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Trunk inclination and hip extension mobility, but not thoracic kyphosis angle, are related to 3D-accelerometry based gait alterations and increased fall-risk in older persons

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ABSTRACT

Background: Only a portion of the increased variability in gait parameters observed in ageing can be explained by age and gait speed alone. Other factors, like musculoskeletal changes of the spine, might contribute to higher variability of gait parameters, slower walking speed and subsequently increased fall-risk in ageing.
Research question: Are spinal posture and mobility related to 3D-accelerometry based gait analysis, functional performance and fall-risk in ageing?
Methods: Forty elderly presenting increased fall-risk (OFR, 80.6 ± 5.4yrs), 41 old controls (OC, 79.1 ± 4.9yrs), and 40 young controls (YC, 21.6 ± 1.4yrs) were assessed for spinal posture and mobility (SpinalMouse®), gait analysis (DynaPort MiniMod), and functional performance (grip strength, grip work, timed-get-up-and-go-test, performance-oriented mobility assessment).
Results: Compared to OC, OFR showed significantly ($p < .05$) larger trunk inclination angle (INC), smaller sacral extension mobility, slower walking speed, and lower medio-lateral step and stride regularity. Thoracic kyphosis angle (TKA) was similar in all groups. INC and sacral extension mobility showed the highest correlation with walking speed, gait parameters, functional performance and fall-risk. INC (OR = 1.14) and sacral extension mobility (OR = 1.12) can moderately explain fall-risk in elderly participants and showed fair capacity to discriminate OFR from OC, the diagnostic value on fall-risk is however low (best probabilistic cut-off value, INC: -0.83° [sensitivity = 70%, specificity = 61%, PPV = 64%, NPV = 68%, LR+ = 1.79, LR- = 0.49, AUC = 0.71]; sacral extension mobility: 8.5° [sensitivity = 70%, specificity = 73%, PPV = 72%, NPV = 71%, LR+ = 2.61, LR - = 0.41, AUC = 0.71]).
Significance: Larger trunk inclination and smaller sacral extension mobility (i.e. hip extension mobility) are moderately related to increased fall-risk, gait alterations, lower muscle performance and worse functional mobility in ageing. Contrary to our hypothesis, TKA showed no relation with parameters of gait and/or fall-risk. INC and sacral extension mobility have fair discriminative power to distinguish older persons with increased fall-risk from those without and might be considered as therapeutic targets.

1. Introduction

Musculoskeletal changes due to ageing can contribute to slower walking speed [1], which is associated with frailty [1], increased fall-risk [2] and mortality [3] in older adults. Walking speed is related to qualitative and quantitative aspects of gait, for which the lower extremities and the spine are the major contributing bodily structures. Therefore, lower extremity and spine function are jointly linked to gait

Abbreviations: INC, trunk inclination angle; LLA, lumbar lordosis angle; OC, old controls; OFR, elderly presenting increased fall-risk; POMA, performance-oriented mobility assessment; SIA, sacral inclination angle; TKA, thoracic kyphosis angle; WS, walking speed; YC, young controls

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characteristics [4]. Ageing-related changes in these structures are therefore most likely to influence gait parameters in older persons, and possibly trunk posture adaptation precedes decline in gait speed in frailty [5].

On the one hand, ageing-related alterations in spinal structures and function (e.g. degenerative disc disease, spondylarthrosis, osteoporosis, low-impact fractures, pain, decreased segmental mobility/stability, decreased muscle performance) can lead to poor posture and mobility disorders of the vertebral column [6]. A distinctive feature of poor posture in ageing is a pronounced thoracic kyphosis (hyperkyphosis), which is present in 20–40% of older persons [6]. Conversely, age-related alterations in structures and functions of the lower extremity (e.g. sarcopenia, osteoarthritis, osteoporosis, pain, decreased joint mobility/stability, decreased muscle performance) can negatively influence gait [1], impacting balance and increasing fall-risk [7]. Falls occur in 30–60% of older adults yearly [7,8]. Hyperkyphosis and falls at higher age, for which the aetiology is multifactorial and complex, can be considered as distinctive geriatric syndromes [6,8] and are associated with adverse health outcome [6–8].

The ageing-related increased variability of gait features and increased fall-risk can partly be explained by age and gait speed alone [9]. Other factors like loss of strength and flexibility of the spine and lower extremity could contribute to the higher variability in gait parameters in ageing [10].

