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Original Article

Changes in physical activity predict changes in a comprehensive model of balance in older community-dwelling adults. A longitudinal analysis of the TILDA study

Ilona I. McMullan[1], Brendan P. Bunting[1], Suzanne M. McDonough[2,3,4], Mark A. Tully[1,5], Karen Casson[6]

[1]UKCRC Centre of Excellence for Public Health (NI), Ulster University, UK; [2]Institute of Nursing and Health Research, Ulster University, UK; [3]School of Physiotherapy, University of Otago, New Zealand; [4]School of Physiotherapy, Royal College of Surgeons in Dublin, Ireland; [5]Institute of Mental Health Services, Ulster University, UK; [6]Institute of Nursing and Health Research, Ulster University, UK

Abstract

Objective: Falls due to poor balance can cause injury, disability, and death in older adults. The relationship between free-living physical activity (PA) and balance over time is poorly understood. The aim of this study is to explore the association between PA and balance in older adults over time. **Methods**: Using two waves of data from the TILDA study (n=8,504 participants) a structural equation model was used to identify a composite measure of balance that incorporated measures of Timed Up and Go; handgrip strength; Mini Mental State Exam; vision; hearing; and steadiness. The patterns of change in PA and balance were then compared over time (controlling for covariates). **Results**: The results showed that one extra metabolic equivalent of task (MET) minute of PA improves balance by 4% over one week (Est=-0.10, SE=0.12), and by 5% cumulatively over two years (Est=-0.13, SE=0.02). Medication, alcohol consumption, sex, age, fear of falling, education, pain, and problems performing activities of daily living (ADL) were risk factors for balance. **Conclusion**: This study provides a novel and robust model that should guide comprehensive balance assessment. PA promotion should engage older adults in more free-living PA that may be more relevant to them.

Keywords: Falls, Low-intensity physical activity, TILDA

Introduction

The global prevalence of falls is high, with approximately one in three community-dwelling older adults (≥65 years) falling each year resulting in injury, disability, loss of independence, and death in older adults[1,2]. In the UK, falls were reported as the ninth highest cause of disability adjusted life years (DALYs)[3] with associated costs estimated at £2 billion per year[1,2]. Consequently, falls present a considerable public health challenge.

The general health benefits of moderate-to-vigorous physical activity (MVPA) are well understood[4-11]. In contrast, there is a lack of understanding of the effects of everyday living PA, lower intensity physical activity (LIPA) such as walking for leisure, occupational, or transportation purposes, on balance which may require a longer period of study than that typically afforded by clinical trials[4,12,13]. Furthermore, our group recently published a systematic review (n=1,547 participants; 30 studies) supporting the effects of PA for balance and found moderate quality cross-sectional studies (26 studies) making conclusions regarding causality difficult[14].

The other significant challenge in this area is that balance assessment is complex. Contemporary balance theory proposes that comprehensive balance assessment should incorporate the assessment of neuromuscular, cognitive, and sensory body systems to accurately assess balance and effectively reduce falls[15-19]. Functional measures of balance

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Corresponding author: *Ilona I. McMullan, Ulster University, School of Nursing, Shore Road, Newtownabbey, BT37 0QB, UK*

E-mail: *i.mcmullan@ulster.ac.uk*

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such as the Timed Up and Go test are widely used due to low cost and ease of implementation, but many different functional measures are available (26 measures[7]; 66 measures[19]; and 40 measures[14]), and guidance on which combination comprehensively assess balance is lacking[20]. Furthermore, McMullan et al.'s (2018) systematic review found only one of 30 studies included functional measures across all of the body systems required for comprehensive balance assessment[14].

Therefore, using data from the Irish Longitudinal study of Ageing (TILDA), a robustly designed longitudinal study that provides data relating to PA and balance over a two-year period from a large sample of community-dwelling participants (≥50 years) (n=8,504 participants), this study aims to investigate the longitudinal association between free-living PA and comprehensively measured balance in older adults.

