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ABSTRACT

Background: Physical activity (PA) has many health benefits but may increase falls risk among older adults. We study how objectively measured habitual daily PA is related to falls, exploring the modifying effect of mobility limitations and the mediating role of fitness and lower limb strength. **Methods:** 1655/3137(53%) of surviving participants (men aged 71-91 years) in an ongoing UK population-based cohort study wore an Actigraph GT3x accelerometer over the hip for one week in 2010-12 to measure PA (exposure) and reported demographic and health status including mobility limitations. One year later, 825 men reported falls history (outcome). **Results**: 700/825 men had ≥600 minutes/day of accelerometer wear on ≥3 days. 19%(n=128) reported falls one year later. Associations between PA and falls differed by presence of mobility limitations. Among 66%(n=471) men without mobility limitations, number of falls increased incrementally; Incidence Rate Ratio (IRR) 1.50 (95%CI 1.10,2.03) per 30 minutes of moderate to vigorous PA (MVPA), adjusted for falls risk factors. Step count was not related to number of falls below 9000 steps/day, but ≥9000 steps/day, the IRR was 1.59 (95%CI 1.16,2.18) per additional 1000 steps/day. Among 33%(n=229) men with mobility limitations, falls risk declined with increasing activity; IRR 0.80 (95%CI 0.70, 0.91) per 1000 steps/day and IRR 0.61 (95%CI 0.42, 0.89) per 30 minutes of MVPA, and IRR 1.22 (1.07,1.40) for each additional 30 minutes of sedentary behaviour of 600 or more minutes/day. **Conclusions:** Interventions to promote MVPA in older men should incorporate falls prevention strategies and among adults with mobility limitations, trials should investigate whether increasing MVPA levels can reduce falls risks.

Key words: older adults, physical activity, accelerometer, falls, mobility limitations, cohort study

INTRODUCTION

Physical activity (PA) reduces the risk of many important causes of morbidity and mortality in older adults and helps to maintain good mobility and functioning(8). Older adults have the lowest PA levels of any age group(1, 2, 10, 12, 38) but physical activity promotion must also consider potential adverse consequences, which include falls and associated injuries. One quarter to one-third of over 65 year olds living in the community fall each year(4, 37) and with increasing longevity worldwide, falls prevention are a global public health challenge(42).

Epidemiologic studies have identified many risk factors for falling in older people, the most consistent being abnormal gait and poor balance(16). Trials demonstrate that these physiological deficits can be improved with exercise programs including a sufficient dose (>50 hours) of moderate-to high balance challenging activities(33). Yet, in practice, very few older people habitually engage in these planned and structured exercise programs. Instead, older adults derive their daily PA mostly from unstructured lifestyle PA, which includes functional activities such as walking for transport or recreation, household chores and gardening, caring or volunteering work(14). Understanding how habitual activity relates to falls has important public health implications for physical activity recommendations.

Prospective studies of older adults have investigated how self-reported physical activity (from questionnaires) is related to falls but findings are inconsistent. Some report that only high levels of moderate to vigorous-intensity PA reduce risk of falls (22, 30, 36), and conversely others report that high PA levels increase risk of falls(7), whilst others report that both high and low PA levels raise risk of falls(29), resulting in the hypothesis that there may be a u-shaped association where falls risk is elevated both among older adults who are very active (perhaps due to increased exposure to environmental risks) and also very inactive (perhaps due to poorer muscle strength, co-ordination and balance). The relationship between PA and falls may differ according to functional abilities and age: in the oldest old (>80 years) those with lower PA levels were at increased risk of falls, whereas among younger old (<80 years)(6) and those with better functional ability (stronger leg strength)(7) those with higher PA levels had increased falls risk.

Inconsistencies in the findings about the shape of the dose-response relationship between PA and falls may partly be due to limitations of prior studies, including how PA was measured (e.g, examining just one PA domain, such as leisure), using self-reported PA (resulting in misclassification biases) and also inadequate control for confounders(18). Some of these limitations can be overcome using objective measures of PA. We therefore use data from hip-worn accelerometers to investigate how objectively measured PA is prospectively related to onset of falls, to our knowledge this is the first study to do so. Given the importance of understanding dose-response relationships for formulating PA guidelines, we investigate (i) the shape of the associations between total amount and intensity of PA and occurrence of falls (ii) whether associations between PA levels and risk of falls differ by age and mobility status, and (iii) the role of selected mediators. We study these questions using a sample of community dwelling older adults who were part of an on-going cohort study including the oldest old, in order to better understand these associations in a representative sample of community dwelling adults.

METHODS

Study population: The British Regional Heart Study is an ongoing prospective cohort. 7735 free-living men were recruited from a single Primary care centre in each of 24 British towns in 1978-80 (age 40-59 years) and were followed up repeatedly, in 1998-2000 participants (aged 60-79 years) completed a questionnaire, providing information on habitual PA (77% response rate)(40). For the purposes of this paper, the baseline time point is in 2010-2012 when 3137 surviving community-dwelling men were invited to attend a physical examination, complete questionnaires and to participate in a study of objectively measured PA. One year later, men were sent a questionnaire where they reported falls history. The National Research Ethics Service (NRES) Committee for London provided ethical approval. Participants provided informed written consent to the investigation, which was performed in accordance with the Declaration of Helsinki.

Measures

Baseline accelerometer data: In 2010-12, participants were asked to wear the GT3x accelerometer (Actigraph, Pensacola, Florida) over the right hip on an elasticated belt for 7 days, during waking hours, removing it for swimming or bathing. Data collected were processed using standard methods; raw data collected from movements registering on the vertical axis were integrated into 60 second periods (epochs). Non-wear time was identified and excluded using a commonly used and freely available computer package "Physical Activity"(9). Valid wear days were defined as ≥600 minutes wear time, and participants with 3 or more valid days were included in analyses, a conventional requirement to estimate usual PA level(13, 19, 20). The number of minutes per day spent in PA of different intensity levels was categorised using standard count-based intensity threshold values of counts per minute developed for older adults(11): <100 for sedentary behaviour (SB) (<1.5 metabolic equivalents [MET]),100-1040 for light activity (1.5-3 MET) and ≥1040 for MVPA,(>3 MET). The following variables were used as exposures; steps per day (to indicate total volume of activity), minutes per day of sedentary, light and MVPA in 1 minute bouts and minutes per day of MVPA accumulated in 10 minute bouts were used to indicate intensity of activity. For each PA variable, the mean value from all valid days over the week was averaged to obtain an average per valid day. Coefficients were scaled to 1000 steps and 30 minutes of sedentary, light and MVPA for ease of interpretation in regression models.

Baseline covariate data: In 2010-12, men completed questionnaires including the following questions: "At the present time are you afraid that you may fall over?"[very fearful, somewhat fearful, not fearful]; responses to a similar single question about fear of falling correlate with validated scales including the Falls Efficacy Scale and the Survey of Activities and Fear of Falling in the elderly scale(25). "Do you have any difficulties getting about outdoors?"[none vs slight, moderate, severe and unable to do]. Men were identified as having vision problems if they reported suffering from macular degeneration, glaucoma or cataract. The number of chronic conditions that men suffered from the following list was recorded "heart attack, heart failure, angina, other heart trouble, diabetes, stroke, osteoporosis, claudication, Parkinson's disease and arthritis affecting knees hips or feet". Men completed the 4-item Geriatric Depression score and those scoring >=2 were classified as depressed. Men reported if they lived alone or with others. They completed the Duke Activity Status Index (DASI) fitness scale (a series of questions about ability to do increasingly strenuous activities) from which a fitness score was calculated that estimates peak $V0_2$(23). Nurses administered a sit to stand test, recording the number of times within a timed 30 second period that men could sit down on a chair and stand up again without using their hands.

