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References

1. Sager MA, Rudberg MA. Functional decline associated with hospitalization for acute illness. Clin Geriatr Med 1998; 14: 669–79.
2. Creditor MC. Hazards of hospitalization of the elderly. Ann Intern Med 1993; 118: 219–23.
3. Brown CJ, Friedkin RJ, Inouye SK. Prevalence and outcomes of low mobility in hospitalized older patients. J Am Geriatr Soc 2004; 52: 1263–70.
4. Brown CJ, Williams BR, Woodby LL, Davis LL, Allman RM. Barriers to mobility during hospitalization from the perspectives of older patients and their nurses and physicians. J Hosp Med 2007; 2: 305–13.
5. Fisher SR, Kuo YF, Graham JE, Ottenbacher KJ, Ostir GV. Early ambulation and length of stay in older adults hospitalized for acute illness. Arch Intern Med 2010; 170: 1942–43.
6. Bjornson KF, Belza B, Kartin D, Logsdon R, McLaughlin JF. Ambulatory physical activity performance in youth with cerebral palsy and youth who are developing typically. Phys Ther 2007; 87: 248–57.
7. Storti KL, Pettee KK, Brach JS, Talkowski JB, Richardson CRKriska AM. Gait speed and step-count monitor accuracy in community-dwelling older adults. Med Sci Sports Exerc 2008; 40: 59–64.
8. Cavanaugh JT, Coleman KL, Gaines JM, Laing L, Morey MC. Using step activity monitoring to characterize ambulatory activity in community-dwelling older adults. J Am Geriatri Soc 2007; 55: 120–4.
9. Foster RC, Lanningham-Foster LM, Manohar C *et al*. Precision and accuracy of an ankle-worn accelerometer-based pedometer in step counting and energy expenditure. Prev Med 2005; 41: 778–83.
10. Allore H, Tinetti ME, Araujo KL, Hardy S, Peduzzi P. A case study found that a regression tree outperformed multiple linear regression in predicting the relationship between impairments and Social and Productive Activities scores. J Clin Epidemiol 2005; 58: 154–61.
11. Mahoney JE, Sager MA, Jalaluddin M. Use of an ambulation assistive device predicts functional decline associated with hospitalization. J Gerontol A Biol Sci Med Sci 1999; 54: M83–8.
12. Hansen K, Mahoney J, Palta M. Risk factors for lack of recovery of ADL independence after hospital discharge. J Am Geriatr Soc 1999; 47: 360–65.
13. Kamel HK, Iqbal MA, Mogallapu R, Maas D, Hoffmann RG. Time to ambulation after hip fracture surgery: relation to hospitalization outcomes. J Gerontol A Biol Sci Med Sci 2003; 58: 1042–45.
14. Harpur JE, Conner WT, Hamilton M *et al*. Controlled trial of early mobilisation and discharge from hospital in uncomplicated myocardial infarction. Lancet 1971; 2: 1331–34.
15. Kelley-Moore JA, Ferraro KF. The black/white disability gap: persistent inequality in later life? J Gerontol B Psychol Sci Soc Sci 2004; 59: S34–43.
16. Sands LP, Landefeld CS, Ayers SM *et al*. Disparities between black and white patients in functional improvement after hospitalization for an acute illness. J Am Geriatr Soc 2005; 53: 1811–16.
17. Kershaw TS, Lewis J, Westdahl C *et al*. Using clinical classification trees to identify individuals at risk of STDs during pregnancy. Perspect Sex Reprod Health 2007; 39: 141–8.
18. Bartali B, Frongillo EA, Guralnik JM *et al*. Serum micronutrient concentrations and decline in physical function among older persons. JAMA 2008; 299: 308–15.
19. Chen YT, Miller PD, Barrett-Connor E, Weiss TW, Sajjan SGSiris ES. An approach for identifying postmenopausal women age 50–64 years at increased short-term risk for osteoporotic fracture. Osteoporos Int 2007; 18: 1287–96.
20. D'Alisa S, Miscio G, Baudo S, Simone A, Tesio L, Mauro A. Depression is the main determinant of quality of life in multiple sclerosis: a classification-regression (CART) study. Disabil Rehabil 2006; 28: 307–14.
21. Litvan I, Campbell G, Mangone CA *et al*. Which clinical features differentiate progressive supranuclear palsy (Steele-Richardson-Olszewski syndrome) from related disorders? A clinicopathological study. Brain 1997; 120: 65–74.
22. Averill RF, Goldfield NI, Muldoon J, Steinbeck BA, Grant TM. A closer look at all-patient refined DRGs. J AHIMA 2002; 73: 46–50.
23. Lagman RL, Walsh D, Davis MP, Young B. All patient refined-diagnostic related group and case mix index in acute care palliative medicine. J Support Oncol 2007; 5: 145–9.