Method

Study design

The Irish Longitudinal Study of Ageing (TILDA) is a nationally representative prospective cohort study exploring social, health and economic aspects of community dwelling older adults in the Republic of Ireland[21-23]. Data collection included (i) a computer-assisted personal interview (CAPI) that included detailed questions on sociodemographic, wealth, health, lifestyle, social support and participation, use of health and social care and attitudes to ageing; (ii) a self-completed questionnaire; and (iii) a detailed health assessment carried out by qualified and trained research nurses that included cognitive, cardiovascular, mobility, strength, bone and vision tests. This study uses data collected from both waves 1 and 2 of the TILDA study. Ethical approval for TILDA was obtained from the Trinity College Dublin Research Ethics Committee, and all participants provided written informed consent.

Measures

Measurement of balance

Balance is a multidimensional phenomenon, requiring the contribution from cognitive, neuromuscular, and sensory systems[16], and six functional measures of balance across the different body systems are available from the TILDA dataset.

Sensory system

Research suggests an association between conversational hearing and vestibular disfunction[24]; poor vision and increased sway[25]; and proprioceptive feedback issues and poor balance in older adults[26]. Self-rated measures of vision and hearing are reported to be good indicators of actual vision and hearing when compared with objective measures[27,28]. Vision and hearing were assessed using: "Is your eyesight (using glasses or corrective lenses)?"; "Is your hearing (with or without a hearing aid)?", excellent (1), very good (2), good (3) fair (4) or poor (5)?" A low score indicates good vision or hearing.

Cognitive system

Age is a risk factor for cognitive degeneration which can affect balance in older adults[29,30]. TILDA uses the Mini Mental State Examination (MMSE)[31], a 30-item scale measuring attention, concentration, memory, language, visio-constructional skills, calculations, and orientation which provides a summary score for each participant. A high score indicates good cognitive function.

Neuromuscular system

TILDA objectively measures maximum grip strength using the highest score (Kg) from two tests on each hand from a Baseline hydraulic hand dynamometer (Fabrication, White Plains, NY, USA). This analysis uses the highest score on the dominant hand (Kg). A high score indicates good strength.

An objective measure of strength, mobility and gait speed was collected using the Time Up and Go test (TUG) using a chair with armrests and seat height of 46 cm. Participants were asked to rise from the chair, walk 3 meters at normal pace, turn around, walk back and sit down again. The time taken from the command "Go", to when the participant sat with their back resting against the back of the chair was recorded (s). A low score indicates good function.

Self-reported steadiness is reported in TILDA using: "when standing do you feel?" "when getting up from a chair, do you feel?" and "when walking, do you feel?" (1) very steady, (2) slightly steady, (3) slightly unsteady, (4) very unsteady. The summed score of steadiness is shown to be a predictive and reliable measure of falls in older adults[32,33].

Measurement of physical activity

TILDA uses the International Physical Activity Questionnaire (IPAQ), a self-reported measure of physical activity that estimates habitual practice of physical activities[34]. The short form of the IPAQ is used which contains 8 items to estimate the time spent (days per week, minutes per day, hours per day) performing physical activities over the last 7 days (vigorous/moderate/walking). A summary measure of the total number of minutes per week on any physical activity is used in this analysis and was corrected in the analysis for measurement error by using the ICC of 0.76[34].

Covariates

Factors affecting balance that are not caused by other variables in the model were included[2].

Demographics

The variable of age (yrs), sex (female/male); and education level (primary education is <11 years of full-time; secondary education is 11-13 years of full-time; and tertiary education includes diploma/degree/higher) were included.

