Age and Ageing 2011; **40:** 205–210
doi: 10.1093/ageing/afq166
Published electronically 14 January 2011
© The Author 2011. Published by Oxford University Press on behalf of the British Geriatrics Society.
All rights reserved. For Permissions, please email: journals.permissions@oup.com

Exploring patterns of daily physical and sedentary behaviour in community-dwelling older adults

SUE LORD[1], SEBASTIEN FRANCOIS MARTIN CHASTIN[2], LYNN MCINNES[3], LINDA LITTLE[3], PAM BRIGGS[3], LYNN ROCHESTER[1]

[1]Institute for Ageing and Health, Newcastle University, Clinical Ageing Research Unit, Campus for Ageing and Vitality, Newcastle upon Tyne NE4 5PL, UK
[2]Glasgow Caledonian University, Glasgow, UK
[3]Northumbria University, Newcastle, UK

Address correspondence to: L. Rochester. Tel: (+44) 191 248 1291; Fax: (+44) 191 248 1251. Email: lynn.rochester@ncl.ac.uk

Downloaded from https://academic.oup.com/ageing/article/40/2/205/46837 by guest on 20 August 2022

Abstract

Background: recent evidence suggests that the interaction between periods of sedentary and activity behaviour is important for health; providing distinctive information to assessment of activity alone. This study quantified activity and sedentary behaviour in older, community-dwelling adults.
Methods: fifty-six community-dwelling older adults with an average age 79 (SD) years wore an ActivPAL accelerometer for 7 days and were assessed for a range of motor, cognitive and affective characteristics. Seven variables derived from accelerometry considered to represent four characteristics of habitual behaviour (volume, frequency, intensity and variability) were submitted to principal components factor analysis (PCA). Factor scores were retained and used as dependent variables in regression analysis.
Results: three significant orthogonal factors emerged from the PCA, accounting for 80% of the variance in test scores: 'walking behaviour' which accounted for 39% of variance in the model; 'sedentary behaviour' explaining 24.3% of total variance; and 'postural transitions' which accounted for 16.7% of total variance. For the regression analysis, younger age and lower body mass index (BMI) emerged as significant predictors of physical behaviour, explaining 36% of the total variance. For postural transitions, lower BMI was the unique contributor, explaining 15% of total variance. Significant predictors of sedentary behaviours were not identified.
Conclusions: walking, sedentary and transitory behaviours are distinct from each other, and together explain daily function. Further research on a larger sample is indicated to explore the characteristics that explain these behaviours, in particular the interplay between sedentary behaviour and periods of physical activity.

Keywords: *monitoring, ambulatory, non-linear dynamics, aged, exercise, elderly*

Introduction

The protective effect of sustained physical activity over the life span is well recognised, even in older adults who participate in physical activity at a later stage in life [1]. Higher levels of activity are associated with increased survival, independent living and improved quality of life [2] and public health initiatives encourage physical activity even in very old adults to optimise health outcomes. Duration and intensity of physical activity diminishes with age, especially for older women who perform half the number of minutes of moderate and vigorous activity as young women [3].

Daily activity may be monitored over time using wearable, motion-sensing devices such as accelerometers, which record positional change and motion. Different measures of daily activity have been used such as number of steps, minutes of activity, intensity of activity and frequency of postural transitions [4]. Recent research has extended the scope of activity measurement to include parameters that reflect the accumulation and randomness of activity.

Cavanaugh *et al.* [5] developed a 'bouts' metric to quantify the number of activity epochs in a day, and using non-linear, dynamical theory were able to represent random minute-to-minute fluctuations in activity. Variability and randomness measures were shown to be more sensitive than mean parameters of activity (such as daily step count) in a group of adults in their 8th and 9th decade of life compared with younger adults, suggesting a shift with age towards less complex, less physiologically demanding patterns of activity.