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Relationship between sedentary behaviour, physical activity, muscle quality and body composition in healthy older adults

SIR—Sedentary behaviour (SB), defined as time spent sitting or lying, has been shown to be a major modifiable risk factor for chronic disease, disablement and frailty [1] independently physical activity levels (PA) [2, 3]. Time spent sitting or lying affects muscle physiology [4], is thought to accelerate sarcopenia [5], and to be a determinant driver of the obesity epidemic [6]. These two effects of SB: obesity and low muscle strength appear to potentiate each other to increase risk of disablement and frailty in older adults [7].

Interventions promoting a decrease in sedentary time and an increase in energy expenditure are advocated for the treatment and prevention of sarcopenia [8–10] and obesity, but studies have shown that programmed PA is accompanied by a spontaneous increase in sedentary periods both before and after PA [11] as a strategy to maintain the energy. Therefore efforts to maintain muscle strength and expend energy might be counteracted by the effects of increased prolonged periods of SB with potential fat gain [12, 13].

The aim of this study was to investigate the relationship between patterns of SB, habitual PA, body composition and muscle strength in older men and women using objectively measured data in free-living conditions.

Methods

The study was based on a cross-sectional design with a convenience sample of ($n = 30$) healthy older adults volunteers ($n = 16$ men, age = 79.0 ± 3.6 years and $n = 14$ women, age = 79.3 ± 3.4 years) (see Table 1 for physical characteristics and Table A1 in Appendix A in the Supplementary data available in Age and Ageing online for medication and functional capacity data). They were defined as healthy on the basis of their responses to previously published health selection criteria [14] (given in Table A2 in Appendix 1). None was engaged in any form of physical training. All procedures received local ethical committee approval. Informed written consent was obtained from the volunteers prior to their participation in the study. The study conformed to the standards set by the Declaration of Helsinki.

Body composition was measured using dual X-ray absorptiometry (DEXA Hologic Discovery) and lower limb extensor power (LLEP) using the Nottingham Power Rig [10]. Muscle mechanical quality (MQ) was defined as LLEP/lower limb fat free mass (W kg^{-1}).

PA and SB were recorded continuously over a 7-day period using an activPAL^{TM} activity monitor [11], which has been shown to be valid, accurate and sensitive in older adults [15, 16].

SB, i.e. total and pattern of sedentary time was measured by extracting bouts of time spent seated or lying from the activPAL^{TM} records. The total sedentary time was computed by summation of all the bouts and the pattern (fragmentation F) calculated as the ratio of the number of sedentary bouts divided by the total sedentary time [11].

PA was measured as the percentage time spent walking and the percentage time spent walking at a low (cadence <93 step/min), moderate and vigorous intensity (cadence > 124 step/min). These intensity levels were defined by the MET compendium [17] (low <3MET, vigorous >6 MET) and converted to thresholds of walking cadence using a previously reported relationship between cadence and walking intensity [18].

Associations between total sedentary time and F with body composition and leg power were measured using Pearson's correlation analysis and significance level set at 0.05. Using a generalised linear model, we investigate the effect of sedentary time on muscle quality taking into account that interruptions of sedentary periods occur with different intensities of PA (low, moderate, vigorous). In this model the muscle quality was the dependent variable and sedentary fragmentation considered as a predictor. Total time spent walking at different intensities (low, moderate and vigorous) were entered into the model in a step-wise fashion.