Habitual PA level was self-reported in a questionnaire completed 10 years earlier (in 1998-2000); a six point PA score based on self-reported usual walking, cycling, sporting and recreational activities, which is validated against forced expiratory volume in one second (FEV_1) and heart rate(41). Social position was based on longest held occupation reported in previous surveys (classified as manual or non-manual).

Outcome data: Men were followed-up (in 2011-13), one year after the accelerometer survey, and completed a questionnaire. Men were asked "Have you had a fall in the past 12 months?"[yes/no] and "if yes, how many falls have you had in the past 12 months?" This question has high specificity and acceptable sensitivity for detecting falls in the previous 12 months(17).

Statistical methods: Summary measures of baseline demographic and social variables were calculated according to history of falls in the past 12 months. Linear regression models tested differences in continuous variables across the three groups of non-fallers, single fallers and recurrent fallers, differences in categorical variables were tested using Chi Squared tests. The same approach was taken to compare men with and without mobility limitations.

The number of falls was highly positively skewed (mean 0.4, variance 3.3), indicating over-dispersed data. Therefore negative binomial models were used: these are comparable to a Poisson regression in terms of mean structure, but have an extra parameter to model the over-dispersion (3). The incidence rate ratio (IRR) for the total number of falls over the year (range 0 to 40) was estimated for each PA measure. Interactions between each PA variable and (i) mobility limitation (no difficulty vs some, moderate or more difficulty getting about outdoors) and (ii) age (under or over 80 years) were tested fitting an interaction term and testing model fit with a likelihood ratio test (LRT). When significant interactions were detected, analyses were stratified.

We investigated the hypothesis that the association between PA and number of falls may be non-linear using negative binomial generalised additive models (GAMs). The GAM is a non-parametric model which permits non-linear relationships to be modelled flexibly without specifying the non-linear functional form. This modelling approach is an extension of the Generalised Linear Model (GLM), where parametric regression terms are replaced by non-parametric functions such as scatter plot smoothers (21). We used GAM to approximate the synergistic contribution of a number of covariates, such as PA levels and participants characteristics, to the response variable (number of falls after 1 year) without making any *a priori* assumptions about the underlying processes or trends, which may be highly complex. Analyses were performed using the "mgcv" package in R (version 2.15.3, Copyright © 2013, The R Foundation for Statistical Computing)(21, 31, 43). The best fit GAM model was chosen on the basis of the Akaike Information Criteria (AIC) and by using the lowest number of degrees of freedom if AIC score was approximately the same. The predictions from the GAM were plotted, restricted to the central 95% of the data, because data were very sparse at the extremes of the distribution (although all data were retained in regression models).

Next we assessed the role of mediators between each PA variable and onset of falls. For linear associations, negative binomial models with PA variables fitted as linear variables were used. For non-linear associations, we used stata function "mkspline" to model the associations between

PA and risk of falls, specifying one knot, at a point selected based on the shape of the association seen in the GAM. The spline model provides an estimate of the association before and after the turning point of the function (knot). To evaluate the role of potential mediators, Model 1 was adjusted for confounders; age, region of residence, season of accelerometer wear, accelerometer wear time (minutes/day). Model 2 additionally included history of falls at baseline. Model 3 additionally included risk factors for falls; number of chronic diseases, number of medications, depression, vision problems (presence of glaucoma, macular degeneration or cataract), and living alone. Model 4 included the DASI as a measure of fitness and Model 5 included the sit to stand test as an indicator of lower limb muscle strength. Analyses were conducted in Stata version 13(35). Sensitivity analyses (i) used a higher cut-point of 1952cpm which was calibrated to identify MVPA in middle aged (rather than older) adults and is widely used(15), and (ii) compared single fallers to non-fallers and recurrent fallers to non-fallers, to evaluate the importance of recurrent falls.

RESULTS

3137 surviving men were invited to attend a clinic based rescreen in 2010-2012, of which 1655 (52%) agreed to attend and to wear an accelerometer, of these 1566/1655 (95%) returned an accelerometer. The sample was restricted to 1455/1655 (88%) community dwelling men (living at home, ie excluding residents of care homes) who did not report being confined to a chair, with >=600 minutes accelerometer wear time on 3-7 days, with a mean age of 78.3 years (range 71-93). Among these men, 940/1455 (65%) provided follow-up data 10-14 months later, of whom 700/940 (74%) had complete covariate data (see Table, Supplemental Digital Content 1, Flow chart for participants in study at baseline and follow-up, http://links.lww.com/MSS/A522). Comparing the 700 participants retained in the analysis to men who completed 2010-12 questionnaires but were not included in the analysis, those retained were more active (62% compared to 52% self-reported light or more PA 10 years earlier ($p<0.001$) and less likely to have fallen once or more at baseline in 2010-12 (16% compared to 19%, $p=0.03$).

Participant characteristics: Among the 700 ambulatory men, at the one year follow-up 9%(n=61) of men reported one fall in the previous 12 months and 10%(n=67) had recurrent falls (range 2-40, only 2 men fell more than 10 times). Among fallers, the median number of falls was 2 (IQR1,3) per man. Characteristics of the analysis sample are reported in Table 1, both overall and stratified according to falls at one year follow-up. Single fallers had more similar characteristics to non-fallers. However, compared to non-fallers and single fallers, the recurrent fallers were older, more often from manual social class, had more chronic diseases, higher prevalence of fear of falling, vision problems and depression and were more likely to live alone. Recurrent fallers had lower scores on the sit to stand test (weaker lower limb strength) and lower DASI fitness score. They had lower activity levels (total counts, steps, MVPA and less sedentary behaviour) than single and non-fallers.

The characteristics of 66% (n=471) of men who reported that they had no problems getting about outdoors and 33% (n=229) of men who reported slight to severe mobility problems outdoors are in Table 1. Men with no mobility difficulties had higher scores on the sit to stand test (better lower limb strength) and higher DASI fitness scores. They took more steps per day (5730 vs 3435, $p<0.01$) and spent more time in light and MVPA and less time in sedentary behaviour than men with mobility difficulties. Men reporting mobility limitations also reported more difficulties with activities of daily living (see Table, Supplemental Digital 2, Characteristics of men with and without mobility limitations, http://links.lww.com/MSS/A523).

Associations between PA and number of falls in men with and without mobility limitations: Associations between baseline PA levels (for step counts, sedentary, light and MVPA) and number of falls differed by presence of mobility limitations, likelihood ratio test for interaction $p<0.05$ for all PA types. However, there was no evidence of interaction with age group (<80 compared to $\geq$ 80 years), likelihood ratio test for interaction $p>0.05$ in each case. Models were therefore stratified by mobility limitations.