We recently extended this work by comparing sedentary behaviour in people with Parkinson's disease (PD) with healthy controls and showed that although total sedentary time was comparable, there was a significant increase in the length of sedentary bouts for people with PD [6]. As an independent risk factor for poor health outcomes and yielding distinctive physiological consequences, sedentary behaviour is more than the converse of activity [7, 8]. Activity and sedentary behaviours are complex, multidimensional entities and difficult to capture in a single measure. Understanding the patterns and drivers of both behaviours may enable a more complete behaviour of daily function to emerge, and inform intervention and measurement approaches.

This study aimed to quantify and describe habitual active and sedentary behaviour in older, community-dwelling adults and to explore the characteristics that contribute to this behaviour. Using factor analysis, we first developed a model of daily function in older adults that considered both these aspects.

Methods

Participants

Participants of the current study also took part in a larger, two-centre longitudinal study of ageing in the UK [9]. Three hundred and eight of the longest serving volunteers (86 males and 222 females) who constitute the 'oldest old' were invited to take part in this aspect of the study. All participants gave informed written consent. Ethical consent for this aspect of the study was granted by Northumbria University School of Psychology and Sports Science Ethics Committe.

Experimental protocol

Participants were assessed on three occasions over a 6-month period for explanatory variables likely to influence daily activity. During the first visit, demographic details, height, weight and self-reported number of illnesses were collected. Gait speed was assessed under single and dual task conditions over a 10 m walk using GaitRITE, a flexible electronic walkway providing an automated means of measuring the spatial and temporal parameters over 366 cm at a sampling rate of 30 Hz [10]. Participants were also measured using the Timed Up and Go (TUG) test [11], the Falls Efficacy Scale International [12], the Community Health Activities Model Programme for Seniors (CHAMPS) questionnaire [13]. For the second assessment participants were visited at home and fitted with an ActivPAL™ (PAL Technologies Ltd, Glasgow, UK) accelerometer which was worn for 7 days. Cognitive status was assessed during the third visit with the Cambridge Neuropsychological Automated Testing Battery (CANTAB) [14], the National Adult Reading Test (NART) [15] and the Mini Mental State Exam [16]. Lastly, participants were sent out the Becks Depression Inventory [17] and the State Trait Anxiety Inventory (STAI; Form Y1, i.e. 'how you feel at the moment') [18] to complete in their own time.

Accelerometer measures

ActivPAL is a small (53 × 35 × 7 mm), lightweight (20 g) uniaxial accelerometer sensor worn on the thigh, with a sampling frequency of 10 Hz. ActivPAL identifies changes in postures from seating and lying to standing or walking, records number of steps and cadence of walking bouts and estimates energy expenditure. The analysis algorithm is described elsewhere in detail and has been validated in different groups [19].

Seven variables were extracted from ActivPAL data to represent characteristics of active and sedentary behaviour: volume, frequency, intensity and pattern (see below).

(1) Volume: This is the total amount of walking time and is computed by summation of all bouts of walking and normalised by expressing it as a percentage of the total recording time.
(2) Frequency: It was represented by the number of sit to stand transitions.
(3) Intensity: It was reported as the total metabolic equivalents (METS).
(4) Pattern: We used two characteristics to describe patterns of activity and sedentary behaviour: (1) *Gini Index (G)* This parameter characterises how total time is accumulated from different bout lengths. Computations of this parameter are described in [7]. It varies between 0 and 1. A high G (close to 1) indicates that long bouts contribute more to the pattern of accumulation. Conversely, a low G indicates that the accumulation is more fragmented. For sedentary time (*Gsed*) a high *Gsed* indicates long periods of rest, for walking (*Gw*) a low *Gw* indicates a very fragmented walking behaviour with a dominance of short walking bouts. (2) *D_1 index (D_1)* provides further depth to the analysis by characterising how diverse the bouts of activity are. Bouts are characterised by their duration and in addition their cadence (for walking bouts). D_1 quantifies how many different type of bouts and how regularly they are used. For example, if two people do 100 bouts of walking a day but Subject 1 $D_1 = 50$ and Subject 2 $D_1 = 10$, Subject 2 has a less diverse pattern of walking with bouts consistent in length and speed that occur at regular intervals and

