Original Research Article

Dementia and Geriatric Cognitive Disorders

Dement Geriatr Cogn Disord 2012;34:181–189
DOI: 10.1159/000343077

Accepted: August 28, 2012
Published online: October 11, 2012

Physiological Fall Risk Factors in Cognitively Impaired Older People: A One-Year Prospective Study

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Key Words
Accidental falls · Dementia · Cognition · Risk factors · Balance

Abstract
Background/Aims: Cognitively impaired older people are at twice the risk of falls compared to cognitively intact, with approximately 60% falling once or more per year. This study aimed to investigate sensorimotor and balance risk factors for falls in cognitively impaired older people. ***Methods:*** 177 community-dwelling older people with mild to moderate cognitive impairment (Mini-Mental State Examination <24, Addenbrooke's Cognitive Examination-Revised <83) were assessed using the Physiological Profile Assessment (PPA). Falls were recorded prospectively for 12 months using monthly calendars with the assistance of carers. ***Results:*** Seventy-one participants (43%) fell ≥2 times in the follow-up period. Impaired simple reaction time, postural sway, leaning balance and increased PPA fall risk score were significantly associated with multiple falls. The area under the receiver-operating characteristic curve for the PPA model including tests of vision, proprioception, knee extension strength, reaction time, postural sway and leaning balance was 0.75 (95% confidence interval: 0.68–0.83). ***Conclusion:*** These findings indicate poor performance on physiological fall risk factors, particularly balance, increases the risk of falls in older cognitively impaired people.

Introduction

Falls, dementia and the related costs of both pose an international health challenge. Approximately 60% of older people with dementia fall annually, a rate twice that found in cognitively intact older people [1]. Falls result in injury, institutionalization, fear, reduced quality of life,

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social isolation and loss of function [2–5]. The consequences of falls in older people with cognitive impairment and dementia are significant and include increased fracture risk, institutionalization and mortality [4, 6–8]. With population ageing, this health care challenge will grow rapidly, and it is estimated that by 2050 there will be more than 115 million people living with dementia worldwide [9].

Cognitive impairment is a known risk factor for falls [1, 10, 11]. However, the reasons behind this increased risk are poorly understood as few prospective studies have investigated fall risk in this population. A number of studies have focused purely on Alzheimer's disease [12–14] and used varying fall definitions and follow-up procedures. Asada et al. [15] found that previous falls and measures of activities of daily living were associated with fall-related injuries that required medical attention in a sample of 86 older community-dwelling people (≥55 years) diagnosed with dementia. The largest study, by Allan et al. [16], examined fall risk factors in a diverse sample of older people with dementia from both community and residential care settings. They identified cardiac medication use, poor Tinetti gait (<7) and balance (<22) scores, symptomatic orthostatic hypotension, autonomic dysfunction, depression and reduced physical activity as significant modifiable risk factors for falls [16].

Determining the relative contribution of medical conditions to risk of falling can enable clinicians to institute appropriate therapies, but attributing a degree of fall risk to a specific medical diagnosis is problematic because the severity of conditions may vary considerably among individuals. Furthermore, deterioration in sensorimotor function due to age, inactivity, medication use or minor pathology may be evident in older people with no documented medical illness. In previous studies, we have taken a physiological impairment rather than a disease-oriented approach to evaluating fall risk factors to address this issue [17]. This approach has included the development of simple tests of sensory and motor systems that measure aspects of vision, peripheral sensation, muscle strength, reaction time and balance [17]. In studies undertaken in cognitively intact older people, weighted contributions from these measures can discriminate between older multiple fallers and non-fallers with an accuracy of up to 75% [17].

To date, deficits in sensorimotor function and balance have not been sufficiently investigated as fall risk factors in older people with cognitive impairment despite being potentially modifiable and amenable to intervention. In the current study, we prospectively examined physiological fall risk factors in mild to moderate cognitively impaired community-dwelling older people with the ultimate aim of identifying risk factors to inform future intervention strategies.

