ORIGINAL RESEARCH

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Accelerometer-based measures of sedentary behavior and cardio- metabolic risk in active older adults

Abstract

Purpose: Sedentary behavior has been proposed as an independent cardio-metabolic risk factor even in adults who are physically active through recreational activity. Because little is known about the metabolic effects of sedentariness in seniors, the relationship between sedentary behavior and cardio-metabolic risk was examined in physically active older adults.

Methods: Fifty-four community dwelling men and women > 65 years of age (mean 71.5 years) were enrolled in this cross-sectional observational study. Subjects were in good health and free of known diabetes. Activity levels (sedentary, light, moderate to vigorous activity time per day) were recorded with accelerometers worn continuously for 7 days. Cardio-metabolic risk factors measured consisted of the American Heart Association diagnostic criteria for metabolic syndrome (waist circumference, triglycerides, high-density lipoprotein, systolic blood pressure and fasting glucose) as well as low-density lipoprotein (LDL). The relationships between activity measures and cardio-metabolic risk factors were examined. Significant variables were then entered into a stepwise multivariate regression model.

Results: All but one subject achieved exercise levels recommended by the American College of Sports Medicine. The average proportion of time spent at a sedentary activity level each day was 72.7%. From the regression analysis, the only significant association found between cardio-metabolic risk outcomes and activity predictors was between LDL and sedentary time, with LDL detrimentally associated with average sedentary time per day (Standardized Beta Correlation Coefficient 0.302, $p < 0.05$).

Conclusion: Sedentary behavior is associated with an adverse metabolic effect on LDL in seniors, even those who meet guideline recommendations for an active “fit” adult.

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Sedentary behavior (usually defined as the length time sitting or lying down) has recently emerged as an independent risk factor for diabetes mellitus, dyslipidemia, hypertension and obesity in younger adult populations [1,2]. The associations persist despite accounting for concomitant levels of moderate and vigorous physical exercise [3]. These findings suggest that sedentary behavior may carry a risk for cardio-metabolic disease that is distinct from physical exercise, or the lack thereof.

Despite older adults being the most physically inactive and sedentary group of all [4,5], the metabolic effect of sedentary time in seniors has not been adequately studied. Cross sectional survey based studies have associated less activity with adverse metabolic parameters [6,7]. Because most older adults do not meet current guidelines for physical activity [8], it is difficult to discern whether it is a lack of exercise, excessive sedentary behaviour, or both that leads to metabolic risk.

In an attempt to separate these effects, a physically active older adult population, one that was already meeting or exceeding current guidelines for physical activity, was recruited. Our objective was to examine the relationship between sedentary behaviours (as quantified by accelerometer measures) and cardio-metabolic risk factors in an active older adult population. We hypothesized that increased sedentary time would continue to associate with metabolic disease even in the setting of concomitant high levels of exercise.

Materials and Methods

This was a cross-sectional observational study. This study was approved by the Human Subjects Committee of the University of British Columbia, and all subjects gave written informed consent.

Subjects and Recruitment

Fifty-four community dwelling men and women > 65 years of age were recruited through their affiliation with the Whistler Seniors Ski Team of British Columbia, Canada, via a study poster and information session. Subjects were enrolled between October of 2011 and June of 2012.

Inclusion/Exclusion Criteria

All subjects had to be able to independently perform all basic activities of daily living, climb one flight of stairs and walk two blocks without assistance. Current smokers, those with known diabetes mellitus or cardiovascular disease in the form of prior strokes, transient ischemic attacks, angina, myocardial infarction or coronary revascularization in the last 2 years were non-eligible.

Potential Correlates with Measures of Activity

The following variables were chosen *a priori* as potential correlates with the various accelerometer measures of activity:

1. Criteria for the Metabolic Syndrome:

Given recent work demonstrating a relationship between the duration of time spent sedentary and the presence of the metabolic syndrome [9], various individual criteria defining this syndrome were considered as potential correlates with activity measures [10]. These measures were diastolic blood pressure, systolic blood pressure, waist circumference, high density lipoprotein cholesterol (HDL), fasting blood glucose and total triglycerides.

2. Low Density Lipoprotein (LDL):

Despite LDL having been shown to be a strong predictor of cardiovascular risk [11], the relationship between LDL and time spent in sedentary behavior has been poorly examined; in fact, most studies focus exclusively on examining the various components of the metabolic syndrome. Since recent observational work has suggested a relationship between the duration of time spent in sedentary behaviours and LDL cholesterol levels [12], this measure was added as a potential correlate.