The shape of the associations between each PA measure and number of falls was investigated using GAM models; Figures 1 and 2 present the predicted estimate and 95% confidence interval (CI) from the GAM models stratified by mobility limitations and adjusted for falls risk factors (baseline number of falls, age, BMI, number of chronic diseases, number of medications, depression, vision problems, living alone) and measurement-related confounders (wear time, region and season). In men with no mobility limitations, higher activity levels (step counts and minutes of MVPA as 1 minute or 10 minute bouts, Figure 1a,1c,1e) were associated with increased risk of more falls, whereas the trend of higher number of falls at lower levels of SB was not statistically significant (Figure 2c). The opposite pattern was seen for men with mobility limitations; lower activity levels (step counts, 1 or 10-minute bouts of MVPA; Figure 1b,1d,1f) and more time in SB were related to higher risk of more falls (Figure 2d). There was a trend that light PA was associated with falls risk in the same direction as MVPA, but more weakly, although this did not reach statistical significance in either mobility limitations group (Figure 2a,b). A visual examination of the plots suggested that there was little suggestion of non-linear associations with the exception of the association between step count and number of falls in the men without mobility limitations; men with highest step counts had raised risks of more falls. At around 9000 steps per day the lower 95% CI crosses the risk of 1 fall (indicating that the risk increases significantly) and risk increased rapidly thereafter; at around 11,000 steps per day the risk had doubled to two falls. However, only 12% of participants took over 9000 steps/day. The other potential non-linear association was between sedentary time and number of falls among men with mobility limitations: risk of falls began to rise after >=600 minutes/day in sedentary time, this level of SB was reached by 72% of participants. In these two cases, we then investigated whether a categorical variable of high step count >=9000 steps/day compared to less, and >=600 minutes/day sedentary compared to less were associated with falls.

Table 2 presents the continuous associations indicating the strength of association between each PA measure and number of falls. Models were sequentially adjusted for measurement-related confounders (Model 1) and falls history (Model 2). Further adjustments for falls risk factors (Model 3) and potential mediators (Model 4 and 5), changed the strength of associations very little. Therefore Model 3 (adjusted for falls risk factors) is discussed here. Among men with no mobility problems, there was no evidence that light activity or SB were related to falls (Table 2). However, each 30 minutes of MVPA (accumulated in one minute bouts) was associated with IRR for falls of 1.50 (95%CI 1.10, 2.03), Table 2, Model 3. MVPA accumulated in bouts of 10 minutes or more was even more strongly related to number of falls (IRR 1.97[1.20,3.22]) and in sensitivity analyses using a higher cut-point of 1952cpm to define MVPA, the IRR was 1.98 (1.28,3.08). Further adjustments for mediators DASI fitness scale (Model 4) and sit to stand test (Model 5) changed the estimates very little. Higher step count was associated with raised risk of more falls, but given that the GAM suggested a non-linear association, negative binomial regression models using a spline with a knot at 9000 steps/day are presented in Table 3. There was no significant association between steps per day and falls risk for men taking <9000 steps per day 1.03 (95%CI 0.85, 1.24) whereas the IRR for falls was 1.59 (95%CI 1.16, 2.18), per 1000 steps, starting at 9000 steps/day (Table 3, Model 3). Step count was related to MVPA level: men taking >=9000 steps/day had geometric mean 106 (IQR 88-128) minutes/day of MVPA >1040cpm, compared to mean 38 (IQR 22-56) minutes/day in men taking less than 9000 steps/day.

The associations between PA and number of falls were in the opposite direction among men with self-reported mobility problems. Higher step counts and MVPA levels were associated with reduced risks of falls and higher sedentary time with raised risks of falls. The IRR for number of falls was 0.80 (95%CI 0.70, 0.91) per 1000 steps/day (Table 2, Model 3); 0.87 (0.78, 098) for each 30 minutes of light activity; 0.61 (0.42, 0.89) for each 30 minutes in MVPA accumulated in one minute bouts and 0.14 (0.04, 0.46) for MVPA accumulated in bouts of 10 minutes or more. In sensitivity analyses using the higher cut-point of >=1952cpm for MVPA the IRR was 0.29 (0.12, 0.69). Further adjustments for DASI fitness scale (Model 4) and sit to stand test (Model 5) slightly attenuated the associations between steps and long bouts of MVPA with number of falls. The associations between both light PA and short bouts of MVPA with number of falls were fully attenuated on adjustment for DASI and sit to stand. Overall, higher levels of SB were related to higher IRR for falls: 1.14 (1.03, 1.25) per 30 minutes of SB per day (Table 2), however given that the GAM identified a non-linear relationship, Table 3 presents a spline regression model using a knot at 600 minutes/day SB. No significant association between SB and falls risk 0.98 (95%CI 0.79, 1.21) was observed for men with <600 minutes/day SB, but for more sedentary men the IRR for falls was 1.22 (95%CI 1.07, 1.40), per 30 minutes SB starting at 600 minutes/day (Table 3, Model 3). The raised risk was totally mediated on adjustment for DASI score (Table 3, Model 4), but not sit to stand test (Table 3, Model 5).

Sensitivity analyses comparing single fallers to non-fallers and recurrent fallers to non-fallers suggest that the associations were not strongly influenced by individuals with many falls.

DISCUSSION

In this study of free-living older men, the associations between PA levels and subsequent risk of falls depended on mobility status. Among men without mobility problems (who were a more active group), there was an incremental increase in number of falls (IRR 1.5) for each 30 minute increase in MVPA. There was a steeper increase in the number of falls at the highest step counts (>=9000 steps/day, a level achieved by only the most active 10% of the study sample), but lower step counts were not related to falls risk. Conversely, among men with mobility limitations, number of falls increased incrementally with lower step counts, lower levels of MVPA and a nonlinear association between falls risk and SB was observed; more than 10 hours per day of SB was associated with steeper increases in number of falls.

How our findings fit with other studies: Based on existing literature(7), we hypothesised that the association between PA and falls may differ by mobility limitations and found this to be the case. PA could either increase and decrease falls risk, dependent on functional status, which may explain prior findings of a U-shaped relation between PA and falls risk(18, 29). One unifying explanation for these opposite relationships may be that highly active individuals are performing beyond their abilities(7). Men with mobility limitations may be more aware of their physical capacities, or exercise under practitioners' supervision or guidance due to their limitations, hence the activity workload is proportional to their abilities and provides the expected benefits to prevent falls. In contrast, men without mobility limitations may expose themselves to greater risk, either being too fatigued to initiate corrective responses to prevent falls, or by engaging in activities that do not suit their age and abilities. It is also possible that people with mobility limitations may do different types of activity compared to those without limitations (accelerometer data is informative about duration intensity and frequency but not type of activity) and if the activities have inherently different risk of injury, for example if walking had a lower risk than gardening, this could account for the different associations between activity level and risk of falls in the groups defined by mobility limitations.

Men with mobility limitations: The men with mobility limitations were less active than the men without mobility limitations. Among men with mobility limitations, higher step counts, light PA and MVPA were associated with lower number of falls. The number of falls declined by around 15% for every 30 minutes of light activity and by 40% for MVPA in bouts lasting one minute, and the reduction was even greater considering MVPA in bouts of 10 minutes or more. However for adults with difficulties getting around outdoors, doing 30 minutes per day of MVPA in bouts of ten minutes or more would be especially hard as this level of activity is unlikely to occur indoors. The associations between light PA and MVPA and number of falls were not much mediated by falls history (except for MVPA levels) but were mediated in part by lower fitness levels and weaker lower limb strength. The men with mobility limitations had lower baseline levels of fitness and weaker lower limb strength than the men without limitations, so may have more potential to gain from PA. Indeed lower limb weakness is reported to be an important predictor of falls(27), and increasing muscle strength may prevent falls in part due to better central and peripheral neural function which may in turn improve balance(32). However aerobic fitness is not considered an important fitness dimension for fall prevention(33). We observed that higher levels of SB were associated with increased number of falls, particularly above 10 hours of SB per day. The effect is in the same direction as prior observational studies of self-reported SB(36), although most studies just reported SB as low PA level, rather than asking about sedentary activities. To our knowledge, the only other study investigating objectively measured SB in relation to falls used an arm worn monitor rather than a hip worn monitor. Whilst results were not statistically significant, that study found that the associations were in the same directions as in our study; among men aged over 80 years, higher levels of SB were associated with higher risks of falls(6). A note of caution may be needed in interpreting findings in men with mobility limitations, in that the degree of inactivity may in fact be a sensitive indicator of the severity of disabling disease, and that people with such a condition (who will also have limited strength) will be more likely to fall. We addressed this issue in the analyses, by adjusting for presence of a wide range of chronic conditions.