Methods

Participants

One hundred and seventy-seven cognitively impaired participants were recruited from a number of routine health service settings, community services and via advertisements in the local press. Participation was dependent on (1) age ≥60 years, (2) living in the community or a low-level care facility and (3) having an identified and willing 'person responsible' with at least 3.5 h of face-to-face contact per week. Cognitive impairment was defined as a Mini-Mental State Examination <24 [18], or an Addenbrooke's Cognitive Examination-Revised <83 [19] or a diagnosis of cognitive impairment or dementia by a specialist clinician. Exclusion criteria were: recent stroke (within 18 months), progressive neurodegenerative disorders (excluding dementia), insufficient English to complete the assessments or known end-stage illness. Six hundred and seventy-one persons were screened for possible inclusion in the study. Of these, 239 (36%) did not meet the inclusion criteria. Twenty-two participants (3%) died before initial contact and 74 (11%) could not be contacted despite repeated attempts. One hundred and fourteen participants (17%) declined participation and in 42 cases (6%) the participant's carer declined. Thus 177 (26%) persons were enrolled, equating to a participation rate of potentially eligible and contactable persons of 53%. The study was approved by the South East Sydney Human Research Ethics Committee and consent was obtained from all participants and their person responsible prior to assessment.

Assessments

Participants and their person responsible were assessed in the home environment, with information obtained on demographics, medical and medication history and usual level of function.

Physiological Assessment

Physiological function was assessed with the short-form Physiological Profile Assessment (PPA), a validated measure of fall risk involving tests of vision, simple reaction time, proprioception, knee extension strength and postural sway (fig. 1a) [17]. *Visual contrast sensitivity* was assessed using the Melbourne Edge Test (MET). The MET consists of 15 bisecting circles with reducing contrast. The edges are produced using four variations in orientation: vertical, horizontal, 45° right and 45° left [17]. Participants were encouraged to wear their usual reading glasses. A response card was used and a response was forced where possible. *Proprioception* was measured using a composite lower limb matching task, primarily involving the knee and ankle joints. In this test, participants are seated with their eyes closed. They were asked to align their lower limbs simultaneously on either side of a vertical clear acrylic sheet (60 × 60 × 1 cm) inscribed with a protractor and placed between their legs. Error in degrees in matching the position of the great toes was recorded [17]. *Knee extension strength* in kilogram-force was measured in the dominant leg with participants seated [17]. The angle of the hip to the knee was 90° and the