Early exercise interventions targeting posture and gait may help to delay progression to frailty and maintain independence [5]. However, the influence of musculoskeletal changes of the spine on gait parameters and fall-risk in ageing remain unclear [4]. Therefore, this explorative cross-sectional study aimed to investigate which aspects of spinal posture and mobility are related to 3D-accelerometry based gait analysis, clinical correlates of gait and fall-risk in ageing.

2. Methods

2.1. Participants

121 persons participated: 40 elderly presenting increased fall-risk (OFR, aged ≥65 years); 41 elderly controls (OC, aged ≥65 years); and 40 young controls (YC, aged 18–30 years). Elderly participants were recruited from the geriatric department of a university hospital, from the research department's database of elderly volunteers, and from seniors' organisations. YC were recruited among staff and students of the university. Subjects were screened for exclusion criteria by interview and excluded when cognitively deficient (Mini-Mental-State-Examination score ≤23/30, or when unable to understand/perform the test instructions/procedures); when unable to walk 20 m without assistance; when presenting with Parkinson's disease or antecedents of cerebro-vascular accidents with loco-motor disability. Co-morbidity was not an exclusion criterion per se, except for acute/uncontrolled conditions. The local ethical committee approved the study protocol and all participants gave written informed consent.

2.2. Measurements

2.2.1. Muscle performance

Grip strength and endurance of the dominant hand were measured using the Martin Vigorimeter (Elmed Inc., Addisson, USA). The subject was asked to squeeze the large bulb of the Vigorimeter as hard as possible; the highest of three attempts was considered as maximal grip strength (kPa). Afterwards, the subject was instructed to squeeze the bulb as hard as possible and to maintain this maximal pressure; the time (seconds) during which grip strength dropped to 50% of its maximum was recorded as fatigue resistance. Grip work was calculated by multiplying the fatigue resistance by 75% of the maximal grip strength [11].

2.2.2. Increased fall-risk

Increased fall-risk was documented by a positive score on at least one of three different criteria: a recent (previous 6 months) history of fall(s), defined as unintentionally coming down on the floor or a lower level, not induced by a major intrinsic or extrinsic event and/or Timed-Get-Up-and-Go-test > 15seconds and/or Performance-Oriented Mobility Assessment (POMA-Balance/Gait) score ≤24/28; which are respectively a self-reported scale, a single-task, and a multiple-task performance test (a more valid method for identifying fall-risk than each test alone) [12].

2.2.3. Spinal posture & mobility

Spinal posture and mobility were assessed using a SpinalMouse® (Idiag, Fehraltorf, Switzerland), comprising a hand-held inclinometer connected wirelessly to a computer. The SpinalMouse® was rolled paravertebrally along the spine from the 7th cervical to the 3rd sacral vertebra (rima ani) while the patient was standing barefoot and holding the arms crossed in front of the chest: first with the spine in a neutral upright position, then maximally flexed and, finally, maximally extended; with emphasis on end-range positions of the spine and hips (knees extended) [13]. The SpinalMouse® software provides a table with inclination angles at each vertebral segment. The three positions were measured 3 times consecutively and the mean inclination at each vertebral segment was calculated. Spinal posture was assessed by the mean (sum of segments) upright inclination angles from the thoracic spine (TKA), lumbar spine (LLA) and sacral spine (SIA). Also, the mean inclination angle of the total spine was assessed, comprising the angle between a vertical line from C7 to S3 and the plumb line, called the trunk inclination angle (INC) [14]. The mobility of the thoracic spine, lumbar spine and sacral spine were calculated by subtracting the mean upright values from the mean flexion values for flexion mobility and subtracting the mean extension values from the mean upright values for extension mobility. Although the mobility measured at the level of the sacral spine is mainly hip induced, for the sake of readability, the measurements obtained from the sacral spine are called as such (Fig. 1). The SpinalMouse® has proven to be a reliable tool for regional assessment of spinal posture and mobility (intra-observer reliability ICC = 0.89–0.99, SEM = 1.15°–2.05°) [13] and correlates well with Rx (r = .73–.76) [15].

