Baseline Measures of Physical Activity and Function Do Not Predict Future Fall Incidence in Sedentary Older Adults: A Prospective Cohort Study

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Baseline Measures of Physical Activity and Function do not Predict Future Fall Incidence in Sedentary Older Adults: A Prospective Cohort Study

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Abstract

Physical Activity (PA) and Physical Function (PF) are modifiable risk factors for falls in older adults, but their ability to predict future fall incidence is unclear. The purpose of this study was to determine the predictive ability of baseline measures of PA, PF and Lower-Limb Strength (LLS) on future falls. 104 participants underwent baseline assessments of PA, PF, and LLS. Falls were monitored prospectively for 12-months. 18 participants fell at least once during the 12-month follow-up. Participants recorded almost exclusively sedentary levels of activity. PA, PF, and LLS did not differ between fallers and non-fallers. Twelve participants, who reported a minor musculoskeletal injury in the past 6-months, experienced a fall. The results of this study suggest that in a cohort of highly-functioning, sedentary older adults, PA does not distinguish fallers from non-fallers and that the presence of a recent musculoskeletal injury appears to be a possible risk factor for falling.

Introduction

Falls are a leading cause of severe injuries in older adults including hip fractures (Hayes et al., 1993) and traumatic brain injuries (Jager et al., 2000). It is estimated that one in four adults over the age of 65 experience a fall each year (Bergen et al., 2016). Falls among older adults represent a major global public health concern (James et al., 2020), contribute to high hospitalization rates (Australian Institute of Health and Welfare, 2022) and substantial financial burden at all levels of health care systems (Florence et al., 2018; Hoffman et al., 2022). There are many documented risk factors for falling including previous falls, balance impairment, decreased muscle strength and functional limitations (Tinetti & Kumar, 2010), such as those that may occur as a result of injury and inactivity.

We have previously demonstrated that reactive stepping behavior to a forward loss of balance and the Physiological Profile Assessment (PPA) (Lord et al., 2003) were predictive of prospective falls in this same cohort of community dwelling older adults (Carty et al., 2015). While these assessments of fall risk were effective in terms of fall prediction, their utility in community and clinical settings is likely limited due to the time, expertise and equipment required to conduct them. Alternatively, factors such as physical function, physical health limitations and physical activity can all be assessed by clinicians with relative ease. For instance, physical function is often assessed using measures of strength and mobility such as dynamometry or the Timed Up and Go (TUG), respectively. While physical health limitations can be accessed via questionnaires such as the Baecke Questionnaire and the Short-Form 36 Item (SF-36) Survey. Physical activity (PA) may be defined as any bodily movement that requires energy expenditure and refers to all movement including movement during leisure time, transport or as part of a person's work. PA can be assessed in a variety of low effort methods including self-report questionnaires or the use of pedometers and accelerometers.

Previous investigations of the relationship between physical activity and falls in older adults have tended to use indirect, self-reported measures of PA and are often retrospective in nature. For instance, Chang & Do (2015), found higher levels of self-reported PA were protective against falls in older men and women. Similarly, Moreira et al. (2018) found that lower self-reported PA and functional mobility (Timed-Up and Go score) were associated with an increased retrospective fall incidence in older adults. The retrospective design of those studies makes it difficult to determine whether lower PA contributes to falls, if prior falls lead to a subsequent decline in PA, or whether another factor (such as illness or injury) could lead to a reduction in both PA and falls.

Studies that have prospectively examined the relationship between falls incidence and PA have led to contradictory conclusions. For example, in an investigation of the relationship between PA and fall incidence, Klenk et al., (2015) found no overall association between PA level and falls per person year. However, that study also reported less active older adults experienced significantly more falls per hour walked compared to their more active counterparts. In a similar investigation, Okubo et al., (2016), found participation in a 16-month walking program led to a significant reduction in fall risk per person-step compared to an active control group. Those authors also found that the presence of two or more falls risk factors modulated the association between habitual walking and falls history (Okubo et al., 2015), walking increased fall risk in high-risk older adults and decreased fall risk in low-risk older adults. Although those results taken together suggest physical function may influence the relationship between habitual PA and fall risk, a recent systematic review concluded there was a high level of uncertainty regarding the evidence for habitual PA and reduced prospective falls risk (Sherrington et al., 2020).