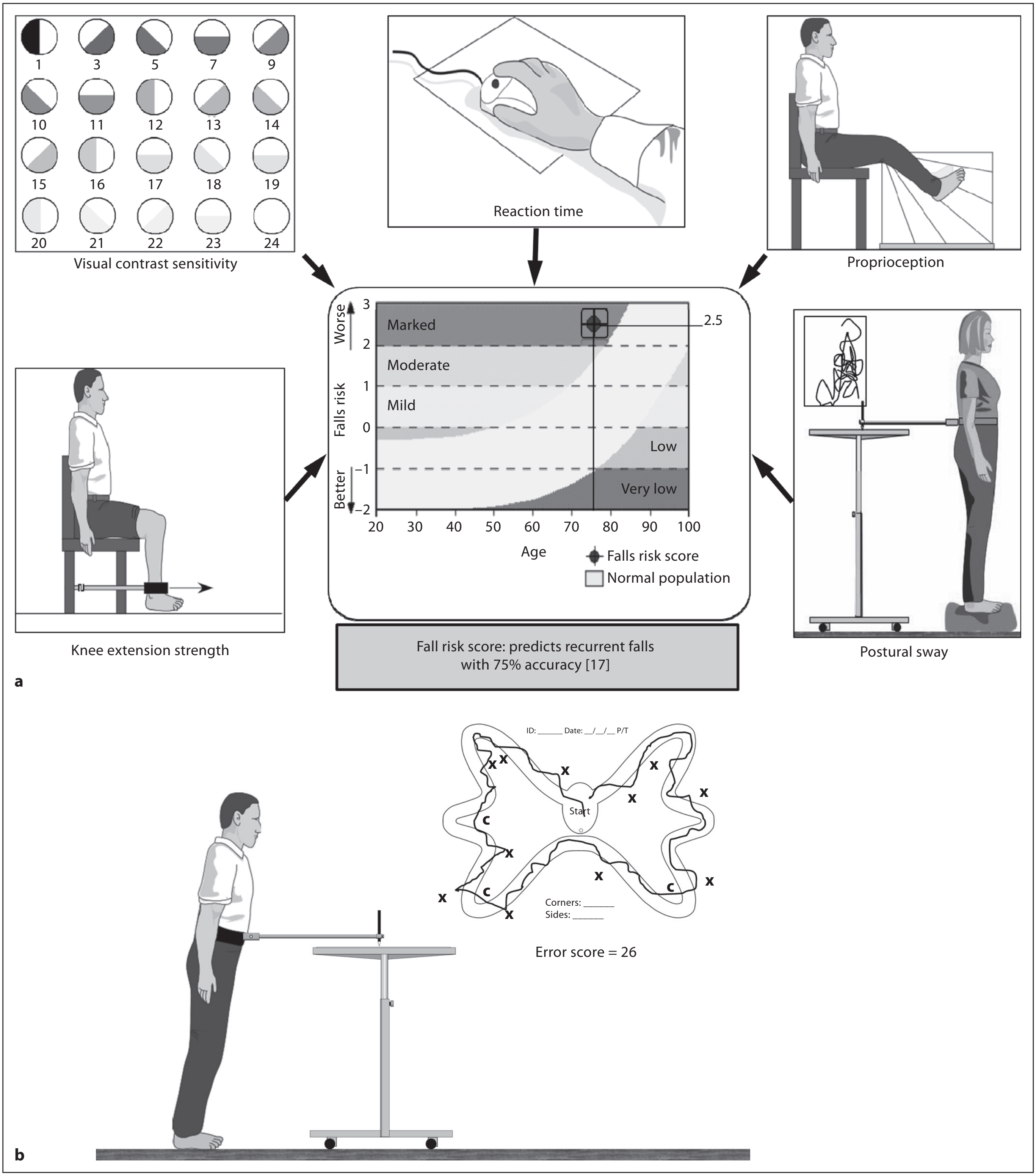

Fig. 1. **a** Physiological Profile Assessment – short form. **b** Coordinated Stability: a controlled-leaning test.

best of three trials was recorded. *Simple hand reaction time* was measured using a visual stimulus and a finger press response; the average of ten trials was recorded in milliseconds [17]. *Postural sway* was measured using a swaymeter that measured displacements of the body at the level of the waist for a 30-second period [17]. Testing was performed with participants standing on a firm surface, as well as foam rubber mat (65 × 65 × 15 cm thick) with eyes open. In previous studies, weighted contributions from these five variables (not including sway on floor) provided a fall risk score that can predict those at risk of multiple falls with 75% accuracy in cognitively intact community- and hostel-dwelling older people [11, 17, 20, 21]. The standardized canonical correlation coefficients from a community-dwelling sample [20] were –0.33 for visual contrast sensitivity, 0.20 for proprioception, –0.16 for knee extension strength, 0.47 for simple reaction time and 0.51 for sway on foam. Whilst this assessment is used predominantly in cognitively intact populations, preliminary studies have shown that it is feasible in people with Alzheimer's disease [22, 23] and other forms of cognitive impairment [24].

The coordinated stability test was administered as a measure of controlled leaning balance. This test measures the participants' ability to adjust body position in a steady and coordinated way while placing them at or near the limits of their base of support (fig. 1b) [25]. In this test, the swaymeter (described above) is attached to the participant at waist level, with the rod extending anteriorly. A pen at the end of the rod rests on a piece of paper attached to an adjustable-height table in front. Participants were then asked to adjust the position of their body without moving their feet so that the pen followed and remained within a convoluted track marked on the piece of paper. To complete the test without errors, participants had to remain within the 1.3-cm-wide track and therefore be capable of adjusting the position of the pen 25 cm laterally and 18 cm anteroposteriorly. A total error score was calculated by summing the number of occasions that the pen on the swaymeter failed to stay within the path. Where participants failed to negotiate an outside corner, 5 additional points were accrued. This score was corrected for body height [score × (participant's height/average height of sample)]. Participants attempted the test twice, with the better trial taken as the test result.