Downloaded from https://academic.oup.com/ageing/article/40/2/205/46837 by guest on 20 August 2022

does not show flexibility in walking activity by using a temporally diverse array of short, long, slow, fast bouts. These two characteristics may be reflected in different ways. An individual may present with a high *Gsed* and a high D_1 (long periods of rest spaced at irregular intervals) or conversely a high *Gsed* and low D_1 (long periods of rest spaced at regular intervals).

We have reported these variables elsewhere [6, 7] apart from D_1 which was included to extend the scope of analysis for patterns of behaviour (For D_1 calculations please see Supplementary data available in *Age and Ageing* online).

Preliminary data analysis

Factor analysis

Preliminary factor analysis was conducted to identify which parameters or combination of parameters best capture habitual behaviour. Seven variables derived from accelerometry data were submitted to principal components factor analysis (PCA): total time spent walking, number of sit to stand transitions; METS; Gini Index *(G)* for physical and sedentary behaviour and the D_1 index for physical and sedentary behaviour. Varimax rotation was used to derive orthogonal factor scores, with the minimum eigenvalue for extraction set at 1. Factor scores were retained and used as dependent variables in regression analysis.

Data analysis

Prediction of sedentary and activity behaviours

Univariate and bivariate analysis were used to describe the data. Pearson's product correlation coefficients were calculated to explore associations between personal characteristics (excluding gait variables) and dependent variables. Variables with correlation coefficients >0.20 were entered into multiple regression models. Collinearity diagnostics (eigenvalues and condition indices) were inspected to test for multicollinearity and the Durbin–Watson statistic was used to identify autocorrelation (values <1 and >3 were problematic). All data met assumptions for regression analysis and we aimed to recruit a minimum of five participants per variable for the PCA [20]. The alpha level was set at 0.05. SPSS for Windows (V 17) was used to analyse the data.

Results

Sample characteristics

Fifty-six older adults with an average age of 79.9 years who were living independently in the community took part in the study. Thirty-two participants (57.1%) were married, and the cohort reported on average fewer than two illnesses. Body mass index (BMI) was slightly lower than reported age-matched values [21]. Average MMSE scores were high [16], and CANTAB scores were within age-matched percentile values [14]. Scores for depression and anxiety were low and below the threshold for clinical diagnosis [17, 18]. Twenty-seven (54%) people reported at least one fall in the previous 6 months, with FESI scores indicating a moderate level of concern of falling [12]. Compared with age-matched normative data, participants walked at 'very fast' speeds under single task conditions [22], which reduced to a 'moderately fast' gait speed when walking under dual task conditions (walking and perform a secondary, cognitive task), indicating the preservation of gait automaticity. Total number of steps and CHAMPS scores indicate a moderately active group (Table 1).

Principal component analysis

A PCA of activity and sedentary parameter scores yielded three significant orthogonal factors (walking behaviour, sedentary behaviour, postural transitions) that accounted for a total of 80% of the variance in test scores. Item loadings were >0.50 with negligible item cross-loadings (Table 2).

Multiple linear regression analyses: prediction of sedentary and activity behaviours

On the basis of the results of bivariate analysis, Factor 1 (walking behaviour) and Factor 3 (postural transitions) were taken as dependent variables in multiple regression analyses. There were no were no significant correlations between Factor 2 (sedentary behaviour) and explanatory characteristics, and regression analysis was not conducted for this factor. Younger age and lower BMI emerged as significant predictors of walking behaviour explaining 36% of the total variance. For postural transitions, lower BMI was the unique contributor, explaining 15% of total variance (Table 3).