Results

All outcome measures were normally distributed ($P > 0.05$ in Kolmogorov Smirnov test) except for the percentage of time spent in vigorous activity ($P = 0.010$) which appeared to be log-normally distributed. A log transformation was applied to this variable for subsequent analysis.

For women, no significant correlations were found between total sedentary time and percentage body fat ($r = 0.382$; $P = 0.276$), lower limb body fat ($r = 0.117$; $P = 0.748$) LLEP ($r = 0.151$; $P = 0.678$) and MQ ($r = 0.186$; $P = 0.607$). Significant and strong negative correlations were found between sedentary time fragmentation (F) and percentage body fat ($r = -0.847$; $P = 0.002$) and lower limb fat mass ($r = -0.806$; $P = 0.005$) but not between F and LLEP ($r = -0.158$; $P = 0.663$) or MQ ($r = -0.465$; $P = 0.176$).

For men total sedentary time was significantly associated with body fat ($r = 0.548$; $P = 0.042$), lower limb fat mass ($r = 0.765$; $P = 0.001$), LLEP ($r = 0.739$; $P = 0.003$) and MQ ($r = 0.607$; $P = 0.021$). Significant negative correlations were found between sedentary time fragmentation and percentage body fat ($r = -0.600$; $P = 0.023$), lower limb fat

Table 1. (a) Mean (SD) % body fat, lower limb composition, lower limb extensor power (LLEP), muscle mechanical quality (MQ), sedentary behaviour and physical activity variables

Gender	Percentage of body fat	Lower limb fat free mass (kg)	Lower limb fat mass (kg)	LLEP (W)	MQ (W kg^{-1})	Total sedentary time (h)	Fragmentation of sedentary time (F) (bouts/sedentary hours)	Total walking time (h)	Time spent walking at low intensity (h)	Time spent walking at moderate intensity (h)	Time spent walking at vigorous intensity (h)
Women	31.6 (7.7)	6.0 (0.9)	3.9 (1.2)	64.3 (26.1)	10.6 (3.8)	16.8 (1.6)	3.3 (0.4)	1.8 (0.5)	1.4 (0.4)	0.3 (0.2)	0.1 (0.02)
Men	22.9 (3.8)	8.5 (1.1)	2.6 (0.7)	129.9 (41.7)	15.3 (4.8)	17.7 (1.8)	2.6 (0.8)	1.7 (0.9)	1.4 (0.3)	0.3 (0.4)	0.1 (0.02)

Values of lower limb composition, LLEP and MQ averages for left and right legs.

Table 2. Standardised coefficient β and significance level of parameters for generalised linear model predicting muscle quality

Model parameter	B	$p_{parameters}$	p_{Model}	Adjusted R^2
Women				
F	−0.465	0.176	0.118	0.176
F+	−0.647	0.168	0.054	0.341
Total walking	0.287	0.518		
F+	−0.607	0.119	0.124	0.261
Low intensity walking	0.351	0.339		
F+	−0.455	0.279	0.080	0.427
Moderate intensity walking	−0.02	0.959		
F+	−0.436	0.123	0.443	0.053
Vigorous intensity walking	−0.593	0.049		
Men				
F	−0.620	0.018	0.018	0.333
F+	−0.985	0.035	0.040	0.340
Total walking	0.437	0.310		
F+	−0.583	0.151	0.069	0.273
Low intensity walking	−0.047	0.903		
F+	−0.910	0.070	0.020	0.420
Moderate intensity walking	0.457	0.123		
F+	−0.733	0.002	0.03	0.594
Vigorous intensity walking	0.534	0.013		

The grey area highlights the model predicting the largest amount of variance in muscle quality.

mass ($r = -0.734$; $P = 0.003$), LLEP ($r = -0.683$; $P = 0.07$) and MQ ($r = -0.620$; $P = 0.018$).

Table 2 presents the results of the generalised linear model predicting muscle quality from sedentary time fragmentation and different intensities of habitual PA interrupting SB. The model could not predict muscle quality in women. However, sedentary time fragmentation and the total time spent active approached significance ($P = 0.054$). For men, the largest amount of variance (42.0%) was explained by the combination of sedentary fragmentation and time engaged in vigorous walking.