Observed variables	Wave 1	Wave 2
	(N=population; mean (standard deviation); range)	
Balance		
Vision (Likert scale 1-5) (high score is poor)	N=1709; 2.47 (0.99)	N=1529; 2.56 (0.89)
Hearing (Likert scale 1-5) (high score is poor)	N=1709; 2.46 (1.20)	N=1530; 2.60 (1.04)
MMSE (max. score 30) (high score is good)	N=1406; 28.30 (3.86); (range 15-30)	N=1530; 28.54 (3.96); (range 15-30)
Hand Grip test (kg) (high score is good)	N=1381; 26.05 (106.53); (range 2-65)	N=1412; 29.26 (158.21); (range -98-75)
TUG (secs) (high score is poor)	N=1392; 9.34 (13.25); (range 4.82-63.53)	N=1483; 9.81 (14.43); (range 2-51)
Steadiness (Likert scale 1-5) (high score is poor)	N=1707; 4.43 (4.74)	N=1707; 4.52 (5.04)
PA measure		
PA (total metabolic equivalent of task (MET) mins per week) (high score is good)	N=1707; 2.72 (10.19); (range 0-19.28)	N=1709; 2.19 (9.40); (range 0-17.89)
Covariates	**N=1709**	
Age	74.3yrs	
Sex	Female (42%) male (58%)	
ADL	yes (85%) no (15%)	
Pain	Yes (55%) no (45%)	
Education	Primary (27%), secondary (60%), tertiary (13%).	
Fall history	Yes (30%) no (74%)	
Medication	Yes (80%) no (20%)	
Alcohol	Yes (91%) no (9%)	
Sleep	Trouble falling asleep yes (18%) no (82%), trouble waking up too early yes (40%) no (60%)	

Table 1. Descriptive statistics for the TILDA sample.

Lifestyle and health

Fear of falling ("Are you afraid of falling?" yes/no); medication use (yes/no); pain ("Does pain affect your day to day activities?" yes/no); alcohol consumption (a) "Have people annoyed you by criticising your drinking?"; (b) "Have you ever felt guilty about drinking?"; and (c) "Have you ever felt you needed a drink first thing in the morning to steady your nerves or to get rid of a hangover?" yes/no); sleep (a) "How often do you have trouble falling asleep?" (b) "How often do you have trouble with waking up too early and not being able to sleep? 1=always, 2=most of the time, 3=sometimes, 2=hardly ever, 1=never); and difficulty performing any of six activities of daily life (ADL) such as dressing, walking across a room, bathing or showering, eating, getting in or out of bed, and using the toilet (yes/no).

Statistical analysis

This study uses a structural equation modelling (SEM) approach (Mplus, version 7.4; Muthen & Muthen, Los Angeles, CA) to analyse the TILDA data. SEM enables the composite measure/latent construct of balance to be modelled using multiple functional tests of balance across neuromuscular, cognitive and sensory body systems[35]. Confirmatory factor analysis (CFA) within SEM tests factorial invariance (configural; scalar; and metric) which identifies whether differences over time in balance are due to true change in the underlying construct thus improving the consistency and reliability of the results[36,37]. The structural relationships between PA and balance were also explored and PA was allowed to have a direct effect on balance at waves 1 and 2[37,38]. Covariates were introduced and regressed onto PA at both waves 1 and 2. If the model fit indices indicated that the model did not adequately describe the data, then a direct effect was introduced from the covariate to balance.

A robust form of Maximum Likelihood Estimation (MLE) uses a model-based estimation strategy for missing data thereore reducing standard errors. Missing data was assumed to be missing at random[39]. Model fit was evaluated using a Root Mean Square Error of Approximation (RMSEA)