2.2.4. Gait analysis procedure and data processing

A 3-D piezoresistive accelerometer (DynaPort MiniMod, McRoberts, The Hague, the Netherlands) was positioned with a neoprene strap at the sacrum between the spinae ilaca posterior superior. Two strips were taped on the floor of a straight hospital corridor with 18 m distance in between. Subjects were instructed first to stand immobile just before the first mark, then to walk comfortably to the next mark and to stop and stand immobile when he/she passed that mark. The exact distance covered was measured to the nearest 0.01 m and recorded as walk-1. Next, the same procedure was repeated for the way back (walk-2). After walk-2, the accelerometer was removed and the raw accelerometer data were uploaded on a local computer using DynaPort GAIT-test acquisition software (MiRA1.9.4.b2; McRoberts, The Hague, the Netherlands) and signals corresponding to each walk were identified. Accelerometer data were processed via GaitWeb. The mean values of two walks were used for statistical analysis of gait parameters. The procedure showed high reliability when based on two walks of 18 m for walking speed (WS), step and stride regularity (intra-observer reliability ICC = 0.81–0.99; inter-observer reliability ICC = 0.84–0.99). Data processing and calculation of gait parameters have been described more in detail elsewhere [2]. 3D-accelerometry based gait analysis and SpinalMouse® assessment were performed by separate assessors who were blinded for other outcomes.

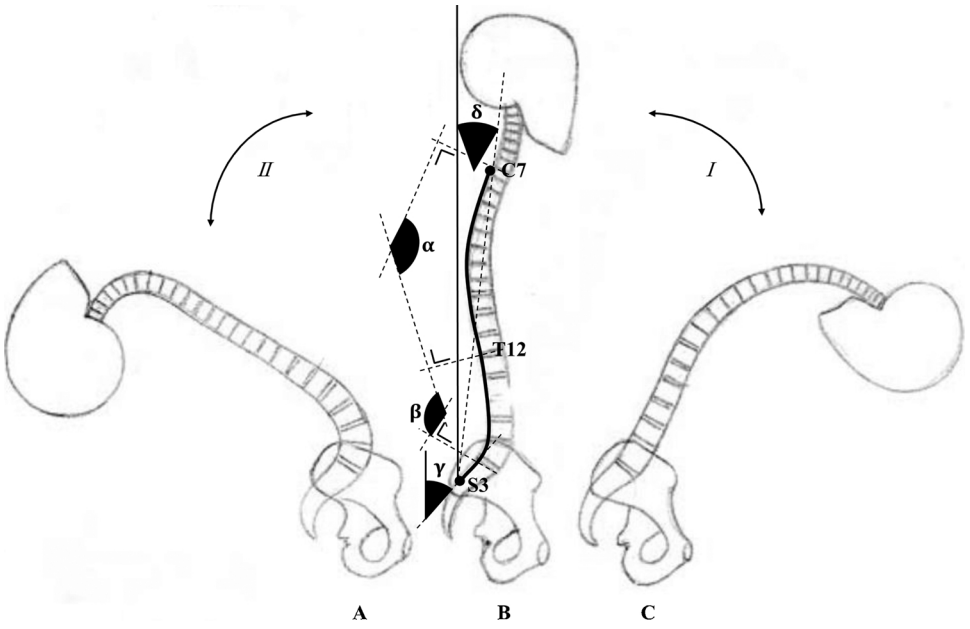


Fig. 1. SpinalMouse® positions, movements and angles: **A** Maximally extended, **B** Upright, **C** Maximally flexed, **I** Flexion mobility, **II** Extension mobility, **α** Thoracic kyphosis angle (TKA), **β** Lumbar lordosis angle (LLA), γ Sacral inclination angle (SIA), **δ** Trunk inclination angle (INC); positive values ventral of plumb line, negative values dorsal of plumb line.

Table 1
Participants' characteristics.