To our knowledge, no prior study has prospectively investigated the relationship between falling and direct estimates of PA and physical function. Therefore, the purpose of this investigation was to determine the ability of baseline measures of physical activity and function to predict prospective fall incidence in a cohort of community dwelling older adults.

Methods

Participants

Data for this study were collected from February 2010 to August 2013. One hundred and four community-dwelling older adults, above the age of 65 (50 men and 55 women; mean (standard deviation); age: 71.8 (4.92) years; height: 1.7 (0.09) m, mass: 74.8 (13.2) kg) were randomly contacted from the local electoral roll. Individuals who had previously been diagnosed with any major neurological, cardio-pulmonary, metabolic, musculoskeletal, or visual conditions/impairments that would be reasonably expected to adversely influence their motor function were excluded. Ethics approval was obtained from the Institutional Human Research Ethics Committee and all relevant ethics guidelines including provision of informed consent were followed.

Recent minor musculoskeletal injury

As a part of the normal screening process, volunteers were also asked if they had experienced any minor musculoskeletal injuries such as muscle, ligament or tendon strains, sprains, or tears of any kind within the last 6 months.

Physical Function

Prior to the activity monitoring period, participants completed a baseline assessment including medical history as well as questionnaires and surveys regarding their overall health and habitual activity level. The Short-Form 36-Item (SF-36) Survey 1.0 (QualityMetric: Washington, USA) and the Baecke questionnaire (Baecke: Netherlands) were used to assess the overall health status of the participants and identify mobility limitations (Syddall et al., 2009). Participants answered questions regarding habitual physical activity levels to provide a self-reported measure of physical activity level (low, moderate, and high activity) (Baecke et al., 1982). The Timed-Up and Go (TUG) (Podsiadlo & Richardson, 1991) was completed by participants to assess their general mobility.

Lower Limb Strength

Lower limb maximal voluntary isometric strength was assessed as described by Carty et al., (2012). Briefly, lower limb maximum voluntary isometric strength was assessed at baseline, across the joint range of motion, for the ankle, knee and hip flexors and extensors using an isokinetic dynamometer (Biodex System 4, Biodex Medical Systems, USA). Participants completed submaximal practice trials at the second angle for each joint, until investigators were confident the participant was able to produce maximal effort. Strength measurements were first taken distally, at the ankle, and progressed proximally, to the hip, and were progressed from greater flexion angles to lesser flexion angles. Participants completed two maximum voluntary flexion and extension trials for each joint and joint angle combination. Trials were three seconds and participants were instructed to flex or extend the joint “as hard as they could” for the whole trial. Investigators gave verbal encouragement throughout the trial to maximize effort. Participants rested for 60 seconds between trials. For ankle strength measurement, participants were seated with arms resting on their thighs and hips and knees in 90° and 60° of flexion respectively. Ankle strength was assessed at 0, 15 and, 30° of flexion as well as end range of motion in dorsiflexion and plantarflexion. For knee strength measurement, participants remained seated with hands on thighs with hips at 70° of flexion and the ankle in 5° of plantar flexion. Knee strength was assessed at 30, 60 and, 90° of knee flexion as well as end range of motion in extension. Hip strength measurements were taken with participants in a standing position, the knee was constrained to a 60° flexion angle using a post-surgical knee brace. A custom frame was used to stabilize the contralateral limb as well as the upper body during the measurement of hip strength. Hip strength was measured at 10, 40 and 70° of flexion, as well as end range of motion in flexion and extension. Based on the recommendations of Kellis & Baltzopoulos (1996), isometric joint moments were adjusted to account for the weight of the dynamometer. Data from Dempster (1955) were used to estimate body segment parameters. A moment angle curve was created for each joint, in each direction, by a second order polynomial fitted to the data. Isometric strength for each joint in each direction was defined as the peak value on the moment angle curve.