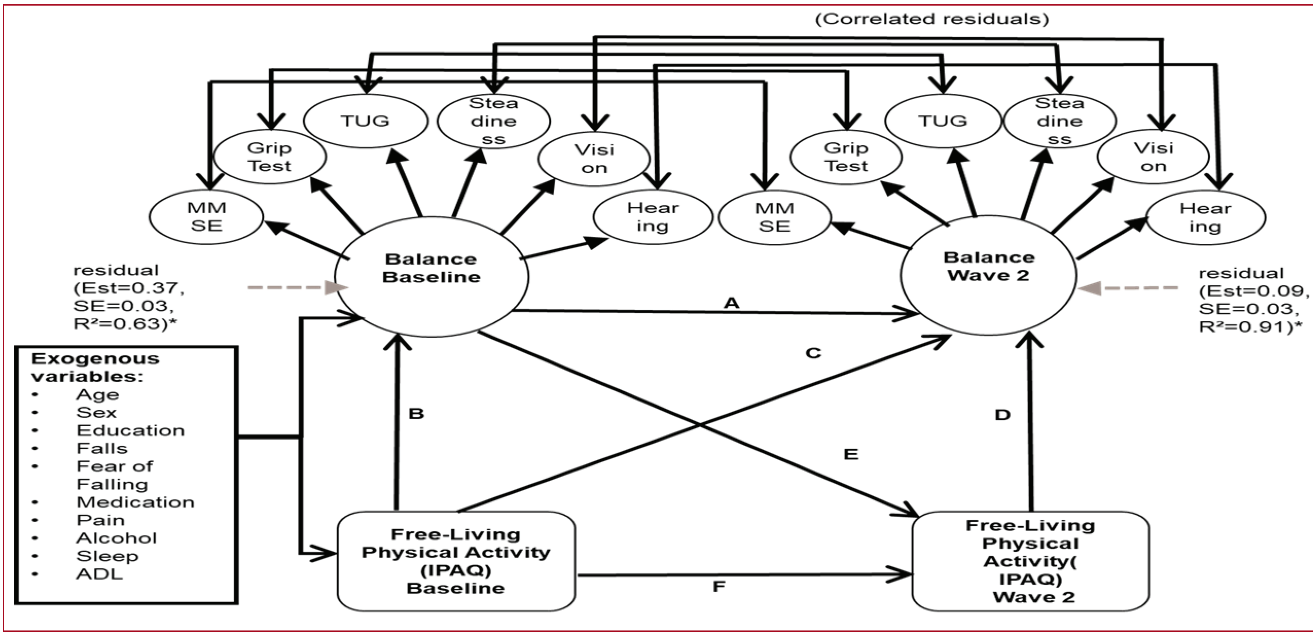

Figure 1. The relationship between PA and balance over a 2-year period controlling for covariates.

≤0.05 with an upper limit (90% CI) ≤0.08; a Comparative Fit Index (CFI) ≥0.95; a Tucker Lewis Index (TLI) ≥0.95; and a Standardised Root Mean Square Residual (SRMR) ≤0.05[37]. Where the levels of fit indices were not achieved, the modification indices were examined, and where appropriate, the necessary adjustments were made.

Results

A total of 1709 participants were included in the analysis. Table 1 provides the descriptive statistics for the sample. The mean age of the sample was 73.3 years; 58% were male; 73% had a secondary education or above; 74% had never fallen; 82% had no trouble falling asleep, and 60% had no problem waking up too early. A high proportion of the sample had an increased risk of falls where 85% had a disability in one ADL, 55% experienced pain which affected their everyday activities, 80% were taking medication, and 91% had high alcohol consumption.

Balance

Standardised factor loadings indicated that MMSE (Est=-0.33, S.E.=0.04), vision (Est=0.27, S.E.=0.02), hearing (Est=0.23, S.E.=0.03), handgrip strength (Est=-0.22, S.E.=0.03), TUG (Est=0.71, S.E.=0.04) and steadiness (Est=0.86, S.E.=0.04), had a statistically significant relationship with the composite measure/latent construct of balance (Figure 1). A residual correlation between vision and hearing was introduced because these measures showed a variance not explained by balance (Figure 1). A series of successive restrictions on the factor loadings for each measure of balance (metric invariance) can be assumed for each factor loading at both waves, showing that each measure demonstrated equal relationships with balance across time. Scalar invariance could not be assumed for the measures of balance excluding MMSE, demonstrating partial invariance (Table 2). Balance at wave one and two was highly correlated (Est=0.98). The mean difference score between baseline and wave two balance shows that balance declined after two years (Est=-0.67). In other words, a one-unit change in the baseline score results on average in a change of only 0.676 units and not a value of one, which it would be if no change had occurred. This amounts to a reduction of approximately 25% (normal distribution table) of one unit across this two-year period.