Follow-Up of Falls

Monthly falls calendars and reply-paid envelopes were given to the participants/carers to ensure accurate data collection with regard to falls. The fall definition articulated to the participant and carer was: 'In the past month, have you had any falls including a slip or a trip in which you lost your balance and landed on the floor or ground or lower level?' [26]. If a participant/carer failed to return a calendar, a telephone call was made to the participant/carer/person responsible to obtain the participant's falls data. A multiple faller was defined as someone who fell at least twice during the 12-month follow-up period.

Statistical Analysis

For continuous variables with skewed distributions, data were normalized and all parametric analyses were conducted on normalized data. Missing value imputation was performed to provide knee extension strength scores for participants who were unable to perform the test due to contraindications such as lower limb wounds, severe oedema or recent hernia operation (n = 27). Participants who were physically unable to perform a physiological test were given scores three SDs worse than the mean and included in the analysis. Extreme scores in any test were also censored at three SDs worse than the mean. In line with previous studies evaluating the PPA, multiple fallers were compared to non-multiple fallers as it has been reported that recurrent falls are more likely to indicate physiological impairments and chronic conditions and are therefore more clinically important [11, 27]. Univariate logistic regression analysis was initially used to determine which physiological variables were associated with multiple falls and odds ratios with 95% confidence intervals (95% CIs) for these continuously scored variables are presented in terms of SD increments. Multivariate logistic regression analysis was then used to determine whether the short-form PPA items were able to discriminate between non-multiple and multiple fallers and whether additional physiological measures could add to the discrimination between the faller groups. In line with our physiological approach described in the Introduction, the regression analyses were not further adjusted for sociodemographic or medical variables. Discrimination (the ability of a model to distinguish between non-multiple fallers and multiple fallers) was quantified using the area under the receiver-operating characteristic curve (AUC). The data were analysed with SPSS (SPSS Inc., Chicago, Ill., USA) and STATA (StataCorp LP, College Station, Tex., USA) statistical programs.

Results

Follow-up data on falls were available for 165 participants. Of the 12 participants for whom follow-up data were missing, 4 died, 3 moved to a nursing home before the initial assessment was completed, 2 were lost to follow-up and 3 withdrew. There were a total of 340 (range 0–28) falls in the 165 participants with follow-up data on falls. Fifty-eight (35%) participants did not fall during the follow-up period, 36 (22%) fell once, 24 (15%) fell twice, 14 (9%) fell 3 times, 10 (6%) fell 4 times and 23 (14%) fell 5 or more times. Overall, 107 (65%) participants fell at least once and 71 (43%) fell twice or more in the 12-month follow-up period.

Baseline demographic characteristics, medical history and medication use for the non-multiple fallers and multiple fallers are displayed in table 1. Multiple fallers were more likely to have fallen in the previous year, use a walking-aid indoors, take more medications and report medical conditions such as cardiac arrhythmias and claudication.

Physiological performance scores for the non-multiple fallers and multiple fallers are displayed in table 2. In univariate analyses, multiple fallers performed significantly worse on simple reaction time, in all measures of balance and had higher overall PPA fall risk scores. These significant associations were also evident when non-fallers (0 falls) and fallers (≥1 falls) were compared.

Table 1. Participant characteristics: displaying p values for univariate analysis