Men without mobility limitations: Among men without mobility limitations, very high levels of activity were associated with higher risks of falls, potentially due to men stretching themselves beyond their abilities and exposing themselves to greater fatigue and hence risk of falls. The finding about higher step count increasing risk of falls fits with a meta-analysis which showed that walking attenuated the beneficial effect of exercise programmes on falls prevention, and high amounts of walking (>3 hours/week) but not total MVPA level increased the incidence of fractures (28, 33). Similarly, in the MrOS cohort the strongest men in the highest quintiles of households' activities were at the highest risk of falling(7). We did not see clear evidence that physical capabilities were important mediators between PA and falls risk in the men without mobility limitations, perhaps because they already had higher baseline levels of lower limb strength and aerobic fitness.

We know from other prospective studies that PA is important for prevention of development of mobility limitations(39) which may in turn then contribute to risk of falls. Whilst we did not aim to investigate whether higher activity levels were associated with reductions in the prevalence of mobility limitations in this study, we did find that 65 % of men who reported mobility limitations at baseline also reported mobility limitations one year later.

Strengths and limitations

The study sample is a prospective study drawn from a community dwelling cohort of older men panning a twenty year age range, rather than a special “at risk” clinical population, which permitted us to investigate interactions between PA and both age and presence of mobility problems on falls risk. Our sample size is large compared to previously published studies of objectively measured PA in older adults and our study also benefits from extensive data on covariates which are risk factors for falls or mediators. Uniquely, the study benefits from using objectively measured PA at baseline, to our knowledge this is the first study to investigate how objectively measured sedentary behaviour using a hip worn sensor is prospectively related to risk of falls. To date only one prospective study has investigated how objectively measured physical activity is related to risk of falls(6) using the arm mounted Sensewear accelerometer but the comparability of Sensewear data with the most commonly used and validated hip-mounted accelerometer is unknown. Whilst accelerometers have the benefit of measuring intensity of PA, the type of activity that generated the MVPA was not recorded, hence we are unable to determine if the association with MVPA is type- or volume-dependent. This is important because of the different effects of MVPA on falls risk for those with or without mobility limitations; if people with mobility limitation are aware of their risk and therefore derived the MVPA from safer activities in a safe setting, then the protective effect could be due to the type of activity rather than the volume. Our response rate was 52% and which was higher than other accelerometer studies of older adults: 21% (13), 43%(19) and in the Health Survey for England 37% women and 48% men over 75 years had 4 or more days with valid data(12). However after restrictions our analytic sample was smaller, which could introduce some selection bias. Whilst it is likely that physically inactive and immobile men are underrepresented, this will not necessarily affect the observed associations between PA and falls risk. Our study is limited to men, who based on existing literature, would be expected to have lower rates of falls and higher levels of PA, particularly MVPA, compared to women(24). Therefore our results may not be generalizable to older women. Prevalence of falls was a little lower in our study than in other studies(26) which may be partly explained by the male sample, or because of selection bias as the healthier individuals were more likely to participate and be followed up, (we found that the men with accelerometer data who were followed up has higher self reported PA levels and lower prevalence of falls compared to the men who only completed the baseline questionnaire in 2010-12). Our assessment of falls at follow-up is a retrospective question about the past year, so not a truly prospective assessment, which may result in under-reporting of falls compared to studies which use prospective monthly fall diaries; any non-differential under-reporting should bias the results are towards the null, which may mean that our estimates of associations are conservative. A review of studies investigating the effect of the duration of the recall period for falls reporting found that recall of falls over the previous year was specific (specificity 91–95%) although it was less sensitive (sensitivity 80–89%) than the gold standard of prospective data collection using fall calendars or postcards(17).

Policy implications

PA has a wide range of benefits for many health outcomes and is encouraged by public health guidelines. One of the few potential side effects is accident and injury, and older adults are at the highest risk of falls which can have serious health and social consequences, both for the faller and for society in terms of subsequent long term rehabilitation and care. Programmes to encourage older adults with no mobility limitations to be physically active may need to incorporate falls prevention strategies to avoid excess falls, particularly among the most active individuals. Older adults mostly have low activity levels and our data suggest that moderate increases in PA (especially light PA and overall step count) would have a very small impact small on falls risk. However, if policies focus on increasing MVPA (which is needed to achieve national PA guidelines) then the need to include falls prevention measures alongside PA intervention becomes more critical. To date the most effective falls prevention programmes (Otago, FAME etc(5, 34)) incorporate balance-challenge activities and this may be an important aspect of PA which is not fully addressed by encouraging walking. Additionally, there may be a role for awareness and educational strategies for falls prevention in older adults that encourage individuals to perform within reasonable activity level. Future interventions could investigate whether programmes to encourage more PA and spend less time in sedentary behaviours may help reduce risk of falls in adults who report mobility limitations outdoors.

We stratified our sample using a simple one item self-report of mobility problems outdoors, a question that could easily be used in primary care practice to screen for mobility problems. The results of the question were highly related to reports of problems with activities of daily living, so has content validity. This question could therefore be used as a screening question to identify older adults who may have increased risk of falls if they are highly active and have no mobility problems, or conversely have reduced risk of falls if they are highly active but suffer mobility limitations.

CONCLUSIONS

PA has multiple health benefits in older adults who are at high risk of diseases that can be ameliorated by PA. Activities which reduce risk of falls, such as balance challenge activities (which current UK PA guidelines recommend should be done twice a week), should be encouraged in highly active older adults who have no mobility impairments in order to reduce risks of falls. Our findings can help shape public health recommendations for older adults without mobility limitations. However among older adults with mobility limitations who have low levels of activity, our results suggest that future trials could investigate whether interventions increasing time spent in ambulation and reducing sedentary time may prevent falls, and if increasing moderate to vigorous activities which raise heart rate and induce breathlessness might be particularly effective at reducing risk of falls. Although we have described the associations between different intensities of activities and number of falls, we do not know exactly what type of activities were carried out, so further research is needed to understand relationships between types of activities (eg walking, gardening, bowls) and falls.