Physical activity (PA)

Baseline PA had a statistically significant direct effect on PA at wave two (Est=0.40). Based on modification indices a direct effect was introduced for handgrip strength on baseline PA (Est=-0.4) and wave two PA (Est=0.1) also.

Physical activity (PA) and balance

Direct effects

Our model assumes that PA influences balance, and analysis found that baseline PA has a statistically significant effect on baseline balance, where an extra MET-minute of PA per week improves balance by -0.10 SDs or 4% (normal distribution table) (Figure 1, path B), but had no statistically

Models	Information Criteria		Chi squared			RMSEA[1]		CFI[2]/TLI[3]		SRMR[4]
	Akaike (AIC)	Bayesian (BIC)	value	df	P-value	Estimate	90 % C.I.	CFI	TLI	Value
1.1 Model of balance at wave 1 & 2 (configural variance)	338974.21	339303.48	253.90	43	0.0000	0.03	(0.02, 0.03)	0.97	0.95	0.03
1.2 Model of balance at wave 1 & 2 (metric invariance)	339283.97	339571.20	342.29	49	0.0000	0.03	(0.02, 0.03)	0.96	0.94	0.05
1.3 Model of balance at wave 1 and 2 (scalar invariance)	339117.30	339397.53	313.07	50	0.0000	0.03	(0.02, 0.03)	0.96	0.95	0.04
1.4 Model of PA, balance & covariates at wave 1 & 2	90876.18	91322.56	503.74	205	0.0000	0.03	(0.03, 0.03)	0.95	0.94	0.04

Note: (Hoyle, 1995).
[1] RMSEA is the Root Mean Square Error of Approximation (≤0.05 with an upper limit (90% Confidence Interval (CI)) ≤0.08)
[2] CFI is the Comparative Fit Index (≥0.95).
[3] TLI is the Tucker Lewis Index (≥0.95)
[4] SRMR is the Standardised Root Mean Square Residual (≤0.08)

Table 2. Fit statistics for the model of balance at wave one and two, and the model of PA, balance and covariates.

significant effect (p>0.05) on wave two balance (Est=0.04) (Figure 1, path C). The data for PA and balance are at the same time point (baseline) and so it was not possible to also test the effect of baseline balance on PA, because there are no independent uncorrelated predictors for balance or PA. Baseline balance was shown to have a statistically significant positive effect on wave two PA (Est=-0.14) (Figure 1, path E).

Wave two PA has a statistically significant effect on wave two balance, where an extra MET-minute of PA per week improves balance by -0.05 SDs or 2% (normal distribution table) (Figure 1, path D).

Indirect effects

Baseline PA has a statistically significant total indirect effect on wave two balance via wave two PA (Figure 1, path F, D); baseline balance (Figure 1 path B, A); and via baseline balance on wave two PA (Figure 1, path B, E, D) (Est=-0.13), where an extra MET-minute per week of PA improves balance by -0.13 SDs or 5% over two years.

Covariates

Gender (Est=-1.28), medication (Est=-0.98), and Activities of Daily Living (ADL) (Est=-0.2) had a statistically significant effect on PA, and because PA indirectly affects balance, then an indirect effect on balance. For example, females, those taking medication, or with any ADL impairments engaged in less PA, resulting in poorer balance. Additionally, increased age (Est=0.15), fear of falling (Est=1.13), lower education (primary: Est=1.09; secondary: Est=0.7), pain (Est=-0.23), higher alcohol consumption (Est=-0.31), and problems performing ADL (Est=2.12), over and above their effect on PA (i.e. an independent effect), were found to adversely directly affect balance. Sleep quality and a history of falls were not significant for PA or balance.