Discussion

Our results show a positive association between sedentary time and lower limb adiposity in older men. Most studies link obesity with a reduced amount of moderate or vigorous PA rather than actual SB [19]. Our results suggest that there is a direct relationship between SB and adiposity in older men. The pattern of accumulation of SB also seems to be important with less fragmented sedentary time associated with higher total body and lower limb adiposity for both men and women, indicating that individuals who break up their sedentary time have lower body fat compared with those who engage in more prolonged periods of sedentary time.

Considering these results we expected less sedentary individuals and those breaking up SB more often to have higher LLEP and MQ. Surprisingly, in men both increased sedentary time and decreased fragmentation of SB were associated with increased LLEP and MQ despite an increase in lower limb fat mass. These results are counter-intuitive but there are three possible explanations. In this high functioning group, who spend on average over an hour a day walking, carrying more body fat associated with longer sedentary time may provide a training stimulus for muscle and hence help to maintain leg power.

The second explanation is that the adoption of different PA strategies to conserve energy [20] may lead to different patterns of interruption of SB. Older adults might spontaneously compensate for an increase in energy expenditure by adopting a less fragmented SB with longer sedentary bouts. It is also possible that this is mediated by the participant's fatiguability or fitness. The greatest variance in muscle quality is explained by a combination of vigorous walking and SB fragmentation for men, hinting that muscle quality is higher if they undertake more frequent, shorter bouts of vigorous walking interspersed with longer, continuous periods of sitting. Finally it is possible that the results reflect adiposity developing in previously strong men who have recently become sedentary.

Our results show an association between a more fragmented SB and lower total body fat. Therefore, it is tempting to advocate a 'do little, but often' exercise prescription strategy to break down SB into shorter bouts. However, simply breaking down sedentary time does not necessarily lead to improved muscle quality which is associated with mobility [21]. This appears to depend on the intensity of the activity interruptions. Vigorous habitual PA appears to be associated with higher muscle quality but may result in spontaneous compensatory behaviour in which an older adult adopts a less fragmented SB which in turn is associated with increased adiposity. The concurrent presence of adiposity and low muscular strength is associated with sarcopenic obesity [22], so vigorous PA might have a more preventative role in males with high percentage body fat. These factors should be considered when devising exercise or PA interventions to prevent sarcopenia and obesity in older adults.

These results should however be interpreted with caution. The activity profile of the sample is comparable with that of other studies in older adults using objective measures [23]. However, the participants of our sample were healthy and high functioning therefore the range of values of body composition, muscle power and muscle quality is relatively narrow. This might explain why our results are different for women as mean and range of leg power in the women is half that of men in our sample. This lack of spread in value of leg power might explain why the effect of SB appears to follow the same trend (see Figure A1 in the Supplementary data available in Age and Ageing online) but the correlation is weaker than in the women. Other characteristics such as medication, functional capacity and amount of ambulatory activity were comparable between genders.

The intensity levels for walking are derived from models which are not specific to older adults our threshold therefore likely to be too conservative.

Key points

- Older adults accumulate sedentary time predominantly in long bouts.
- The pattern of accumulation varies between older adults and is associated with adiposity and muscle quality.
- The fragmentation of sedentary time with different activity intensity is associated with different phenotype.

Supplementary data

Supplementary data mentioned in the text is available to subscribers in *Age and Ageing* online.