Discussion

Participants in this study, who were living independently in the community towards the end of their 8th decade, represented a group of people who were ageing successfully. Activity behaviours were comparable to earlier reports of pedometer-based estimates of 6,000–8,500 steps per day for healthy older adults and within recommended physical activity guidelines [23]. Caloric expenditure over the week for all listed physical activities, measured by the CHAMPS questionnaire, was higher than the mean value of 2,420 reported by Stewart [13] who assessed 249 adults with a mean age of 74 years.

Frequency of sedentary time bouts was similar to earlier reports indicating that older adults engage in up to twice as many sedentary bouts per day than young adults, with differences most marked in the evening [3]. Initiation of physical activity may be more challenging for older adults

Downloaded from https://academic.oup.com/ageing/article/40/2/205/46837 by guest on 20 August 2022

Table 1. Participant characteristics

	Mean	SD	Range	*n*
Personal characteristics				
Men/Women, 26/30				
Married/single, 32/24				
Age (years)	78.9	4.9	70–88	56
MMSE	28.1	2.0	21—30	55
Cornell Medical Index	1.7	1.5	0–6	52
BMI	24.8	3.6	17.1–35.6	50
Becks Depression Inventory (>21 represents depression)	6.8	4.9	0–27	55
State-Trait Anxiety Inventory (STAI Form Y1)	29.7	9.6	20–62	54
Cognitive characteristics				
National Adult Reading Test (NART)_Predicted IQ	120.2	4.3	105–126	55
CANTAB I: Pattern Recognition Memory (mean correct latency) (ms) (50th percentile = 2525.60)	2516.81	658.0	1543.40–4161.14	53
CANTAB 2: Choice Reaction Time (latency of response) (ms) (50th percentile = 387.0)	403.7	48.6	319.6–540.6	53
CANTAB 3: Intra-Extra Dimensional Set Shift (total number of errors adjusted) (50th percentile = 28.0)	27.4	26.5	7–176	53
Physical characteristics				
Falls Efficacy Scale International (FES-I) (range: 16–64)	22.3	6.3	16–49	55
TUG (s) (Age-matched norms for 8th decade 9 s)	11	4.9	6.6–38.7	56
Community Health Activities Model Programme for Seniors (CHAMPS) (caloric expenditure per week)	3217.19	2607.32	370–14070	48
Gait speed single task (10 m Timed Walk) (cm/s)	108.5	24.9	35.3–157.3	56
Gait speed dual task (10 m Timed Walk) (cm/s)	89.4	30.3	21.1–170.3	56
Activity measures				
Total daily upright time (min)	250.9	103.7	94.1–666.5	56
Total daily sedentary time (min)	747.3	116.5	340.2–971.6	56
Number of steps (average per day)	6343.2	2807.1	864.8–15847.1	56
Volume: Total time walking (average minutes per day)	80.9	31.4	12.2–173.6	56
Frequency: Sit to stand transitions (average number per day)	39.0	10.7	10.0–63.4	56
Intensity: Energy expenditure (total METS per day)	25.6	1.1	23.1–29.6	56
Pattern[a]: Accumulation of sedentary bouts): Gini Index (sedentary) (*Gsed*)	.836	.04	0.68–0.91	56
Temporal diversity of sedentary bouts D_1sedentary (D_1sed)	15.2	5.3	6.67–40.45	56
Accumulation of walking bouts Gini Index (walking) (*Gw*)	.60	.06	0.46–0.73	56
Temporal diversity of walking bouts D_1walking (D_1w)	14.8	1.7	10.7–18.1	56

[a]Bout parameters are calculated from weekly data.