Discussion

The findings from this secondary analysis of longitudinal data using a large representative sample of data over a 2-year period extends our understanding of the association between PA and balance in older adults. The results show that PA benefits balance over time, where an extra MET-minute per week improves balance by 4% over a one-week period; and an extra MET-minute per week improves balance by 5% over a two-year period. Thus, PA has a positive association with balance in the immediate term as well as a cumulative effect over time. Consequently, programmes of activity for older adults should be developed that may not only be beneficial to balance, but also more appropriate to this population given that this population are failing to meet MVPA guidelines[40]. For example, barriers to increasing PA levels may be overcome if advice includes activities that are carried out as part of everyday living, such as for example walking, or household chores. Additionally, there are both immediate and cumulative benefits of PA on balance in older adults, thus increased activity should be promoted across the lifecycle to ensure the maintenance or improvement in balance in later life.

Furthermore, the findings support previous research regarding the effect of the covariates of sex, medication use,

	Estimate	S.E.	Est./S.E.
Balance & PA Hypotheses:			
Balance (wave 1) on Balance (wave 2)	1.07 (0.95)	0.05	20.49
Physical Activity (wave 1) on Balance (wave 1)	-0.10(-0.12)	0.02	-4.19
Physical Activity (wave 1) on Balance (wave 2)	0.04(0.04)	0.03	1.39
Physical Activity (wave 2) on Balance (wave 2)	-0.05(-.05)	0.02	-2.71
Balance (wave 1) on Physical Activity (wave 2)	-0.14(-0.13)	0.03	-4.72
Physical Activity (wave 1) on Physical Activity (wave 2)	0.40(0.40)	0.05	7.78
Direct effects of covariates on physical activity:			
Sex	-1.28	0.19	-6.55
Age	-0.03	0.01	-3.46
Medication	-0.98	0.28	-3.53
Falls	0.67	0.20	3.42
Education-primary	0.42	0.27	1.56
Education-secondary	0.56	0.24	2.30
Pain	0.15	0.04	3.36
Alcohol	0.06	0.14	0.42
Sleep (2w1)	0.31	0.13	2.41
Sleep (3w1)	-0.12	0.13	-0.92
Fear of Falling	-0.52	0.18	-2.83
ADL	-0.99	0.25	-4.00
Direct effects of covariates on Balance:			
Sex	-	-	-
Age	0.15	0.01	12.25
Medication	0.13	0.10	1.21
Falls	-	-	-
Education-primary	1.10	0.18	6.00
Education-secondary	0.70	0.14	5.02
Pain	-0.23	0.03	-8.32
Alcohol	-0.31	0.08	-3.91
Sleep (2w1)	-	-	-
Sleep (3w1)	-	-	-
Fear of Falling	1.13	0.17	6.53
ADL	2.12	0.30	7.02

Note: Reference group for education is Education-third level (e.g. university level); Unstandardised results reported with standardised estimates in brackets; Direct effect of medication on balance is insignificant when controlling for the direct effect on PA; - indicates that modification indices suggested no direct effect was required.