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References

1. Ashe MC, Miller WC, Eng JJ, and Noreau L. Older adults, chronic disease and leisure-time physical activity. *Gerontology* 2009;55:64-72.
2. Baptista F, Santos DA, Silva AM, Mota J, Santos R, Vale S, Ferreira JP, Raimundo AM, Moreira H, and Sardinha LB. Prevalence of the Portuguese population attaining sufficient physical activity. *Med. Sci. Sports Exerc.* 2012;44(3):466-73.
3. Cameron AC and Trivedi PK. Basic count regression. In: *Regression analysis of count data*. Cambridge: Cambridge University Press; 2013. p. 69-109.
4. Campbell AJ, Borrie MJ, Spears GF, Jackson SL, Brown JS, and Fitzgerald JL. Circumstances and consequences of falls experienced by a community population 70 years and over during a prospective study. *Age Ageing* 1990;19(2):136-41.
5. Campbell AJ, Robertson MC, Gardner MM, Norton RN, Tilyard MW, and Buchner DM. Randomised controlled trial of a general practice programme of home based exercise to prevent falls in elderly women. *BMJ* 1997;315(7115):1065-9.
6. Cauley JA, Harrison SL, Cawthon PM, Ensrud KE, Danielson ME, Orwoll E, and Mackey DC. Objective Measures of Physical Activity, Fractures and Falls: The Osteoporotic Fractures in Men Study. *Journal of the American Geriatrics Society* 2013;61(7):1080-8.
7. Chan BK, Marshall LM, Winters KM, Faulkner KA, Schwartz AV, and Orwoll ES. Incident fall risk and physical activity and physical performance among older men: the Osteoporotic Fractures in Men Study. *Am J Epidemiol* 2007;165(6):696-703.
8. Chodzko-Zajko WJ, Proctor DN, Fiatarone Singh MA, Minson CT, Nigg CR, Salem GJ, and Skinner JS. American College of Sports Medicine position stand. Exercise and physical activity for older adults. *Med. Sci. Sports Exerc.* 2009;41(7):1510-30.

9. Choi L, Liu Z, Matthews C, and Buchowski MS. Physical Activity: Process Physical Activity Accelerometer Data. 2011.Computer Program

10. Colley RC, Garriguet D, Janssen I, Craig CL, Clarke J, and Tremblay MS. Physical activity of Canadian adults: accelerometer results from the 2007 to 2009 Canadian Health Measures Survey. *Health Rep.* 2011;22(1):7-14.

11. Copeland JL and Esliger DW. Accelerometer assessment of physical activity in active, healthy older adults. *J. Aging Phys. Act.* 2009;17(1):17-30.

12. Craig R, Mindell J, and Hirani V. *Health Survey for England 2008. Physical Activity and Fitness. Summary of Key findings*. London: The Health and Social Care Information Centre; 2009. p. 5-9

13. Davis MG, Fox KR, Hillsdon M, Sharp DJ, Coulson JC, and Thompson JL. Objectively measured physical activity in a diverse sample of older urban UK adults. *Med. Sci. Sports Exerc.* 2011;43(4):647-54.

14. DiPietro L. Physical Activity in Aging: Changes in Patterns and Their Relationship to Health and Function. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences* 2001;56(suppl 2):13-22.

15. Freedson PS, Melanson E, and Sirard J. Calibration of the Computer Science and Applications, Inc. accelerometer. *Med. Sci. Sports Exerc.* 1998;30(5):777-81.

16. Ganz DA, Bao Y, Shekelle PG, and Rubenstein LZ. Will my patient fall? *JAMA* 2007;297(1):77-86.

17. Ganz DA, Higashi T, and Rubenstein LZ. Monitoring falls in cohort studies of community-dwelling older people: effect of the recall interval. *J. Am. Geriatr. Soc.* 2005;53(12):2190-4.

18. Gregg EW, Pereira MA, and Caspersen CJ. Physical activity, falls, and fractures among older adults: a review of the epidemiologic evidence. *J. Am. Geriatr. Soc.* 2000;48(8):883-93.

19. Harris TJ, Owen CG, Victor CR, Adams R, and Cook DG. What factors are associated with physical activity in older people, assessed objectively by accelerometry? *Br J Sports Med* 2009;43(6):442-50.

20. Hart TL, Swartz AM, Cashin SE, and Strath SJ. How many days of monitoring predict physical activity and sedentary behaviour in older adults? *Int. J Behav. Nutr. Phys. Act.* 2011;8:62.

21. Hastie TJ and Tibshirani RJ. *Generalized Additive Models*. Boca Raton: Chapman & Hall; 1990

22. Heesch KC, Byles JE, and Brown WJ. Prospective association between physical activity and falls in community-dwelling older women. *J Epidemiol Community Health* 2008;62(5):421-6.

23. Hlatky MA, Boineau RE, Higginbotham MB, Lee KL, Mark DB, Califf RM, Cobb FR, and Pryor DB. A brief self-administered questionnaire to determine functional capacity (the Duke Activity Status Index). *Am J Cardiol.* 1989;64(10):651-4.

24. Jefferis BJ, Sartini C, Lee IM, Choi M, Amuzu A, Gutierrez C, Casas JP, Ash S, Lennon L, Wannamethee SG, and Whincup PH. Adherence to physical activity guidelines in older adults, using objectively measured physical activity in a population-based study. *BMC Public Health* 2014;14(1):382.

25. Lachman ME, Howland J, Tennstedt S, Jette A, Assmann S, and Peterson EW. Fear of falling and activity restriction: the survey of activities and fear of falling in the elderly (SAFE). *J Gerontol. B Psychol. Sci. Soc. Sci.* 1998;53(1):43-50.
26. Masud T and Morris RO. Epidemiology of falls. *Age Ageing* 2001;30:3-7.
27. Moreland JD, Richardson JA, Goldsmith CH, and Clase CM. Muscle weakness and falls in older adults: A systematic review and meta-analysis. *Journal of the American Geriatrics Society* 2004;52(7):1121-9.
28. Nikander R, Gagnon C, Dunstan DW, Magliano DJ, Ebeling PR, Lu ZX, Zimmet PZ, Shaw JE, and Daly RM. Frequent walking, but not total physical activity, is associated with increased fracture incidence: a 5-year follow-up of an Australian population-based prospective study (AusDiab). *J Bone Miner. Res* 2011;26(7):1638-47.
29. O'Loughlin JL, Robitaille Y, Boivin JF, and Suissa S. Incidence of and Risk Factors for Falls and Injurious Falls among the Community-dwelling Elderly. *Am. J. Epidemiol.* 1993;137(3):342-54.
30. Peeters GM, van Schoor NM, Pluijm SM, Deeg DJ, and Lips P. Is there a U-shaped association between physical activity and falling in older persons? *Osteoporos. Int* 2010;21(7):1189-95.
31. R core team. R: A Language and Environment for Statistical Computing. 2013.Computer Program
32. Sherrington C and Henschke N. Why does exercise reduce falls in older people? Unrecognised contributions to motor control and cognition? *Br J Sports Med* 2013;47(12):730-1.

33. Sherrington C, Whitney JC, Lord SR, Herbert RD, Cumming RG, and Close JC. Effective exercise for the prevention of falls: a systematic review and meta-analysis. *J Am Geriatr. Soc.* 2008;56(12):2234-43.

34. Skelton D, Dinan S, Campbell M, and Rutherford O. Tailored group exercise (Falls Management Exercise -- FaME) reduces falls in community-dwelling older frequent fallers (an RCT). *Age Ageing* 2005;34(6):636-9.

35. StataCorp. Stata Statistical Software: Release 13. 2013.Computer Program

36. Thibaud M, Bloch F, Tournoux-Facon C, Breque C, Rigaud AS, Dugue B, and Kemoun G. Impact of physical activity and sedentary behaviour on fall risks in older people: a systematic review and meta-analysis of observational studies. *European Review of Aging and Physical Activity* 2012;9(1):5-15.

37. Tinetti ME, Speechley M, and Ginter SF. Risk Factors for Falls among Elderly Persons Living in the Community. *New England Journal of Medicine* 1988;319(26):1701-7.