Parameter	OFR	OC	YC
Sex (male / female)	20/20	21/20	20/20
Age (years)	*80.6 ± 5.4†*	*79.1 ± 4.9†*	*21.6 ± 1.4*
Height (centimetre)	161.8 ± 12.1†	164.6 ± 7.7†	175.3 ± 8.0
Weight (kilogram)	66.9 ± 15.0	69.7 ± 11.4	68.7 ± 13.4
Body Mass Index (kg/m^2)	25.5 ± 4.3†	25.7 ± 3.6†	22.2 ± 3.3
MMSE (score 0-30)	*27.4 ± 2.2**	*28.3 ± 1.4†*	*30.0 ± 0.0*
bADL-dependency (score 8-32)	8.7 ± 0.9*	8.3 ± 0.6	8.0 ± 0.0
iADL-dependency (9-27)	22.6 ± 3.0*	24.4 ± 2.0†	27.0 ± 0.0
Grip strength (kPa)	48.9 ± 17.8†	58.7 ± 17.5†	98.9 ± 23.5
Grip work (kPa x seconds)	2279.1 ± 1585.0†	2646.1 ± 1249.0†	3475.1 ± 1373.3
Co-morbidity (number)	*3.0 ± 1.4†*	*2.9 ± 1.3†*	*0.3 ± 0.5*
Low-impact fracture (yes/no)	2/38	2/39	0/40
Medication use (number)	*4.7 ± 2.9†*	*4.0 ± 3.0†*	*0.2 ± 0.5*
Timed-get-up-and-go (seconds)	*15.6 ± 10.8**	*8.8 ± 1.7*	*5.8 ± 1.2*
POMA-Balance (score 0-16)	*13.6 ± 1.8**	*15.3 ± 0.8†*	*16.0 ± 0.0*
POMA-Gait (score 0-12)	*10.7 ± 1.4**	*11.9 ± 0.4*	*12.0 ± 0.0*
Fall(s) in history (yes/no)	30/10	0/41	0/40
Upright position			
Thoracic kyphosis angle (degrees)	52.6 ± 14.4	54.0 ± 10.5	51.6 ± 10.3
Lumbar lordosis angle (degrees)	−19.6 ± 11.9†	−22.2 ± 11.6†	−32.9 ± 8.1
Sacral inclination angle (degrees)	6.9 ± 7.8†	4.9 ± 9.9†	12.0 ± 6.1
Trunk inclination angle (degrees)	2.9 ± 6.6*	−1.4 ± 3.6†	−4.9 ± 2.7
Flexion mobility			
Thoracic (degrees)	10.1 ± 7.2†	10.5 ± 6.0†	19.5 ± 9.9
Lumbar (degrees)	28.4 ± 12.1†	31.3 ± 9.3†	60.4 ± 9.0
Sacral (degrees)	55.2 ± 18.7	62.5 ± 12.9†	48.9 ± 13.7
Extension mobility			
Thoracic (degrees)	13.7 ± 6.1	15.1 ± 6.4	15.3 ± 6.9
Lumbar (degrees)	3.7 ± 3.4†	4.0 ± 4.3†	9.5 ± 7.6
Sacral (degrees)	7.5 ± 4.3*	11.1 ± 5.3†	16.0 ± 8.9
Walking Speed (m/s)	0.95 ± 0.28*	1.27 ± 0.19†	1.54 ± 0.15
Step Time Asymmetry (%)	*0.05 ± 0.05*	*0.05 ± 0.05*	*0.05 ± 0.06*
Step Regularity			
Cranio-caudal (r-coefficient)	0.71 ± 0.15	0.82 ± 0.10‡	0.70 ± 0.19
Medio-lateral (r-coefficient)	−0.43 ± 0.15*	−0.53 ± 0.18†	−0.64 ± 0.12
Stride Regularity			
Cranio-caudal (r-coefficient)	0.71 ± 0.18	0.83 ± 0.10‡	0.72 ± 0.19
Medio-lateral (r-coefficient)	0.50 ± 0.17*	0.60 ± 0.15	0.66 ± 0.12

Mean ± SD or number; OFR = Old fall risk, OC = Old controls, YC = Young controls; Significantly different *from OC and YC, †from YC, ‡from OFR and YC; One-way ANOVA with Bonferroni post-hoc test or Kruskal-Wallis test [*in italic*], $p < .05$.

Table 2
Relationships between spinal posture & mobility, and 3D-accelerometry based gait analysis.