Physical Activity Monitoring

Physical activity data were collected for all participants via hip worn ActiGraph-GT3X+ triaxial accelerometers (ActiGraph, Pensacola, FL). Participants were instructed to wear accelerometers for seven consecutive days. Accelerometers were worn continuously throughout the monitoring period except for during activities such as bathing and getting dressed.

Accelerometer data were collected at 30 Hz and all accelerometer outputs are based on data collected from the vertical axis. Custom MATLAB scripts (R2018b; Mathworks, Natick, MA, USA) were used to calculate total step count per day as well as counts per minute. Counts per minute were used in conjunction with age specific cut-point ranges to determine time spent at each level of PA intensity. Four age-specific cut points were used to differentiate between sedentary (<25) (Aguilar-Farias et al., 2014), light (25-809), moderate (809-1013) (Hall et al., 2013) and vigorous (>1013) (Barnett et al., 2016) levels PA.

Fall Monitoring

Following completion of activity monitoring, participants were provided with a monthly fall diary containing questions related to falls and injuries. A fall was defined as 'an unexpected event in which the participant came to rest on the ground, floor, or lower level (Lamb et al., 2005). If a fall was experienced, participants were instructed to complete the questions as soon as possible within the month in which the fall occurred. Participants were contacted via phone by a member of the research team once a month for 12 months to collect fall data. Participants were subsequently classified as either fallers or non-fallers based on whether they experienced a fall during the 12-month fall monitoring period.

Statistical Analysis

General linear models with sex as a covariate were used to assess the association between normalized joint-specific strength, PA, TUG, prior injury status, recent fall history, SF-36, Baecke, BMI, and age, respectively. Statistical analyses were performed using R Statistical Software (v4.1.3; R Core Team). Significance was accepted for $p < 0.05$.

Results

Fall Incidence

18 participants (17%) experienced one or more falls during the 12-month prospective follow-up period (Table 1). Of the 18 participants who experienced a fall, 12 fell once, 4 fell twice, and 2 fell three times (26 falls in total were recorded).

<Insert Table 1 here>

Fall Status and Measures of PA and Physical Function

All measures of lower limb strength as well as height and body mass were significantly different between male and female participants in this cohort. Therefore, sex was added as a control variable to the primary analysis. After controlling for the effects of sex on fall incidence, no significant group differences were detected in average percentage of time spent in sedentary activity levels, SF-36, Baecke, TUG, and lower limb isometric muscle strengths between fallers and non-fallers (All p's > 0.05). All participants spent time in sedentary and light levels of activity and no participant recorded any moderate or vigorous PA.

Fall Status and Prior Minor Injury

Twelve participants reported a minor musculoskeletal injury within the 6 months prior to their initial screening. Minor injuries reported by participants included minor fractures and soft tissue injuries such as sprains, strains, and minor tears. All 12 of these participants reported a fall during the 12-month monitoring period. Prior injury status was the only variable that significantly differed between fallers and non-fallers ($p<0.001$) and as such, was the only variable eligible for entry into the stepwise model selection process. The model selection process revealed that prior injury status was a significant predictor of prospective falls ($P<0.001$, $R^2 = 0.37$).

Discussion

This prospective cohort study found no association between baseline measures of PA, physical function and lower limb strength and prospective fall incidence, in a cohort of 104 highly functioning, largely sedentary, community-dwelling older adults. Secondly, the presence of a prior musculoskeletal injury such as a sprain, strain, or minor fracture, in sedentary older adults with high levels of physical function may be an early warning of fall risk and may need to be considered as a potential risk factor for falling.