Variable	Non-multiple fallers (n = 94)	Multiple faller (n = 71)	p value
Demographics			
Age	81.6±6.9	83.1±6.8	0.172
Female	55 (59)	39 (55)	0.646
Height, cm	162±10	161±8	0.407
Weight, kg	66.7±14.2	65.4±11.9	0.553
Body mass index	25.0±4.1	25.3±4.4	0.810
Falls in the past year	48 (51)	55 (79)	<0.001
Indoor walking-aid use	21 (23)	29 (41)	0.012
Education, years	9.9±2.6	9.8±2.8	0.744
Low-level care resident	24 (26)	16 (23)	0.657
MMSE[1]	23.1±4.0	22.1±4.4	0.158
0–20	23 (25)	26 (37)	–
21–23	24 (26)	13 (18)	–
24–26	23 (26)	20 (28)	–
27–30	24 (26)	12 (17)	–
ACE–R[1]	66.0±12.8	64.0±13.8	0.344
0–56	21 (23)	23 (33)	–
57–68	26 (28)	16 (23)	–
69–76	24 (26)	13 (19)	–
77–100	21 (23)	17 (25)	–
Medical history			
Stroke	14 (15)	12 (17)	0.726
Ischaemic heart disease	27 (29)	18 (25)	0.630
Cardiac arrhythmias	15 (16)	23 (32)	0.013
Hypertension	55 (59)	48 (68)	0.232
Increased cholesterol	44 (48)	33 (48)	1.000
Diabetes	12 (13)	13 (18)	0.325
Claudication	0 (0)	5 (8)	0.015
Arthritis	55 (60)	51 (72)	0.110
Osteoporosis	25 (28)	22 (32)	0.574
Lightheaded on standing	23 (25)	24 (36)	0.152
Depression	20 (23)	24 (35)	0.087
Medication use			
Total number	5.7±3.4	7.2±3.5	0.009
Benzodiazepine use	13 (14)	13 (18)	0.434
Antidepressant use	17 (18)	16 (23)	0.479

Values are means + SD, n and percentages in parentheses. MMSE = Mini-Mental State Examination (/30), ACE–R = Addenbrooke's Examination-Revised (/100).

[1] A higher score represents better performance.

Multivariate logistic regression was initially undertaken on a model that included the 5 items of the short-form PPA (vision, simple reaction time, proprioception, knee extension strength and postural sway on foam). The AUC for this model was 0.70 (95% CI 0.61–0.78). A second analysis was then performed on a model including the above 5 items and coordinated stability. The AUC for this model was 0.75 (95% CI 0.68–0.83), higher than that of the first model, though not significantly (p = 0.060). The adjusted odds ratios for the individual items in both models are shown in table 3.

Discussion

In this prospective study of community-dwelling cognitively impaired older people, we found that 65% of participants fell one or more times in the follow-up year, with 43% reporting multiple falls. This prevalence of falls is approximately twice the rate reported for cognitively intact older people [1] and is similar to other studies that have used rigorous fall-reporting methods in older people with dementia [16]. The results highlight impaired balance, a deficit that can potentially be addressed with intervention as the major contributor to fall risk in this vulnerable population.

Balance deficits have been identified as a fall risk factor in previous studies of people with cognitive impairment [16] and Alzheimer's disease [14]. Standing balance control (postural sway) and controlled leaning balance (coordinated stability) were identified as significant and independent risk factors for falls. The coordinated stability test has previously been shown to have excellent reliability in a population of older people with Alzheimer's disease [22] as well as good reliability and sensitivity to change (with exercise) in cognitively intact older people [25]. It measures dynamic balance and requires shifting of weight to the limits of the base of support and thus may provide an indicator of the ability of older people to undertake many common daily activities that require near limits of equilibrium, such as reaching, bending and changing direction whilst walking. The inclusion of sway on foam, in the multivariate model indicates this measure, which provides an index of standing balance control, contributes substantially to predicting falls.

Cognitively impaired older people are slower in tests of reaction time when compared to their cognitively intact peers [22–24, 28], and reaction time has previously been found to be an independent predictor of falls in cognitively intact older people [11, 20]. One previous study, involving 110 residents of care homes with cognitive impairment also examined reaction time as a fall risk factor. In this care home population, reaction times were very

Table 2. Physiological performance of non-multiple fallers and multiple fallers: univariate analysis