	Walking Speed		Step Time Asymmetry		Step Regularity Cranio-caudal		Step Regularity Medio-lateral		Stride Regularity Cranio-caudal		Stride Regularity Medio-lateral	
	OFR + OC (∂r)	YC (r)	OFR + OC (∂r)	YC (r)	OFR + OC (∂r)	YC (r)	OFR + OC (∂r)	YC (r)	OFR + OC (∂r)	YC (r)	OFR + OC (∂r)	YC (r)
Upright position												
Thoracic kyphosis angle	−.046	.014	*.050*	*−.042*	−.058	−.022	.073	.059	−.077	−.028	−.078	−.020
Lumbar lordosis angle	.057	−.108	*−.165*	*−.126*	−.017	−.113	.034	−.028	−.021	−.113	−.082	−.022
Sacral inclination angle	**−.295†**	.063	***.270****	*.028*	−.164	.042	.030	.194	−.170	.058	.009	−.134
Trunk inclination angle	**−.457†**	−.218	***.284****	*−.270*	**−.355†**	−.239	.186	.310	**−.388†**	−.204	−.208	−.229
Flexion mobility												
Thoracic	.036	.088	*.022*	*.056*	.005	−.089	−.165	.089	−.026	−.086	.147	−.144
Lumbar	.151	.085	*−.152*	*.119*	.219	.210	−.054	.013	.126	.214	.054	.055
Sacral	**.387†**	.106	*−.176*	*−.015*	.122	−.042	−.057	−.066	.157	−.050	.124	.034
Extension mobility												
Thoracic	**.251***	−.123	*−.129*	*−.246*	.128	−.275	−.012	.036	.067	−.275	.071	−.036
Lumbar	.132	**−.418†**	***−.283****	*.060*	.024	−.024	−.109	−.016	−.042	−.008	.026	−.066
Sacral	**.462†**	.306	***−.260****	*.096*	**.287†**	.083	**−.330†**	.046	**.251***	.081	**.330†**	−.048

Pearson correlation coefficient (2-tailed), Spearman correlation coefficient for Step Time Asymmetry (2-tailed) [*in italic*], ∂ = Partial correlation coefficients controlling for age, r = 0–0.19 very weak, 0.2–0.39 weak, 0.4–0.59 moderate, 0.6–0.79 strong, 0.8–1 very strong [29], * $p < .05$, † $p < .01$.

2.3. Statistical analysis

Data were analysed using IBM-SPSS-Statistics-24.0 (SPSS Inc, Illinois, USA). Differences between groups were assessed by one-way ANOVA with Bonferroni post-hoc test. For not-normally distributed values (Kolmogorov-Smirnov-Goodness-of-Fit-test $p < .05$) Kruskal-Wallis-test was used. Correlations were analysed by Pearson correlation coefficient and for non-normally distributed values by Spearman correlation coefficient. Partial correlation coefficients controlling for age were computed also. The explanatory value of spinal posture and mobility parameters for increased fall-risk were assessed by hierarchical binary logistic regression. The discriminative capacity of spinal posture and mobility parameters according to increased fall-risk were analysed by plotting receiver operating characteristics (ROC) curves and computation of the area under the curve (AUC). Diagnostic statistics (sensitivity/specificity, PPV/NPV, LR+/LR-) were computed to test the overall model fit for predefined cut-points (sensitivity = 95%, best probabilistic cut-off value, specificity = 95%). Significance was set a priori at two-sided $p < .05$.

3. Results

As reported previously [2], OFR showed significantly lower mobility and balance, as well as slightly but significantly worse cognition and dependency compared to OC. As expected, YC were significantly taller compared to the elderly participants and showed excellent cognitive and physical functioning. There was no significant difference between the three groups in TKA and prevalent vertebral fractures were equally distributed in OFR and OC. The LLA and SIA were smaller in OFR and OC compared to YC. The three groups significantly differed in INC, with OFR having the largest INC (stooped posture) and YC the smallest INC (erect posture). Flexion mobility of the thoracic and lumbar spine were smaller in OFR and OC. Also, the extension mobility of the lumbar spine was smaller in OFR and OC. The three groups significantly differed in sacral extension mobility with OFR having the smallest sacral extension mobility and YC the largest. WS significantly differed between groups with OFR having the slowest WS. This was accompanied with lower medio-lateral step and stride regularity. Remarkably, OC had the largest sacral flexion mobility which was accompanied with higher cranio-caudal step and stride regularity (Table 1).

As shown in Tables 2 and 3, in elderly participants a more pronounced stooped posture (higher SIA/INC) was significantly related to worse scores on several gait features (WS, step time asymmetry, cranio-caudal step/stride regularity) and physical performance parameters. No significant relationships were found for TKA besides with Timed-Get-Up-and-Go-test in YC and POMA-balance in the older participants. Spinal mobility outcomes, especially lower sacral extension mobility, were significantly related to worse gait (all features) and physical performance in the older participants whereas in YC this relation was only found with step time asymmetry. Noteworthy, better thoracic mobility was related to faster WS and better scores on several physical performance outcomes.