Fall Incidence, PA, Physical Function, and Lower Limb Strength

Our result that PA did not differ between fallers and non-fallers is supported by previous reports that have demonstrated leisure activities (Chan et al., 2007), general PA such as walking (Sherrington et al., 2020) and low amounts of moderate activity and low intensity physical activity alone (Dipietro et al., 2019) do not appear to be protective against falls. It has been demonstrated that structured multicomponent (functional and balance exercises) exercise programs can effectively reduce fall risk (Dipietro et al., 2019; Sherrington et al., 2020). Although older adults' preference to use low intensity activities, such as walking (Amireault et al., 2019), as their primary form of activity, may present a potential challenge to participation in such programs (Rivera-Torres et al., 2019). Therefore, we suggest that future studies should investigate the barriers, benefits, and acceptability of more specific, higher intensity fall prevention programs for older adults.

We also found no group difference in measures of physical function (the TUG, SF-36, and Baecke) and lower limb strength between fallers and non-fallers. This result was somewhat surprising considering previous reports of poor physical function and muscle weakness as established risk factors for falling (Tinetti & Kumar, 2010). One possible reason for the lack of group difference in physical function and strength between fallers and non-fallers may be the relatively high functional capacity of the participants in the present study. To be eligible for the present study, participants were free from any diagnosed neurological, cardio-pulmonary, metabolic, and/or musculoskeletal conditions and had relatively high levels of physical function as indicated by TUG scores, which were well below the recommended fall prediction cutoff of 13.5 seconds (Shumway-Cook et al., 2000). The observed fall rate of 17% was also considerably lower than a recent estimate of fall rates for older adults in Oceania of 34% (Salari et al., 2022). Similar relationships have been reported between functional capacity and fall risk in other populations. For instance, Sheehan et al. (2022) reported functional performance measures and temporal-spatial gait parameters were not associated with fall-risk in young, high functioning individuals with lower limb trauma, despite a high number of reported falls.

Previous investigations, involving this same cohort of community-dwelling older adults, demonstrated that greater lower limb strength was associated with improved balance recovery performance (Carty et al., 2012a; 2012b) and that balance recovery performance was predictive of prospective falls (Carty et al., 2015). While lower limb strength is associated with balance recovery performance, and balance recovery performance is associated with fall incidence, the current findings suggest that strength of the lower limb muscles is not associated directly with falls. We therefore suggest that once an individual attains a minimum threshold of muscular strength and physical function, the intrinsic risk factors that influence fall incidence such as the ability to rapidly generate muscle force and coordinate balance recovery responses may be better predictors of falls than muscle strength alone. Indeed, studies conducted in the same participant cohort as the present study have revealed that lower limb joint power production is a better predictor of balance recovery performance than muscular strength (Graham et al. 2014), and that the muscle recruitment and coordination strategy associated with successful balance recovery by stepping is readily distinguished from unsuccessful attempts to recover balance (Carty et al., 2021a; Cronin et al., 2013; Graham et al., 2015)

Fall Status and Prior Minor Musculoskeletal Injury

Although not one of the main aims of the current study, all 12 participants who reported a minor musculoskeletal injury within the 6 months prior to their involvement in the study experienced a fall during the 12-month prospective fall monitoring period. Furthermore, prior minor injury status was the only variable in the present study that was found to differ between fallers and non-fallers. Prior studies have reported that musculoskeletal conditions such as knee and or hip osteoarthritis appear to increase fall risk (Khalaj et al., 2014; Smith et al., 2018; Tsonga et al., 2015). As, potential participants who reported having clinically diagnosed lower limb osteoarthritis were excluded from the present study, our findings suggest that arguably more minor musculoskeletal conditions such as soft tissue injury, may be an early warning of elevated falls risk, and suggest further investigation of this possibility is warranted in a more definitive study.