Research Procedures

A minimum of one study visit was required by each participant to collect anthropomorphic, blood pressure, laboratory and survey data, and to apply the accelerometer. Anthropomorphic measurements were recorded including height without shoes measured by stadiometer to the nearest 0.1 cm. Weight was measured by mechanical beam balance scale to the nearest 0.1 kg while the subject was wearing light clothes but no shoes. Waist circumference was measured to the nearest 0.1 cm by a plastic tape measure held at the level of the umbilicus directly against the skin. Blood pressure was measured by digital sphygmomanometer while the subject was seated quietly, recording the average of three readings taken 5 minutes apart, after 20 minutes of quiet rest. Blood was drawn in private affiliated laboratories according to standard methods.

Self-administered questionnaires were used to obtain information regarding medical history, medications and substance use.

Sensewear Pro armband accelerometers (BodyMedia, Sword Medical Limited, Blanchardstown, Dublin) were fitted snugly around the right upper arm and used to monitor levels of physical activity 24 hours a day for 7 full days. Subjects were

instructed to wear it continuously, including during sleep, except when bathing or swimming.

Data Collection and Processing

To be included in the analysis, participants were required to comply with wearing the accelerometer for at least 5 valid days. A valid day was defined as at least 21 hours of recorded activity on the accelerometer.

Accelerometer data was recorded in one second epochs. Sedentary behavior, meaning time spent sitting quietly in activities such as reading or watching television, was categorized as any time spent in <1.5 Metabolic Equivalent of Task (METs). Light activity, meaning time spent standing or walking slowly, for example light housework, was categorized as 1.5-3.0 METs. Moderate to vigorous activity, meaning brisk walking or more intense exercise, was categorized as >3.0 METs. Subjects qualified as meeting target guidelines for physical activity when more than 150 minutes in the 7 days was spent at a moderate to vigorous level of activity. Average time per day spent in sedentary (ST), light (LT) and moderate to vigorous activity levels (MT) were recorded as minutes per day.

Statistical Analysis

All measures of physical activity were normalized by the amount of time per day the accelerometer device was worn. In addition to our measures of physical activity (ST, LT and MT), variables to be considered in the multivariate linear regression model were determined a priori. All of the components of the American Heart Association definition [10] for metabolic syndrome (systolic blood pressure, diastolic blood pressure, waist circumference, HDL, triglycerides, fasting blood glucose) as well as LDL cholesterol were considered as potential cardio-metabolic risk factors in our model.

A tiered approach was used whereby the initial model included variables with univariate associations at a level of $p \leq 0.10$. Scatterplots were visually inspected for outlier data and histograms were examined to identify data skewing. MT, triglycerides, fasting blood glucose, and diastolic blood pressure demonstrated skewing on inspection of the histograms and were therefore logarithmically transformed (base ten) prior to both the univariate and multivariate analyses. With each iteration of the stepwise regression model, the least significant variables were removed until only significant correlates remained in the final model. To ensure the assumptions of the multivariate regression were met, tolerance values and variance inflation factors were examined for multi-collinearity. Variables necessary to calculate one another were not included in the same model

to avoid colinearity (specifically HDL and LDL), as well as any variables that demonstrated significant correlations in the univariate analysis. Plots of residuals and a QQ plot were examined in our final minimum effective model. The R core software package version 3.0.1 was used for statistical analysis with a significance level of $p < 0.05$ [13].

Results

One individual was screened and could not participate due to a recent cardiovascular event. Of the 54 originally recruited, there was one withdrawal and three cases where the participant did not meet the compliance criteria, leaving a total of 50 subjects (23 men, 27 women) who contributed to the data analysis. Complete laboratory measures were available for 48 of these participants (22 men, 26 women). The accelerometers were worn for an average of $98.5 \pm 0.2\%$ of the study time. Data were otherwise complete.

Participant Characteristics

Demographic and metabolic characteristics of participants are shown in Table 1.

Activity Levels

On average, subjects spent 157.4 minutes (2.6 hours) per day performing moderate to vigorous physical activity, 236.3 minutes (3.9 hours) per day in light activity, and 1047.0 minutes (17.5 hours) of their time sedentary, 564.2 minutes (9.4 hours) of which was accumulated apart of time spent lying down (Table 1 and Figure 1). All but one subject met the target of 150 minutes per week of moderate to vigorous physical activity recommended in the American College of Sports Medicine guidelines [14].