Table 2. Results of the PCA

Domain	Characteristic[a]	Factor 1: Walking behaviour	Factor 2: Sedentary behaviour	Factor 3: Postural transitions
	Variance (%)	39.0	24.3	16.7
Volume	Time spent walking	**0.918**	−0.156	0.195
Frequency	Sit to stand	0.023	0.017	**0.940**
Intensity	METS	**0.934**	−0.307	0.084
Pattern	*Gsed*	0.004	**−0.891**[b]	−0.269
	D_1sed	−0.001	**0.882**	−0.292
	Gw	**0.829**	0.174	−0.059
	D_1w	**0.577**	0.185	−0.285

[a]Values in bold indicate loading correlations above 0.50.
[b]Negative number indicates that lower values of *G* (short bouts of rest) impact on sedentary behaviour. This variable loads with a positive D_1sed, indicating the impact of regularly timed rest.

Table 3. Summary of regression analyses predicting walking pattern and postural transitions

Condition	Predictors	β	*P*	R^2	*P*
Physical behaviour	Age	−0.29	0.04	0.36	0.01
	BMI	−0.32	0.03		
	Number of meds	−18	0.19		
	Falls Efficacy Scale International (FESI)	−0.05	0.75		
	National Adult Reading Test (NART)	0.09	0.43		
	Timed up and go (TUG)	−0.02	0.88		
	Pattern Recognition	−0.10	0.43		
Postural transitions	BMI	−0.37	0.01	0.15	0.04
	Falls Efficacy Scale International (FESI)	−0.13	0.45		
	TUG	0.11	0.51		

especially later in the day; alternatively longer periods of rest may be required in-between task completion. Furthermore, the pattern of rest to activity appears more orderly and predictable, possibly to reduce system stress [5].

Factors that emerged from the factor analysis yielded minimal cross-loadings, suggesting three distinctive dimensions. Intuitively walking behaviour and sedentary behaviour represent opposite ends of the same construct, suggesting redundancy. However, this cannot be assumed. Sedentary behaviour yields complementary but different information and both are required for a full representation. For example, an individual may exhibit long bursts

Downloaded from https://academic.oup.com/ageing/article/40/2/205/46837 by guest on 20 August 2022

of sedentary behaviour but walk at an intense pace and cover long distances when active, or present with frequent bursts of sedentary behaviour and limited energy expenditure when on the move. Recent research suggests that inactivity produces physiological responses that are qualitatively different from exercise responses, raising the potential for major clinical and public health concerns [24]. Similarly it appears that the diversity of walking bouts plays a role in the activity behaviour, and that encouraging a wider array of ambulatory tasks might be beneficial. Our results corroborate recent reports [25] that describe more complex step count pattern in active than sedentary older adults. Scheduling and timing may become key components of exercise programmes, along with duration, intensity and type of exercise. Knowledge of the distribution and intensity of patterns of activity and inactivity will help quantify thresholds for minimal levels of activity, and refine exercise prescription to yield optimal gains.

The factor structure explained an acceptable amount of variance in the multi-variate data set, indicating that the model is an accurate representation of activity and inactivity. However, one-fifth of total variance was not accounted for, suggesting there may also be features, perhaps unmeasured, that were not included in the analysis.

Consistent with previous work highlighting the importance of non-motor characteristics to effective mobility in home and community environments in older adults with and without pathology [26, 27] we anticipated that a diverse set of variables would be required to predict volume and patterns of activity and inactivity. However, despite including a wide range of demographic, social, cognitive and mobility characteristics in the regression analysis, we did not convincingly identify predictors or explain a substantial amount of the variance in each factor. Age emerged as a significant predictor of walking pattern, in agreement with earlier research [28]. The significant (negative) contribution of BMI to walking behaviour and postural transitions supports a recent multivariate analysis of 415 older adults that identified a significant association between race, gender, BMI, income, education and retirement status with number of steps over 7 days [29]. The FESI correlated significantly with walking behaviour and postural transitions, and was included as an explanatory variable in both regression analyses. Although it was not retained in either model, its presence supports earlier reports that show the importance of self-efficacy to gait and to outdoor mobility [26]. Similarly, Rantakokko [30] reported that 65% of 725 community-dwelling adults aged 75–81 were fearful of moving outdoors; a fear associated with a 4-fold adjusted risk of developing difficulties in walking 0.5 km.