38. Troiano RP, Berrigan D, Dodd KW, Masse LC, Tilert T, and McDowell M. Physical activity in the United States measured by accelerometer. *Med Sci Sports Exerc.* 2008;40(1):181-8.

39. Visser M, Simonsick EM, Colbert LH, Brach J, Rubin SM, Kritchevsky SB, Newman AB, and Harris TB. Type and intensity of activity and risk of mobility limitation: the mediating role of muscle parameters. *J Am Geriatr. Soc* 2005;53(5):762-70.

40. Walker M, Whincup PH, and Shaper AG. The British Regional Heart Study 1975-2004. *International Journal of Epidemiology* 2004;33(6):1185-92.

41. Wannamethee SG, Lowe GD, Whincup PH, Rumley A, Walker M, and Lennon L. Physical activity and hemostatic and inflammatory variables in elderly men. *Circulation* 2002;105(15):1785-90.

42. WHO. WHO Global Report on Falls Prevention in Older Age. 2007; 47 pp.

43. Wood SN. GAMs with GCV/AIC/REML Smoothness Estimation and GAMMs by PQL. 2011;first.Computer Program http://cran.r-project.org/web/packages/mgcv/, accessed January 2014

Figure Captions

Figure. 1 Relationships between steps per day and daily minutes of moderate to vigorous physical activity and number of falls, stratified by mobility limitations[1]

[1]no mobility limitations vs. slight/moderate/severe mobility limitations. For each PA level the smoothed function from GAM, 95% CI (dotted lines), and p-values are reported. Each model is adjusted for wear time, age, region, season, number of falls at baseline, living alone, BMI, number of chronic diseases, depression, vision problems and use of medications.

Figure. 2 Relationships between daily minutes of light physical activity and sedentary behaviour and number of falls, stratified by mobility limitations[1]

[1]no mobility limitations vs. slight/moderate/severe mobility limitations. For each PA level the smoothed function from GAM, 95% CI (dotted lines), and p-values are reported. Each model is adjusted for wear time, age, region, season, number of falls at baseline, living alone, BMI, number of chronic diseases, depression, vision problems and use of medications.

Supplemental Digital Content

Supplemental Digital Content Table 1. Flow chart for participants in study at baseline and follow-up

Supplemental Digital Content Table 2. Characteristics of men with and without mobility limitations

Figure 1

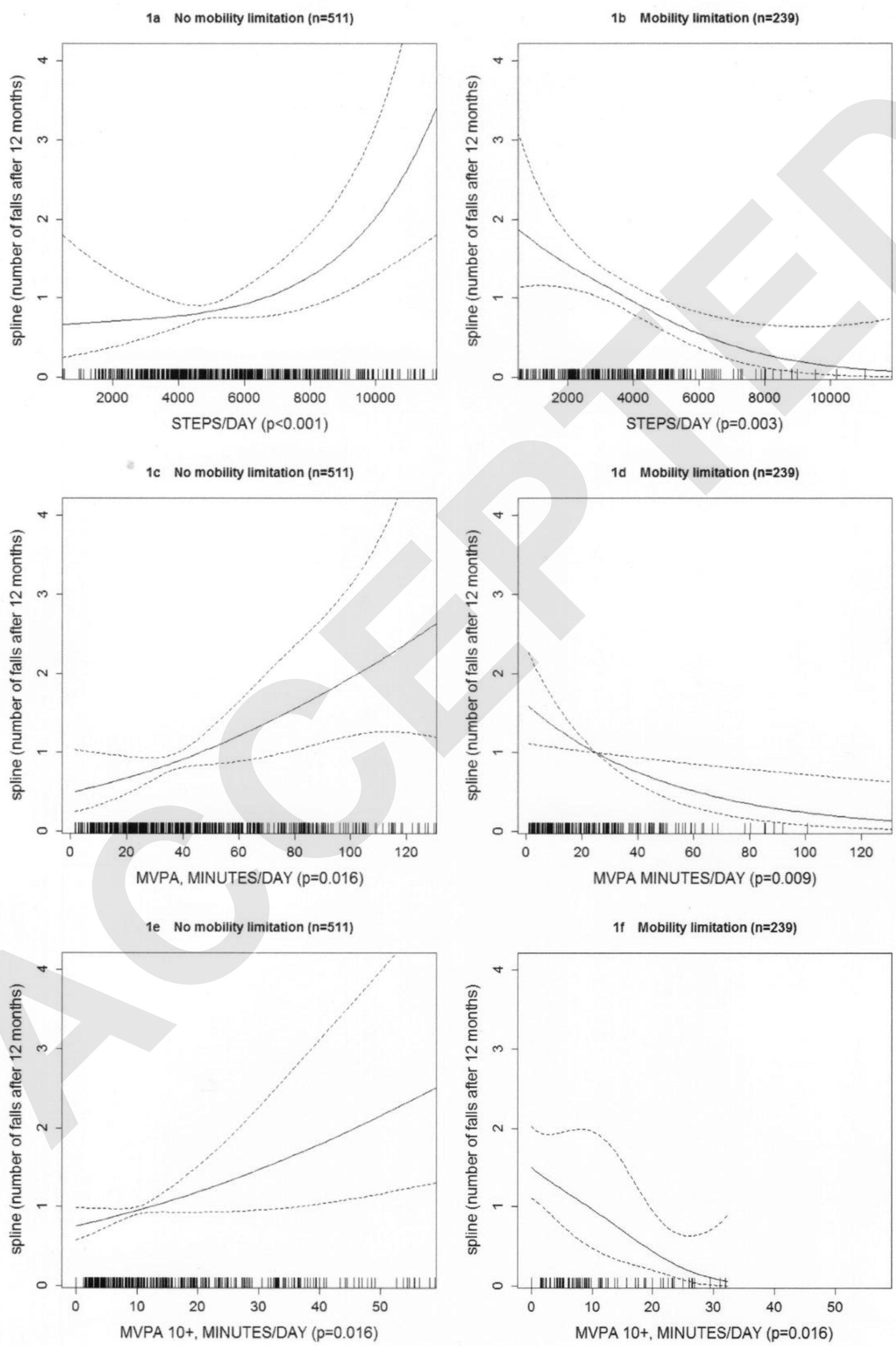
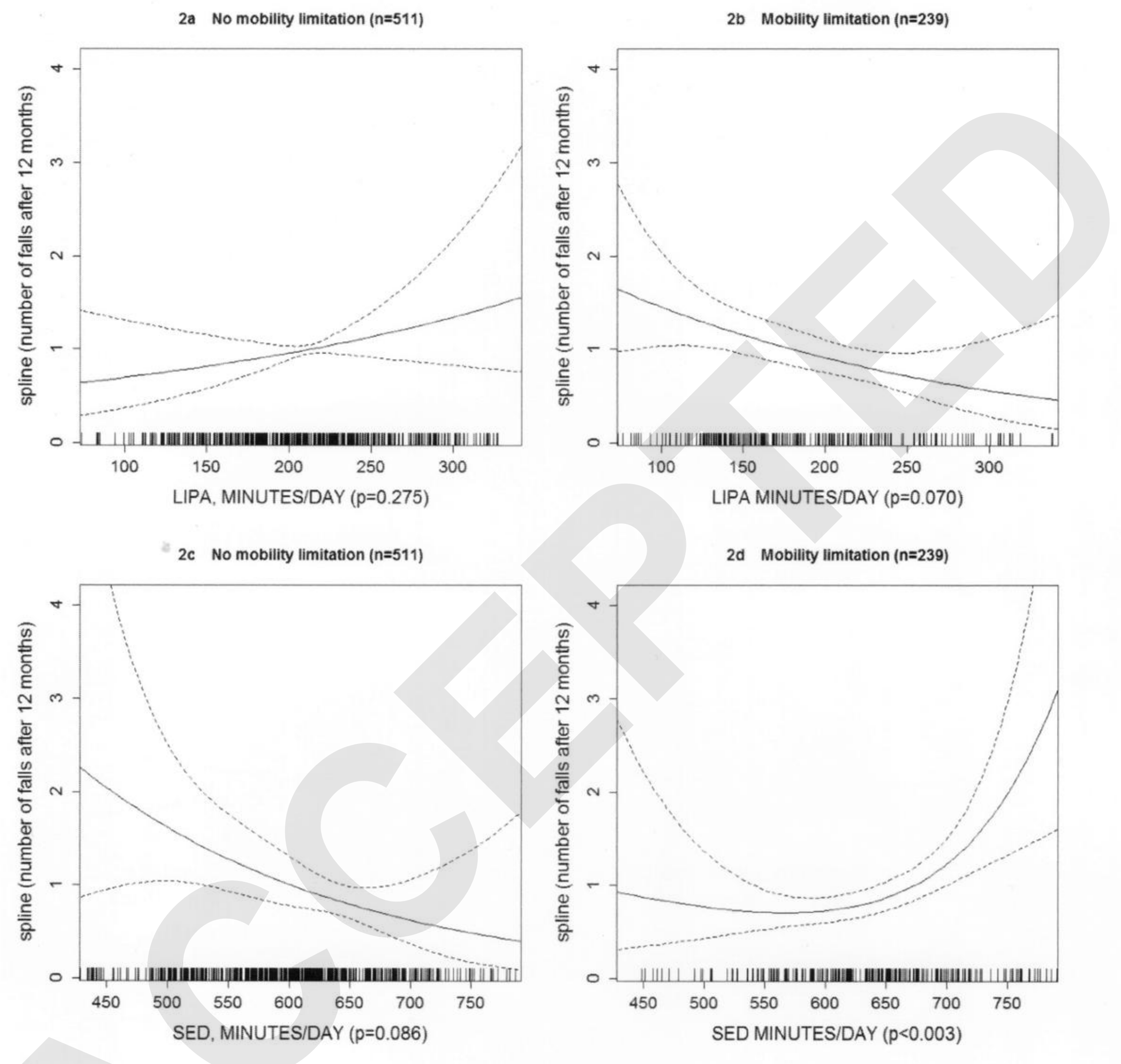