Table 3. Table showing the relationship between Balance, the mediating variable of Physical Activity, and the covariates.

and ADL which were found to have a statistically significant adverse effect on the level of PA and balance. Previous research suggests that older women have a higher risk of falling than older men[41,42]; that medication use is associated with a higher risk of falls and fall-related injuries[43,44]; and where a systematic review found that higher levels of physical activity reduced the incident of ADL disability by 0.51 (95% CI: 0.38, 0.68; p<.001), based on nine longitudinal studies involving 17, 000 participants followed up for 3-10 years[45]. The findings also support that age[6,46,47,48], fear of falling[7], education level[49], pain[50], and alcohol consumption[1], are important risk factors for balance performance, where increased age and alcohol consumption, a fear of falling, a lower SES (indicated by education level), and the presence of pain, all adversely affect balance performance. However, sleep quality and fall history were not found to be statistically significant for PA or balance in our sample, when other relevant factors were statistically controlled. These findings do not support previous research where for example, Min & Slattumoor's (2016) systematic review (n=18 studies) found that insufficient sleep increased fall risk in older community-dwelling adults ≥65 years[51]. However, our study is a longitudinal analysis and most of the studies (11 of 18 studies) included in the review were cross-sectional[51]. Additionally, Edwards et al.'s (2013) longitudinal study (n=2, 299 participants; mean age: men 65.8 years, women 66.6 years; average follow-up 5.5 years) found that fall history in the last year predict falls and fractures[52]. Whilst, Edwards et al.'s (2013) sample reported a low level of fall history (men 7.9%; women 13.9%) which is similar to our sample (74% had no fall history), a lower level of alcohol consumption was reported with only 22% men and 4% women consuming alcohol over the recommended levels. Alcohol consumption in our sample was high with 91% indicating high consumption. Consequently, differences in study design and samples may explain the difference in findings.

Additionally, 74% of our sample had never fallen despite the potentially high risk of falls where 85% had a disability in one ADL, 55% experienced pain which affected their everyday activities, 80% were taking medication, and 91% had high alcohol consumption. This may be because fall history or sleep quality were not statistically significant for PA or balance in our sample, or perhaps because the sample included 58% of males who are at lower risk of falling which may have biased the findings. Also, this study only uses those individual measures (TUG, MMSE, vision, hearing, handgrip, steadiness) available from TILDA and future research should consider additional measures to further develop a composite/latent measure of balance. Furthermore, the measure of PA is self-reported and may be influenced by health status, mood, depression, anxiety, or cognitive ability, as well as seasonal variation in PA patterns, social desirability, or recall issues[53-55]. As a result, actual levels of activity may be inaccurate, where VPA may be overestimated, and LPA or MPA underestimated[53,54]. Future research should consider the use of objective measures of PA to minimise these limitations. Future research should also consider using an objective measure of vision such as LogMAR charts (Minimal Angle of Resolution) and hearing such as the pure tone audiometry test (PTA) to explore the unexplained correlation between self-reported measures of vision and hearing caused by potential bias[27,56-59].

Despite these limitations, this is one of the first studies to explore the association between free-living PA and a comprehensive measure of balance over time. The study uses confirmatory factor analysis within a SEM approach to develop a robust and comprehensive measure of PA and balance as it addresses measurement error[36,60]. It also uses MLR, a model-based strategy for dealing with missing data which enables all participants to be included in the analysis therefore reducing the bias of the results[39]. Furthermore, multiple functional tests across neuromuscular (TUG, [61]; grip strength test, [62]; Steadiness, [63]), cognitive (MMSE, [31]), and sensory (vision and hearing, [64,65] body systems are included to develop the composite/latent construct of balance, and so adheres to Horak's contemporary theory of balance[14,15]. Additionally, functional tests are included that already in use within clinical settings[66], and so could be easily integrated into falls assessment programmes. As a result, the approach used increases the opportunity to explore the association between PA and balance more robustly and accurately.

In summary, this study provides methodologically robust evidence from the analysis of data from the TILDA study that PA improves or maintains balance measures in older adults both in the short-term and cumulatively over a two-year period. It shows that remaining active in older age can improve balance in both the short and longer term, thus is likely to prevent falls in older adults.

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All authors have contributed to the conception or design of the study which includes drafting the work or revising it critically for important intellectual content; final approval of the version to be published; and have agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. Ilona McMullan and Brendan Bunting are responsible in addition for the acquisition, analysis, or interpretation of data.

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