In OFR and OC taken together, increased fall-risk (classified binary, present/absent) was significantly correlated with larger INC and smaller sacral extension mobility (Table 3). In hierarchical binary logistic regression analysis, INC and sacral extension mobility were significant explanators for increased fall-risk in elderly participants. Overall correct classification increased from 51% to 69% when both were included in the equation (Table 4). Adding age to the equation had no effect on the explanatory value of the model and therefore ruling age out as a possible confounder. The capacity to discriminate OFR from OC (best probabilistic cut-off value) shows for INC 70% sensitivity and 61% specificity when using -0.83 degrees as cut-off value (PPV = 64%, NPV = 68%, LR+ = 1.79, LR- = 0.49) and for sacral extension mobility 70% sensitivity and 73% specificity when using 8.5 degrees as cut-

Table 3
Relationships between spinal posture & mobility, and clinical measures of muscle performance, balance, mobility and fall-risk.

	Grip strength		Grip work		Timed-get-up-and-go		POMA-Balance		POMA-Gait		Fall-risk
	OFR + OC *(∂r)*	YC (r)	OFR + OC (∂r)	YC (r)	OFR + OC (∂r)	YC (r)	OFR + OC (∂r)	YC (r)	OFR + OC (∂r)	YC (r)	OFR + OC (∂r)
Upright position											
Thoracic kyphosis angle	.086	−.105	.076	.073	*.105*	***.331****	***−.241****	–	*−.209*	–	−.059
Lumbar lordosis angle	.187	.288	.040	−.050	*−.100*	*−.151*	*.001*	–	*.107*	–	.095
Sacral inclination angle	**−.341†**	−.253	**−.247***	−.033	***.290†***	*−.013*	*−.035*	–	*−.150*	–	.120
Trunk inclination angle	−.148	.190	**−.286†**	.029	***.460†***	*−.012*	***−.322†***	–	***−.322†***	–	**.357†**
Flexion mobility											
Thoracic	−.166	.139	.009	.040	*−.135*	***−.381****	***.257****	–	*.078*	–	−.055
Lumbar	−.045	−.105	.130	−.070	*−.169*	*.016*	*.111*	–	*.150*	–	−.106
Sacral	.058	−.154	**.267***	.231	***−.390†***	*.085*	***.351†***	–	***.359†***	–	−.208
Extension mobility											
Thoracic	**.254***	.040	.218	.287	***−.319†***	*.074*	*.157*	–	***.322†***	–	−.078
Lumbar	.132	**.384***	.212	.185	*−.185*	*−.156*	*.081*	–	*.107*	–	−.036
Sacral	**.283***	−.212	.147	−.076	***−.521†***	*−.209*	***.426†***	–	***.427†***	–	**−.331†**

Pearson correlation coefficient (2-tailed), Spearman correlation coefficient for Timed-get-up-and-go, POMA-Balance and POMA-Gait (2-tailed) [*in italic*], ∂= Partial correlation coefficients controlling for age, r = 0–0.19 very weak, 0.2–0.39 weak, 0.4–0.59 moderate, 0.6–0.79 strong, 0.8–1 very strong [29], Fall-risk classified binary (present / absent), * $p < .05$, † $p < .01$.

Table 4
Explanatory modelling for increased fall-risk.

Variable (Units of increase)	B (SE)	OR (95% CI)	p
Constant	.986 (.573)		
Trunk inclination angle (°)	.131 (.055)	1.140 (1.024–1.270)	.017
Sacral extension mobility (°)	.117 (.057)	1.124 (1.006–1.256)	.039

Hierarchical binary logistic regression, dependent variable: fall-risk; Cox & Snell (R^2) = .195, Nagelkerke (R^2) = .259; Hosmer & Lemeshow (χ^2) = 3.771, df = 8, p = .877, Omnibus tests of model coefficients (χ^2) = 17.521, df = 2, $p < .001$; N = 81(OFR + OC); Percentage correct 69.1% (Increased Fall-risk, Yes: 65.0%, No: 73.2%); SE = Standard Error, 95%CI = 95% Confidence Interval.

off value (PPV = 72%, NPV = 71%, LR+ = 2.61, LR- = 0.41) with both an AUC of 0.71 which is acceptable [16](Table 5).