Research to date [8, 25] suggests that the drivers of walking behaviour and sedentary behaviour in older adults are quite different to those that predict walking, functional mobility and falls status in older adults, and there is a need to select characteristics that have not previously been considered. The notion of 'free will' may be important, along with motivation, personal health beliefs, confidence and environmental constraints.

Limitations of this study included the small sample size, which may have led to under-powered analysis. The high functioning status of the cohort and limited dispersion of scores for some variables may also have influenced results, with insufficient heterogeneity in the results and thresholds of impairment not reached.

Overall, the results from this study provide further support for the use of accelerometry to measure habitual functioning in older adults but points to the complexity of the data and patterns that require further development of analytical techniques. Focusing on one aspect or parameter is insufficient to understand behaviours that lead to successful ageing. Examination of walking, sedentary and transitory behaviours provides a more complete picture. Further research on a larger sample is indicated to explore the characteristics that explain these behaviours.

Key points

- Walking behaviour, sedentary behaviour and postural transitions provide a composite picture of daily activity in adults reaching their 9th decade.
- BMI is a significant predictor of walking behaviour and postural transitions.
- Measurement of the patterns (variability) of daily activity augments volume, frequency and intensity outcomes.
- Sedentary data provides complimentary but distinctive information to physical activity data.

Supplementary data

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

Conflicts of interest

None declared.

Funding

This work was supported by the New Dynamics of Ageing initiative, a multidisciplinary research programme supported by AHRC, BBSRC, EPSRC, ESRC and MRC: Grant number RES – 352–25 – 0023. We acknowledge the support of the UK NIHR Biomedical Research Centre for Ageing and Age-related disease award to the Newcastle upon Tyne Hospitals NHS Foundation Trust.

Downloaded from https://academic.oup.com/ageing/article/40/2/205/46837 by guest on 20 August 2022