Physiological variable[a,b]	Non-multiple faller (n = 94)	Multiple faller (n = 71)	OR and 95% CI	p value
Visual contrast sensitivity, dB[c]	19.4±3.3	18.6±2.9	0.792 (0.581–1.080)	0.140
Proprioception, degrees[c]	2.4±1.5	2.7±1.9	1.190 (0.872–1.624)	0.272
Knee extension strength, kg[c,e]	20.7±10.3	19.1±7.4	0.840 (0.614–1.150)	0.276
Simple reaction time, ms[c]	303.2±136.5	347.9±138.6	1.482 (1.081–2.032)	0.015
Sway on floor, EO, mm^2	511±614	760±812	1.496 (1.071–2.088)	0.018
Sway on foam, EO[c], mm^2	2,588±2566	4,104±2808	1.914 (1.360–2.694)	<0.001
Coordinated stability, errors[d]	27±20	47±26	2.464 (1.677–3.621)	<0.001
PPA falls risk score	1.86±1.85	3.01±1.62	1.969 (1.391–2.788)	<0.001

Values are means ± SD. OR = Odds ratio; EO = eyes open.

[a] Participants who were physically unable to perform a physiological test were given scores 3 SDs worse than the mean and included in the analysis (proprioception, n = 2; sway on floor, n = 4; sway on foam, n = 44, and coordinated stability, n = 24).

[b] Participants who were cognitively unable to perform the test were given the population average (MET, n = 2; proprioception n = 2). Extreme scores in any test were censored at 3 SDs worse than the mean (MET, n = 6; proprioception, n = 2; simple reaction time, n = 3; sway on floor, n = 2; sway on foam, n = 3, and coordinated stability, n = 1).

[c] Measures incorporated into PPA falls risk score.

[d] n = 155; 1 participant cognitively unable to perform task – no score given.

[e] Missing value imputation was performed to provide knee extension strength scores for participants who were unable to perform the test due to contraindications, e.g. lower limb wounds (n = 27).

Table 3. Multivariate logistic regression: physiological variables – non-faller and multiple-faller discrimination

Physiological variable	Model 1		Model 2	
	OR and 95% CI	p value	OR and 95% CI	p value
Visual contrast sensitivity	1.014 (0.709–1.451)	0.938	1.082 (0.719–1.630)	0.705
Proprioception	1.098 (0.788–1.530)	0.581	0.974 (0.678–1.398)	0.885
Knee extension strength	1.114 (0.771–1.611)	0.565	1.470 (0.968–2.233)	0.070
Simple reaction time	1.363 (0.955–1.945)	0.088	1.160 (0.781–1.722)	0.463
Sway on foam, eyes open	1.840 (1.269–2.668)	0.001	1.524 (1.007–2.307)	0.046
Coordinated stability	–	–	2.425 (1.481–3.968)	<0.001

Model 1: 5-item PPA; Model 2: 5-item PPA and coordinated stability.

slow and there was a trend for slow reaction time to be a risk factor for falls. When a reaction time cut point of >453 ms was used, 43% of fallers were categorized as slow compared with 29% of non-fallers [29]. In the current study, we identified reaction time as a fall risk factor in univariate analysis, but the fact that this measure was not included as an independent predictor in the multivariate models suggests it is not as important as balance control in predicting fall risk in community-dwelling older people with cognitive impairment.

Compared to age-matched cognitively intact peers, the current sample performed relatively well in the contrast sensitivity and proprioception tests [28]. This may indicate that these senses are relatively unaffected, over and above age-related changes, in cognitive impairment. There were trends for both vision and proprioception, indicating that fallers performed worse than non-fallers, but it seems that factors more directly related to balance control were more important in predisposing older people with cognitive impairment to falls.

The overall PPA fall risk score was significantly associated with falls, though not all of its components were associated with falls in this population. The multivariate model that included the 5 components of the short-form PPA performed reasonably well (model 1: AUC = 0.70) though not as well as when validated in cognitively intact older people [17]. This appears to be due the lack of faller group discrimination demonstrated by visual contrast sensitivity, proprioception and knee extension strength in the current sample. The addition of a complementary balance measure, coordinated stability, improved the model (model 2: AUC = 0.75).