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References

1. Owen N, Bauman A, Brown W. Too much sitting: a novel and important predictor of chronic disease risk? Br J Sports Med 2009; 43: 81–3.
2. Hamilton MT, Hamilton DG, Zderic TW. Role of low energy expenditure and sitting in obesity, metabolic syndrome, type 2 diabetes, and cardiovascular disease. Diabetes 2007; 56: 2655–67.
3. Lord S, Chastin SFM, McInnes L, Little L, Briggs P, Rochester L. Exploring patterns of daily physical and sedentary behaviour in community dwelling older adults. Age Ageing 2011; 40: 205–10.
4. Hamilton MT, Hamilton DG, Zderic TW. Exercise physiology versus inactivity physiology: an essential concept for understanding lipoprotein lipase regulation. Exerc Sport Sci Rev 2004; 32: 161–6.
5. Kortebein P, Symons TB, Ferrando A *et al*. Functional impact of 10 days of bed rest in healthy older adults. J Gerontol A Biol Sci Med Sci 2008; 63: 1076–81.
6. Hu FB, Li TY, Colditz GA, Willett WC, Manson JE. Television watching and other sedentary behaviors in relation to risk of obesity and type 2 diabetes mellitus in women. JAMA 2003; 289: 1785–91.
7. Stenholm S, Alley D, Bandinelli S *et al*. The effect of obesity combined with low muscle strength on decline in mobility in older persons: results from the InCHIANTI study. Int J Obes (Lond) 2009; 33: 635–44.
8. Friedman PJ, Campbell AJ, Caradoc-Davies TH. Prospective trial of a new diagnostic criterion for severe wasting malnutrition in the elderly. Age Ageing 1985; 14: 149–54.
9. Nelson ME, Rejeski WJ, Blair SN *et al*. Physical activity and public health in older adults: recommendation from the American College of Sports Medicine and the American Heart Association. Med Sci Sports Exerc 2007; 39: 1435–45.
10. Bassey EJ, Short AH. A new method for measuring power output in a single leg extension: feasibility, reliability and validity. Eur J Appl Physiol Occup Physiol 1990; 60: 385–90.
11. Chastin S, Granat M. Methods for objective measure, quantification and analysis of sedentary behaviour and inactivity. Gait and Posture 2010; 31: 82–6.
12. Healy GN, Dunstan DW, Salmon J *et al*. Breaks in sedentary time: beneficial associations with metabolic risk. Diabetes Care 2008; 31: 661–6.
13. Rolland Y, Lauwers-Cances V, Pahor M, Fillaux J, Grandjean HVellas B. Muscle strength in obese elderly women: effect of recreational physical activity in a cross-sectional study. Am J Clin Nutr 2004; 79: 552–7.
14. Greig C, Young A, Skelton D, Pippet E, Butler F, Mahmud S. Exercise studies with elderly volunteer. Age Ageing 1994; 23: 185–9.
15. Grant PM, Dall PM, Mitchell SL, Granat MH. Activity-monitor accuracy in measuring step number and cadence in community-dwelling older adults. J Aging Phys Act 2008; 16: 201–14.
16. Grant PM, Ryan CG, Tigbe WW, Granat MH. The validation of a novel activity monitor in the measurement of posture and motion during everyday activities. Br J Sports Med 2006; 40: 992–7.
17. Ainsworth BE, Haskell WL, Whitt MC *et al*. Compendium of physical activities: an update of activity codes and MET intensities. Med Sci Sports Exerc 2000; 32: S498–504.
18. Tudor-Locke C, Sisson SB, Collova T, Lee SM, Swan PD. Pedometer-determined step count guidelines for classifying walking intensity in a young ostensibly healthy population. Can J Appl Physiol 2005; 30: 666–76.
19. Kaplan MS, Huguet N, Newsom JT, McFarland BH, Lindsay J. Prevalence and correlates of overweight and obesity among older adults: findings from the Canadian National Population Health Survey. J Gerontol A Biol Sci Med Sci 2003; 58: 1018–30.
20. Schrack JA, Simonsick EM, Ferrucci L. The energetic pathway to mobility loss: an emerging new framework for longitudinal studies on aging. J Am Geriatr Soc 2010; 58 (Suppl. 2): S329–36.
21. Bean JF, Leveille SG, Kiely DK, Bandinelli S, Guralnik JM, Ferrucci L. A comparison of leg power and leg strength within the InCHIANTI study: which influences mobility more? J Gerontol A Biol Sci Med Sci 2003; 58: 728–33.
22. Rolland Y, Czerwinski S, Abellan Van Kan G *et al* Sarcopenia: its assessment, etiology, pathogenesis, consequences and future perspectives. J Nutr Health Aging 2008; 12: 433–50.
23. Nicolai S, Benzinger P, Skelton DA, Aminian K, Becker C, Lindemann U. Day-to-day variability of physical activity of older adults living in the community. J Aging Phys Act 2010; 18: 75–86.

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