Activity and Metabolic Correlates

MT, triglycerides, fasting blood glucose, and diastolic blood pressure demonstrated skewing on inspection of the scatterplots and were therefore logarithmically transformed prior to the analysis. In the univariate analysis, LDL was the only cardio-metabolic risk factor that showed any significant ($p < 0.10$) correlation with any of the measures of activity (sedentary time and light time), as shown in Table 2 and Figure 2. There was no correlation between sedentary time and light activity time.

All the variables that showed a significant correlation with LDL (diastolic blood pressure, sedentary time and light time) were entered into a multivariate regression model (Model 1)

TABLE 1. Demographic, metabolic and activity characteristics (N = 50)

Age (years), range	71.5 ± 0.6	(65-81)
Gender (female)	27	(54%)
Demographic Variables		
Caucasian	46	(92%)
Moderate-heavy alcohol *	17	(34%)
Ex-smokers	26	(52%)
University/further education	44	(88%)
Peak income > \$60,000	35	(70%)
Metabolic Variables		
Waist circumference males (cm)	92.0 ± 1.9	
Elevated waist circumference †	4	(8%)
Waist circumference females (cm)	81.0 ± 1.6	
Elevated waist circumference †	7	(15%)
BMI (kg/m ²)	24.2 ± 0.4	(16.5-32.4)
BMI ≤ 18.5 (kg/m ²)	1	(2%)
BMI 18.51 – 24.9 (kg/m ²)	30	(60%)
BMI 25 – 29.9 (kg/m ²)	17	(34%)
BMI ≥ 30.0 (kg/m ²)	2	(4%)
Triglycerides (mmol/l)	1.00 ± 0.08	(0.3-3.61)
LDL cholesterol (mmol/l)	2.84 ± 0.01	(1.25-4.66)
HDL cholesterol (mmol/l)	1.85 ± 0.07	(0.85-3.28)
Systolic blood pressure (mmHg)	117.0 ± 2.4	(90-166)
Systolic ≥ 140 (mmHg)	6	(12%)
Diastolic blood pressure (mmHg)	68.9 ± 1.2	(55-93)
Diastolic ≥ 90 (mmHg)	2	(4%)
Fasting plasma glucose (mmol/l)	5.11 ± 0.10	(3.4-9.1)
Pre-existing Medical Conditions		
Anti-hypertensive medication	14	(28%)
Lipid lowering medication	5	(10%)
Prior cardiovascular disease ‡	2	(4%)
Average Time per Day at Activity Levels (minutes)		
Lying Down	482.8 ± 10.4	(33.5%)
	(341.6-604.2)	
Sedentary (<1.5 METS) §	1047.0 ± 18.7	(72.7%)
	(829.8-1269.6)	
Light (1.5-3.0 METs)	236.3 ± 12.6	(16.4%)
	(91.1-431.2)	
Moderate-Vigorous (>3.0 METS)	157.4 ± 13.9	(10.9%)
	(17.5-417.5)	

* ≥7 drinks/week in women and ≥14 drinks/week in men, † By ethnicity appropriate norms, ‡ 1 myocardial infarction, 1 cerebrovascular event,

§ Includes lying down

FIGURE 1. *Correlation between sedentary time (minutes/day) and LDL cholesterol (mmol/L).* Graph demonstrating the moderate positive correlation between the two variables of sedentary time and LDL cholesterol.

FIGURE 2. *Time in hours at activity levels.* Composite average time in hours that subjects spent at activity levels, including sedentary, light activity and moderate to vigorous activity. Sedentary activity is showed separately from time spent lying down to better delineate the accumulation of time spent in sedentary behaviors.

