be improbable. There is ample existing evidence for coronary risk reduction with greater physical activity, but health promotion does not achieve activity targets sustainably for large numbers, so it will be important to test, prospectively, the proposal that CHD risk might be reduced by increasing time spent in a vertical

posture. It will also be valuable to include a range of ethnic and racial groups and more women in any future studies.

Conclusion

Longer time spent in sedentary posture is significantly associated with higher CHD risk, including larger waist circumference, higher triglycerides and lower HDL cholesterol. Future prospective research is required to ascertain if new targets for sitting, lying, standing and stepping, to avoid metabolic risk, can be proposed. The levels associated with zero risk factors in the present study, >15,000 steps/day or >7 hours per day spent upright, would be challenging and difficult to sustain unless incorporated into occupations.

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Conflict of Interest

This research was funded by Glasgow Caledonian University as part of a PhD project. Although Professor Malcolm Granat is a director of PAL Technologies Ltd, this research is not intended in any way to promote the activPAL monitor or the company. Professor Naveed Sattar's research is supported by the British Heart Foundation and Diabetes UK. Professor Mike Lean's research is supported by Diabetes UK and by Counterweight Ltd. The other authors have no conflict of interest to declare.

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Figure Legends

Figure 1: Associations of predicted cardiovascular risk with time spent in sedentary posture. The regression line and the 95% confidence interval of prediction are shown. Adjustments were made for sex, age, job type, shift worked, family history of CHD, waist circumference (where waist circumference is not the dependent variable), and time spent sleeping and time in upright posture.