Strengths and Limitations

A strength of the present study was the 12-month prospective evaluation of falls and the direct measurement of PA using activity monitors. The use of actigraphy provides an objective estimate of PA level and is considered the gold standard for activity monitoring. Prospective evaluation of falls provides insight into the temporal relationship between habitual PA, prior injury, and falls. There are also several limitations that should be considered when interpreting the results of this study. Firstly, previous studies have reported older adults spend as little as 10 to 20 minutes engaged in moderate to vigorous intensity PA per day (Troiano et al., 2008). However, in the present study the absolute level of physical activity intensity level observed was low (only activity classified as sedentary and light intensity were observed). Therefore, our findings of physical activity intensity not being related to prospective falls in older adults cannot be generalized to higher levels of physical activity intensity. Secondly, the presence of a prior minor injury was recorded during screening, but the exact nature of the injuries was not recorded for all participants. However, due to the overall inclusion criteria for the study we are certain the injuries were minor in nature. Thirdly, the fall rate observed in this study was relatively low (17%) compared to other prospective fall studies in older adults where rates are typically 1 in 3-4 (Klenk et al., 2015; Okubo et al., 2015, 2016). We contend that the low fall rate in the present study may be due to the overall high level of physical function of the participants who were free from chronic health conditions. Finally, the sample size of 104 participants, used in the present study may not be fully representative of the population of older adults in the wider community. Therefore, we caution against generalizing the findings of the present study to other populations.

Conclusion

Baseline measures of PA, physical function and strength did not differentiate between fallers and non-fallers in a cohort of 104 highly functioning, largely sedentary community-dwelling older adults. However, all participants who reported a musculoskeletal injury in the 6 months prior to participation in this study experienced at least one fall, which suggests that musculoskeletal injuries (such as soft tissue sprains and strains) may need to be considered as a potential fall risk factor.

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Table 1.
Summary data for baseline demographic, physical activity, physical function, lower limb strength, and prior injury by stratified by prospective fall status.

Fall Status	Non-Faller	Faller	p
Demographics			
n	86	18	na
Sex (female/male (% female))	45/41 (52%)	9/9 (50%)	na
Age (years)	71.9 ± 5.0	71.1 ± 4.7	0.51
BMI (kg/m^2)	26.7 ± 3.5	27.4 ± 4.1	0.44
Body mass (kg)	74.1 ± 12.8	78.1 ± 15.1	0.24
Height (m)	1.66 ± 0.09	1.68 ± 0.08	0.39
Injury Status			
Prior injury (count (%))	0 (0%)	12 (67%)	<0.001*
Physical Activity Level			
Total counts	10057 ± 12	10056 ± 6	0.97
Vigorous (% total counts)	0	0	na
Moderate (% total counts)	0	0	na
Light (% total counts)	5 ± 3	6 ± 2	0.36
Sedentary (% total counts)	95 ± 2	94 ± 2	0.34
Physical Function			
Baecke	8 ± 5	9 ± 6	0.58
SF-36 total	79 ± 17	84 ± 9	0.25
Physical subscore	76 ± 17	80 ± 11	0.29
Mental subscore	80 ± 17	82 ± 11	0.51
Timed Up and Go (s)	6.0 ± 1.0	6.1 ± 1.0	0.55
Lower Limb Strength (Nm)			
Hip flexion	80.3 ± 27.3	81.0 ± 28.8	0.92
Hip extension	105.9 ± 33.9	111.7 ± 34.4	0.51
Knee flexion	70.9 ± 21.8	71.3 ± 23.7	0.96
Knee extension	78.5 ± 30.7	76.5 ± 26.9	0.79
Ankle Dorisflexion	30.1 ± 8.9	30.9 ± 10.9	0.73
Ankle Plantarflexion	77.9 ± 32.8	72.7 ± 34.9	0.55

T-tests were used to calculate all p values. Data are reported as mean ± standard deviation.