TABLE 2. Pearson correlation matrix for cardio-metabolic risk factors with significant ($p < 0.10$) correlations with measures of activity

Cardio-metabolic Risk Factor	Outcomes with $p < 0.10$	R (CI 95%)	P Value
SBP	DBP	0.715	<0.001
	WC	0.317	0.022
	FBG	0.245	0.080
DBP	SBP	0.715	<0.001
	WC	0.378	0.006
	SBP	0.317	0.022
WC	DBP	0.378	0.006
	FBG	0.256	0.067
	HDL	-0.614	<0.001
HDL	WC	-0.614	<0.001
	LDL	-0.270	0.053
	DBP	0.262	0.061
LDL	HDL	-0.270	0.053
	ST	0.322	0.020
	LT	-0.253	0.071
FBG	SBP	0.245	0.080
	WC	0.256	0.067

Abbreviations: SBP (systolic blood pressure), DBP (diastolic blood pressure), WC (waist circumference), HDL (high density lipoprotein), LDL (low density lipoprotein), FBG (fasting blood glucose), ST (sedentary time), LT (light time)

that initially explained 16% of the variance of LDL. None of these predictors showed a significant ($p < 0.05$) correlation with each other, so there were no issues with multi-collinearity. LT was then removed from our model (see Table 3) leaving our final minimal effective model (Model 2) that explained 18% of the variance of LDL and consisted of:

$$\text{LDL} = b_0 + b_1(\text{ST}) + b_2 \log(\text{DBP}) + e$$

where b_0 is an intercept term, b_1 represents the change in LDL with an increase in ST with the DBP held constant, and b_2 is the change in LDL with an increase in DBP with ST held constant. The error term e represents all sources of unmeasured and unmodeled random variation in LDL (Table 3).

Discussion

The seniors in this study were highly active, spending an average of 2.6 hours each day engaging in moderate to vigorous activity, greatly exceeding the 2.5 hours per week recommended by the American College of Sports Medicine guidelines [14]. Interestingly, although the study population exercised much in excess of the American average [5], time spent sedentary was congruent with the average time spent sedentary

for the general older adult population (9.4 hours per day) [15]. Further, despite the high levels of exercise, sedentary time showed a significant positive correlation with serum LDL levels. This finding suggests that physical exercise is not sufficiently protective against some of the metabolic effects incurred by excess sedentary time.

Time spent sedentary has changed more in the last 50 years than any observed decrease in time spent doing leisure time physical activities, particularly within the domains of “screen time” (i.e.: watching television and computer work) and sedentary occupations [16]. Currently, the average American male over the age of 70 years spends 9.5 hours a day engaged in sedentary activities [15] and the body of literature characterizing the detrimental metabolic risks incurred by excess sedentary time is growing.

Observational studies have implicated sedentary time with an increase in excess adiposity, an increase in triglycerides and an increase in insulin resistance [17,18]. These findings persist even when levels of moderate to vigorous physical activity are controlled for, suggesting that increased sedentary time impacts metabolic risk to some extent regardless of how much an individual exercises. Even in a subgroup of individuals who claimed by survey to exercise regularly, increased television watching

TABLE 3. Multivariate regression models for correlates with low density lipoprotein (LDL) cholesterol

LDL	R ²	Unstandardized β (SE)	Standardized β	P value
Model 1: F(3,49)=3.59	0.158			0.020
<i>ST</i>		0.1538 (0.0646)	0.3493 (0.1466)	0.021*
<i>LT</i>		0.0005 (0.0014)	0.0550 (0.1469)	0.710
<i>Log(DBP)</i>		1.4487 (0.7434)	0.2530 (0.1298)	0.057
Model 2: F(2,50)=5.41	0.178			0.007*
<i>ST</i>		0.1426 (0.0567)	0.3239(0.1288)	0.015*
<i>Log(DBP)</i>		1.4781 (0.7329)	0.2581 (0.1280)	0.049*

Stepwise multivariate regression models of density lipoprotein cholesterol levels (LDL) with sedentary time (ST) per day, light activity time per day (LT) and the logarithm of diastolic blood pressure (logDBP) as predictors. The units of the unstandardized coefficients (β) for ST and LT are in mmol x L⁻¹ x minutes per day⁻¹.

The β for log(DBP) is in mmol x L⁻¹ x log(mm of Hg)⁻¹. Standard errors (SE) and tests of significance are at a level of $p < 0.05$.

was associated with increased markers of metabolic risk in a continuous fashion [3]. As might be expected with increased metabolic risk, sedentary individuals also have an increased likelihood of premature cardiovascular death, making the question of sedentary risk all the more pressing [19,20].