1a No mobility limitation (n=511)
spline (number of falls after 12 months)
STEPS/DAY (p<0.001)
1b Mobility limitation (n=239)
STEPS/DAY (p=0.003)
1c No mobility limitation (n=511)
MVPA, MINUTES/DAY (p=0.016)
1d Mobility limitation (n=239)
MVPA MINUTES/DAY (p=0.009)
1e No mobility limitation (n=511)
MVPA 10+, MINUTES/DAY (p=0.016)
1f Mobility limitation (n=239)
MVPA 10+, MINUTES/DAY (p=0.016)

Figure 2



2a No mobility limitation (n=511)
spline (number of falls after 12 months)
LIPA, MINUTES/DAY (p=0.275)
2b Mobility limitation (n=239)
spline (number of falls after 12 months)
LIPA MINUTES/DAY (p=0.070)
2c No mobility limitation (n=511)
spline (number of falls after 12 months)
SED, MINUTES/DAY (p=0.086)
2d Mobility limitation (n=239)
spline (number of falls after 12 months)
SED MINUTES/DAY (p<0.003)

Table 1. Baseline characteristics of 700 men who reported falls history (left) at 1-year follow-up and baseline mobility limitations (right). Descriptive statistics are reported as %(n) or mean (SD).

	No fall in past 12 months	1 fall in past 12 months	>1 fall in past 12 months	p value [1]		No mobility limitations [2]	With mobility limitations [2]	p-value [1]	Total (n=700)
%(n)	81.7 (572)	8.7 (61)	9.6 (67)			67.3(471)	33.7(229)		100.0(700)
Age, years (mean, SD)	77.7(4.3)	79.5(4.9)	79.3(5.4)	0.022		77.5(4.1)	79.3(5.0)	<0.001	78.0(4.5)
Region, %(n)				0.501				0.848	
South	30.6(175)	26.2(16)	23.9(16)			30.6(144)	27.5(63)		29.6(207)
Midlands	18.7(107)	16.4(10)	14.9(10)			17.6(83)	19.2(44)		18.1(127)
North	42(240)	42.6(26)	47.8(32)			42(198)	43.7(100)		42.6(298)
Scotland	8.7(50)	14.8(9)	13.4(9)			9.8(46)	9.6(22)		9.7(68)
Manual social class, %(n)	48.3(255)	41.4(24)	61.1(33)	0.099		46.8(204)	52.9(108)	0.147	48.8(312)
None or occasional physical activity 10 years earlier, %(n)	21.5(114)	35.7(20)	32.7(18)	0.015		18.1(79)	35.6(73)	<0.001	23.7(152)
Very & somewhat fearful of falling, %(n)	7.3(31)	33.3(17)	52.5(32)	<0.001		3.6(12)	33.8(68)	<0.001	14.9(80)
No mobility limitations outdoors, %(n)	74.5(426)	50.8(31)	20.9(14)	<0.001		-	-		67.3(471)
No falls in the past 12 months - reported at baseline, %(n)	-	-	-			91.0(413)	69.9(146)	<0.001	81.7(572)
>=2 medications, %(n)	79.4(454)	82.0(50)	82.1(55)	0.794		74.1(349)	91.7(210)	<0.001	84.3(559)
No chronic diseases, %(n)	51.2(293)	44.3(27)	25.4(17)	<0.001		55.2(260)	33.6(77)	<0.001	48.1(337)
No major vision problems, %(n)	70.1(401)	50.8(31)	58.2(39)	0.015		70.9(334)	59.8(137)	0.013	67.3(471)
Geriatric Depression Score, (>=2, depressed) %(n)	16.1(92)	18.0(11)	53.7(36)	<0.001		13(61)	34.1(78)	<0.001	19.9(139)

Living alone at home, %(n)	19.4(111)	16.4(10)	35.8(24)	0.002		18.7(88)	24.9(57)	0.056	20.7(145)
Sit to stand test, lowest quartile, %(n)	25.9(150)	14.7(5)	11.3(8)	<0.001		28.8(135)	12.9(28)	<0.001	23.8(163)
DASI fitness score, mean (SD)	41.0(13.8)	37.0(13.8)	25.8(14.2)	<0.001		45.6(11.1)	26.1(12.1)	<0.001	39.2(14.6)
PA levels/day									
Counts/min, mean (SD) [3]	201(106)	185(138)	137(101)	<0.001		222(110)	135(82)	<0.001	194(110)
Steps, mean (SD) [3]	5213(2630)	4628(3258)	3434(2506)	<0.001		5734(2687)	3464(2106)	<0.001	4992(2727)
MVPA (minutes/day), >1040 counts/min, mean (SD) [3]	43(32)	37(36)	23(24)	<0.001		49(32)	25(24)	<0.001	41(32)
LIGHT (minutes/day), 100-1040 counts/min, mean (SD) [3]	206(62)	187(66)	176(64)	0.002		212(60)	179(65)	<0.001	201(64)
Sedentary (minutes/day), <100 counts/min, mean (SD) [3]	611(80)	629(90)	632(86)	0.044		601(80)	641(80)	<0.001	614(82)
Wear time, mean (SD) [3]	860(66)	854(70)	831(69)	0.004		862(67)	845(66)	0.001	857(70)
Number of valid days, mean (SD)	6.7(0.8)	6.7(0.7)	6.4(1.1)	0.018		6.8(0.7)	6.6(0.8)	0.016	6.7(0.8)

[1] p-values from ANOVA (continuous variable) and chi-squared test (categorical variables)

[2] mobility limitations defined from self-report as “no difficulty” compared to “some, moderate and severe difficulty” getting around outdoors.