References

1. Stessman J, Hammerman-Rozenburg R, Cohen A, Ein-Mor E, Jacobs JM. Physical activity, function and longevity among the very old. Arch Intern Med 2009; 169: 1476–83.
2. Hirvensalo M, Rantanen T, Heikkinen E. Mobility difficulties and physical activity as predictors of mortality and loss of independence in the community-living older population. J Am Geriatr Soc 2000; 48: 493–8.
3. Davis MG, Fox KR. Physical activity patterns assessed by accelerometry in older people. Eur J Appl Physiol 2007; 100: 581–9.
4. Copeland JL, Eslinger DW. Acceleremoter assessment of physical activity in active, healthy older adults. J Aging Phys Act 2009; 17: 17–30.
5. Cavanaugh JT, Coleman KL, Gaines JM, Laing L, Morey MC. Using step activity monitoring to characterise ambulatory activity in community-dwelling older adults. J Am Geriatr Soc 2007; 55: 120–4.
6. Chastin SFM, Baker K, Jones D, Burn D, Granat M, Rochester L. The pattern of habitual sedentary behaviour is different in advanced Parkinson's disease. Mov Disord 2010; 25: 214–20.
7. Chastin SFM, Granat MH. Methods for objective measure, quantification and analysis of sedentary behaviour and inactivity. Gait Posture 2010; 31: 82–6.
8. Hamilton MT, Healy GN, Dunstan DW, Zderic TW, Owen N. Too little exercise and too much sitting: Inactivity physiology and the need for new recommendations on sedentary behaviour. Curr Cardiovasc Rep 2008; 2: 292–8.
9. Rabbitt PMA, McInnes L, Diggle P *et al* The University of Manchester longitudinal study of cognition in normal healthy old age, 1983 through 2003. Neuropsychol Dev Cogn B Aging Neuropsychol Cogn 2004; 11: 245–79.
10. Cutlip RC, Mancinelli C, Huber F, DiPasquale J. Evaluation of an instrumented walkway for measurement of the kinematic parameters of gait. Gait Posture 2000; 12: 134–8.
11. Podsiadlo D, Richardson S. The timed 'Up & Go': a test of basic functional mobility for frail elderly persons. J Am Geriatr Soc 1991; 39: 142–8.
12. Yardley L, Beyer N, Hauer K, Kempen G, Piot-Ziegler C, Todd C. Development and initial validation of the Falls Efficacy Scale-International (FES-I). Age Ageing 2005; 34: 614–9.
13. Stewart AL, Mills KM, King AC, Haskell WL, Gillis D, Ritter PL. CHAMPS Physical Activity Questionnaire for older adults: outcomes for interventions. Med Sci Sports Exerc 2001; 33: 1126–41.
14. Cambridge-Cognition-Limited. CANTABeclipse™: Test Administration Guide Manual, 2nd edition. Cambridge, UK. 2005.
15. Nelson HE. National Adult Reading Test (NART) Manual. Windsor, UK: NFER-Nelson Publishing Co., 1982.
16. Huppert FA, Cabeli ST, Matthews FE. Brief cognitive assessment in a UK population sample—distributional properties and the relationship between the MMSE and an extended mental state examination. BMC Geriatr 2005; 4: 5–7.
17. Beck AT, Guthy D, Steer R, Ball RA. Internal consistencies of the original and revised Beck Depression Inventory. J Clin Psychol 1884; 40: 1365–7.
18. Spielberger CD. Manual for the State-Trait Anxiety Inventory. Palo Alto, CA: Consulting Psychologist Press Inc., 1983.
19. 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.
20. Costello AB, Osborne J. Best practices in exploratory factor analysis: four recommendations for getting the most from your analysis. Pract Assess Res Eval 2005; 10: 1–9.
21. Smithers G, Finch S, Doyle W *et al* The National Diet and Nutrition Survey: people aged 65 years and over. Nutr Food Sci 1998; 3: 133–7.
22. Craik RL, Dutterer L. Spatial and temporal characteristics of foot fall patterns. In: Craik R, Oatis C, eds. Gait Analysis: Theory and Application. St Louis: Mosby, 1995.
23. Hughes SL, Seymour RB, Campbell RT, Whitelaw N, Bazzarre T. Best-practice physical activity programs for older adults: Findings from the National Impact Study. Am J Public Health 2009; 99: 362–8.
24. 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.
25. Cavanaugh JT, Kochi N, Stergiou N. Nonlinear analysis of ambulatory activity patterns in community-dwelling older adults. J Gerontol: Med Sci 2010; 65A: 197–203.
26. Lord SE, Weatherall M, Rochester L. Community ambulation in older adults: which internal characteristics are important? Arch Phys Med Rehabil 2010; 91: 378–83.
27. Holtzer R, Verghese J, Xue X, Lipton RB. Cognitive processes related to gait velocity: results from the Einstein ageing study. Neuropsychology. 2006; 2: 215–23.
28. Ayabe M, Yahiro T, Yoshioka M, Higuchi H, Higaki Y, Tanaka H. Objectively measured age-related changes in the intensity and distribution of daily physical activity in adults. J Aging Phys Act 2009; 6: 419–25.
29. Strath SJ, Swartz AM, Cashin SE. Ambulatory physical activity behaviours of older adults. J Aging Phys Act 2009; 17: 46–56.
30. Rantakoko M, Manty M, Iwarsson S, Tormakangas T, Leinonen R, Heikkinen E *et al* Fear of moving outdoors and development of outdoor walking difficulty in older people. J Am Geriatr Soc 2009; 57: 634–40.

Received 20 April 2010; accepted in revised form 27 September 2010

Downloaded from https://academic.oup.com/ageing/article/40/2/205/46837 by guest on 20 August 2022