The main study limitation relates to the non-random sampling of the study population, a method not practical for recruitment of a population subgroup unlikely to participate. We did, however, recruit participants from a range of existing health care settings – mainly cognitive disorders and memory clinics as well as dementia day care centres. Also, we acknowledge that our sample was a heterogeneous one that is likely to have included people with Alzheimer's disease, vascular dementia, dementia with Lewy bodies, as well as mixed dementia. However, we feel our sample reflects the heterogeneous nature of the cognitively impaired population accessing our health care system. Further, although the underlying pathologies may be different, the PPA measures common physiological endpoints (notably poor balance and muscle weakness) that would provide direction for impairment/functional based interventions. We used rigorous fall follow-up procedures including monthly calendars, telephone calls and involved an informant/carer/person responsible. The fall prevalence in this study is similar to that in other studies involving cognitively impaired participants [16] and is twice as high as that commonly reported in cognitively intact older people [1]. However, despite these measures, it is possible that not all falls were reported in this study due to participants' impaired recall.

To date, only one fall prevention intervention study in community-dwelling cognitively impaired older people has been conducted [30]. Shaw et al. [30] implemented a multifactorial intervention known to be effective in cognitively intact older people, and this was not effective in preventing falls. This may in part reflect our limited understanding of factors that increase fall risk in cognitively impaired older people and highlights the importance of identifying modifiable fall risk factors for targeted intervention. From the current study, fall prevention programmes for cognitively impaired older people should target static and dynamic balance and possibly include elements aimed at improving reaction time and, to a lesser extent, strength. The main inclusion items for an exercise intervention do not differ significantly from those applied in cognitively intact older people. However, the delivery of such a programme needs to take into account both the physical and cognitive functioning of the person and therefore may differ considerably. We have previously demonstrated that this cohort of cognitively impaired older people performs significantly worse than age-sex matched cognitively intact people in measures of reaction time, strength and balance (both static and dynamic), perhaps explaining why fall rates are considerably higher in this population [28]. Thus, an exercise intervention should be tailored and may need to continue for longer to achieve 'protective' levels of physiological function. When considering cognitive function, an exercise intervention may need to involve carers who could provide supervision for a home exercise programme or group exercise could be undertaken in smaller groups, with higher therapist-to-participant ratio.

There is emerging evidence that physical functioning can be improved in cognitively impaired older people [31, 32]. Hauer et al. [31] recently demonstrated that a tailored exercise programme produced significant improvements in strength, balance and functional measures in older people with mild to moderate dementia recently discharged from rehabilitation.

It is possible that weakness, poor coordination and instability are in part due to pathological changes in the brain that also contribute to cognitive decline. This has implications for the implementation of fall prevention initiatives for cognitively impaired older people, with evidence to support shared pathways for cognitive and physical performance. For example, functional brain magnetic resonance imaging has shown improved cortical connectivity in healthy older people participating in an aerobic exercise programme [33], and resistance training has been associated with improved executive function [34] and mood [35]. Also, in one small study involving older people with Alzheimer's disease living in residential care, cognitive function improved with a 3 times weekly exercise programme, and these changes were significantly different from those observed in the control group [32]. More research is needed to understand the complex relationship between physiological function and cognition, and whether improvements in physiological function translate into reduced fall rates and injuries in cognitively impaired older people.

In conclusion, this study has identified physiological risk factors for falls in cognitively impaired older people that are potentially amenable to intervention. These are likely to be exercise based and form part of a multifactorial intervention also addressing other important risk factors for this group. Given the high rate of recurrent falls and fall-related injury in this population, it is imperative that more research is undertaken to develop effective intervention strategies. Clearly, the approaches taken need to target identified deficits and take into account the cognitive reserve of the participants so as to develop fall prevention strategies that are both effective and sustainable.

Acknowledgements

This research was conducted as part of a study on Identification and Quantification of Risk of Falls in Cognitively Impaired Older Adults, which has been funded by Australian National Health and Medical Research Council (NHMRC) Grant 455235. S.R.L. is currently an NHMRC Senior Principal Research Fellow and K.D. is an NHMRC Career Development Fellow. The authors would like to thank Jodie Martin (research assistant) for her contribution to participant recruitment, assessment and data entry.

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