Although several observational studies in seniors have implicated increased sedentary time with elevated risk of having the metabolic syndrome [6,7], most well-conducted studies have focused nearly exclusively on younger individuals. This is despite the fact that seniors are the most sedentary group of all; older adults have been found to reach their exercise targets only 0 to 4.9 percent of the time [4,5]. Examining the metabolic consequences of sedentary behavior in seniors has been a challenge for several reasons. The first is that studies exploring the association between sedentary time and cardio-metabolic risk in older adults have not used objective measures of physical activity such as accelerometers, but have relied on surveys, in which subjects are known to consistently overestimate their true physical activity levels [21]. Secondly, since the older populations studied previously did not engage in nearly any meaningful physical exercise, it is difficult to determine whether the metabolic risks observed in them are secondary to an independent effect of sedentary behavior, a lack of physical activity or both in combination.

Our study was the first, in either young or older populations, to deliberately recruit very physically active individuals in an attempt to show that significant exercise cannot completely nullify the detrimental effects of excess sedentary time, in this case the risk for elevated LDL.

Contrary to prior studies, no association was found between sedentary behavior and the components of the metabolic syndrome. This is likely explained by the fact that our study population was the most physically active ever studied in

this manner, and it is possible that extremely high levels of activity can to some extent correct for some of the detrimental metabolic effects seen with excess sedentary time. Supportive to this idea, evidence from a recent observational study [19] suggests that adequate physical exercise is associated with a lower risk of cardiovascular death, regardless of the amount of sedentary time a person engages in.

The high amount of sedentary time seen in this study mirrors that of the general adult population, and suggests that despite significant exercise behavior, time spent in light activity (i.e., standing, slow walking and light housework) is lacking. The importance of light activity was recently demonstrated in a study where individuals who broke up long periods of sedentary time with light activity, for example by standing up, were less likely to have derangements in their metabolic profile, even despite equal time spent sedentary overall [22]. This suggests that it may not simply be the overall time spent sedentary that has a bearing on cardio-metabolic risk, but also the duration of the sedentary periods themselves, with longer sedentary periods increasing cardio-metabolic risk and sedentary breaks reducing cardio-metabolic risk.

Possible Mechanisms

Recent studies attempting to delineate the metabolic response to both exercise and inactivity suggest that in fact the cellular mechanisms involved are qualitatively different. One possible mechanism that could link sedentary behaviour and LDL cholesterol is lipoprotein lipase (LPL). LPL levels have been associated with elevated LDL cholesterol in human subjects (23). Increases in LPL levels with exercise and decreases in LPL levels with inactivity have been shown to occur through completely different cellular mechanisms (24 - 26). These distinct physiologic responses to exercise and inactivity might explain

why increased time spent in sedentary behaviours correlated with elevated LDL levels, despite an otherwise high degree of physical activity during the subjects' non-sedentary portions of the day, although the exact underlying mechanism is beyond the scope of the current study.

Study Limitations

There are some potential limitations to our study findings. The cross-sectional nature of the study design limits inference about causality. Ideally, prospective or preferably interventional trials are needed to define the specific physiologic and behavioral factors behind the associations observed. Because of the small sample size, it is possible that the study was underpowered to detect a relationship between time spent in sedentary behaviours and some of the other cardio-metabolic risk factors, particularly since most subjects had metabolic parameters within the normal range and were largely free of metabolic or cardiovascular disease. The moderate degree of alcohol consumption in this subject group could also have had some effect on the metabolic parameters observed, with relative increases in triglycerides and HDL, and potential lowering of LDL levels beyond that seen in alcohol abstainers [27].

Cut points for different categories of activity by METs were derived from the Ainsworth Compendium of Physical Activity [28]. The Sensewear Pro accelerometer armbands used have been validated to accurately capture energy expenditure in older adults [29]; however, some have suggested that the actual energy equivalent of 1 METs (usually defined as 3.5 ml/min/kg of resting oxygen consumption) varies by age, with the energy equivalent of 1 METs in older adults actually representing a lower average value, for example 2.8 ml/min/kg in one study of people over 65 years [30]. This might have led to an overestimation of time spent sedentary, based on the <1.5 METs cutoff used in this study. Nevertheless, underestimation of sedentary time, if anything, may have blunted the magnitude of correlation in this study and therefore is unlikely to have affected the fact that sedentary time was positively correlated with serum LDL levels. Lastly, because this population was much more active than the general older adult population, the findings noted may not be reflective of levels of metabolic risk seen in generally more sedentary senior populations at large.

Conclusions

This study found a cross sectional relationship between time spent sedentary and LDL as a marker of metabolic risk, despite high levels of activity in this older adult group. This finding may call into question the idea that increasing sedentariness is a

natural part of aging and prompt further studies in the area to reduce sedentariness in older adults.

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