[3] Daily average PA levels are calculated over a valid week (>=3 days with >=600 minutes of wear time on each day)

Table 2. Associations [Incidence rate ratio (95%CI)] between baseline physical activity and onset of falls, n=700 men.

	No mobility problems (n=471)[1]	Any mobility problems (n=229)[1]
Steps, per day (1000s)		
Model 1	**1.17(1.02,1.33)**	**0.80(0.68,0.94)**
Model 2	**1.19(1.06,1.34)**	**0.81(0.71,0.92)**
Model 3	**1.19(1.06,1.34)**	**0.80(0.70,0.91)**
Model 4	**1.20(1.07,1.35)**	**0.85(0.74,0.99)**
Model 5	**1.20(1.06,1.35)**	**0.84(0.72,0.97)**
MVPA in bouts >1 minute, per day (30 minutes)		
Model 1	1.31(0.93,1.84)	**0.61(0.39,0.93)**
Model 2	**1.46(1.08,1.97)**	**0.65(0.45,0.94)**
Model 3	**1.50(1.10,2.03)**	**0.61(0.42,0.89)**
Model 4	**1.51(1.11,2.04)**	0.75(0.51,1.11)
Model 5	**1.50(1.10,2.04)**	0.70(0.48,1.04)
MVPA in bouts >10 minutes, per day (30 minutes)		
Model 1	1.73(0.96,3.12)	**0.13(0.03,0.48)**

Model 2	**1.95(1.19,3.19)**	**0.15(0.05,0.51)**
Model 3	**1.97(1.20,3.22)**	**0.14(0.04,0.46)**
Model 4	**1.96(1.20,3.22)**	**0.20(0.06,0.64)**
Model 5	**1.99(1.20,3.29)**	**0.21(0.07,0.68)**
Light activity, per day (30 minutes)		
Model 1	1.08(0.89,1.33)	0.89(0.78,1.01)
Model 2	1.06(0.89,1.27)	**0.86(0.77,0.96)**
Model 3	1.05(0.88,1.26)	**0.87(0.78,0.98)**
Model 4	1.05(0.88,1.26)	0.93(0.83,1.06)
Model 5	1.04(0.87,1.25)	0.90(0.79,1.01)
Sedentary time, per day (30 minutes)		
Model 1	0.89(0.76,1.05)	**1.13(1.01,1.26)**
Model 2	0.88(0.77,1.02)	**1.14(1.04,1.26)**
Model 3	0.89(0.77,1.03)	**1.14(1.03,1.25)**
Model 4	0.88(0.77,1.02)	1.07(0.97,1.19)
Model 5	0.89(0.77,1.03)	**1.11(1.00,1.23)**

[1]mobility limitations defined from self-report as “no difficulty” compared to “some, moderate and severe difficulty” getting around outdoors.

Model 1 = age + region of residence + accelerometer wear time + season of accelerometer wear

Model 2= model 1+ falls history

Model 3= model 2 + number of chronic diseases, number of medications, depression score, vision problems, living alone

Model 4= model 3+ DASI (fitness scale).

Model 5= model 3+ Sit to stand test.

Table 3. Associations [Incidence rate ratio (95%CI)][1] between baseline physical activity level and onset of falls (i)steps/day and falls in 471 men with no mobility limitations and (ii) sedentary minutes/day and falls in 229 men with mobility limitations

Men with no mobility limitation (n=471)[2]		
Steps, per day (1000s)	<9000 steps	>=9000 steps
Model 1	1.00 (0.82,1.23)	1.65 (1.11,2.46)
Model 2	1.01 (0.84,1.21)	1.65 (1.19,2.30)
Model 3	1.03 (0.85,1.24)	1.59 (1.16,2.18)
Model 4	1.03 (0.85,1.25)	1.58 (1.15,2.17)
Model 5	1.02 (0.85,1.24)	1.60 (1.17,2.20)
Men with mobility limitation (n=229)[2]		
Sedentary time, per day (30 minutes)	<600 minutes/day	>=600 minutes/day
Model 1	0.97 (0.74,1.27)	1.22 (1.03,1.44)
Model 2	0.99 (0.79,1.24)	1.22 (1.07,1.40)
Model 3	0.98 (0.79,1.21)	1.22 (1.07,1.40)
Model 4	0.95 (0.76,1.17)	1.15 (0.99,1.32)
Model 5	0.92 (0.74,1.15)	1.22 (1.05,1.40)

[1] Estimated from negative binomial linear regression models with linear splines.

[2]mobility limitations defined from self-report as "no difficulty" compared to "some, moderate and severe difficulty" getting around outdoors.

Model 1 = age + region of residence + accelerometer wear time + season of accelerometer wear

Model 2= model 1+ falls history

Model 3= model 2 + number of chronic diseases, number of medications, depression score, vision problems, living alone

Model 4= model 3+ DASI (fitness scale).

Model 5= model 3+ Sit to stand test.

Supplemental Digital Content Table 1. Flow chart for participants in study at baseline and follow-up

Flow chart	N	%
Invited to clinic visit (baseline)	3137	100
Accepted	1655	52.8
Returned accelerometer with data	1566	49.9
Missing/lost	53	1.7
Faulty	6	0.4
Returned unworn	30	1.9
With valid week	1528	48.7
With questionnaire at baseline	1455	46.4
Not in residential home or wheelchair	1455	46.4
Follow-up one year later		
Accepted invitation at follow-up	1253	39.9
With questionnaire at follow-up	1057	33.7
Follow up restricted to 10-14 months after clinic visit	940	30.0
Complete data for falls	825	26.3
Complete case analysis (no missing covariables)	700	22.3

Supplemental Digital Content Table 2. Characteristics of men with and without mobility limitations

Activities of daily living	No mobility limitations[1]	Mobility limitations[1]	Total	p-value
Walk 200 yards or more on your own without stopping /discomfort				<0.001
Yes, %(n)	98.7(455)	61.8(139)	86.6(594)	
Walk up and down stairs without resting				<0.001
Yes, %(n)	98.1(458)	65.3(147)	87.4(605)	
Pick up a shoe from the floor when standing				<0.001
Yes, %(n)	97.8(454)	81.8(184)	92.6(638)	
Pulling/pushing large objects (eg chair)				<0.001
No difficulties, %(n)	94.6(440)	55.2(123)	81.8(563)	
Getting in and out of bed				<0.001
No difficulties, %(n)	98.9(461)	82.5(184)	93.6(645)	
Getting in and out of a chair				<0.001
No difficulties, %(n)	98.5(457)	74.9(167)	90.8(624)	

[1]mobility limitations defined from self-report as “no difficulty” compared to “some, moderate and severe difficulty” getting around outdoors.