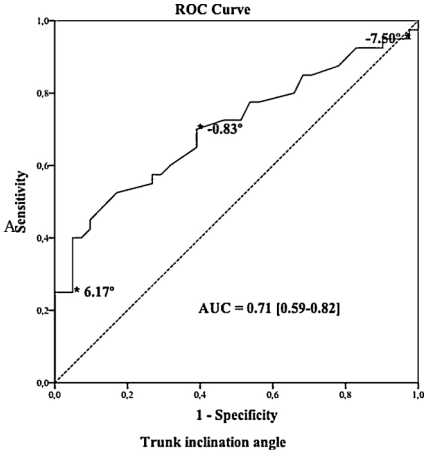
4. Discussion

Our results showed that spinal posture and mobility differed significantly according to age and fall-risk. Especially INC (mean difference = 4.26°) and hip extension mobility (mean difference = 3.58°) differed significantly between OFR and OC exceeding the measurement error (SEM INC = 1.15°, hip mobility = 1.69°) [13]. This is the first comprehensive study demonstrating that larger trunk inclination and smaller hip extension mobility correlate with fall-risk as well as with alterations in gait parameters, lower muscle performance and functional mobility. Trunk inclination and hip extension mobility can moderately explain increased fall-risk with a combined explanatory value of 69% to distinguish OFR from OC (correct fall-risk explanation: yes = 65%, no = 73%). Since diagnostic characteristics (PPV, NPV, LR +, LR-, derived from ROC-curve analysis) are small to moderate, there is no evidence for replacing simple clinical tests for diagnosing fall-risk by measuring INC and/or hip extension mobility. However, the relationships we found indicate increased INC and reduced hip extension mobility are implicated in increased fall-risk and would candidate as therapeutic targets to reduce fall-risk in older persons.

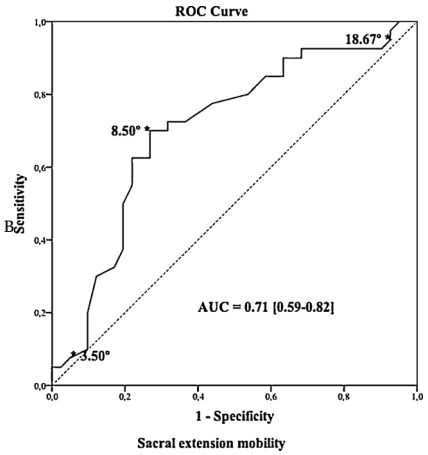
Kasukawa et al. [17] also found a significant difference in INC between fallers and non-fallers. In multiple logistic regression analyses INC was significantly related to falls (b-coefficient = 0.07, p = .04) together with grip strength, back extensor strength, LLA and lumbar spine mobility. In addition, Imagama et al. [18] found that LLA and SIA significantly correlated with balance and increased fall-risk. As well, Ishikawa et al. [19] found a significant difference between fallers and non-fallers in LLA and INC, describing decreased LLA as the only significant factor associated with a history of falls. They established a cut-off value of -3 degrees to be explanatory for falls. In our study, LLA and SIA significantly differed between old and young but showed no correlation with fall-risk. Possibly, Ishikawa et al. found no significant correlation between INC and a history of falls because of a type 2 error (only 14% fallers). In line with our results, all three studies did not find a correlation between TKA and fall-risk. Muramoto et al. [20] defined INC with a cut-off value of 6 degrees (sensitivity = 52%, specificity = 87%) to be a useful spinal parameter to evaluate for adverse outcome (locomotive syndrome), with an OR = 4.3 ($p < .01$) for fall-risk. Our results showed a smaller cut-off value of -0.83 degrees INC, which is slightly backward, to discriminate OFR from OC; in addition, the odds for belonging to OFR increased by 14% for each unit increment in INC. In contrast to our results, Ishikawa et al. [21], found lumbar extension mobility to be a significant feature for falling. In our study, we could not confirm these findings; instead, we found sacral extension mobility to be a significant factor to discriminate OFR from OC with a cut-off value of 8.5 degrees; in addition, the odds for belonging to OFR increased by 12% for each unit decrement in sacral extension mobility. Ishikawa did not evaluate sacral extension mobility in their study, and therefore they possibly detected sacral extension mobility (i.e. hip extension mobility) in lumbar extension mobility outcome by SpinalMouse®.

De Groot et al. [22] found that flexed posture (Occiput-to-Wall distance) is significantly associated with increased thoracic kyphosis (Cobb angle). They postulated that increased thoracic kyphosis may bring the body's centre of mass forward, which requires correcting responses, and reduces the ability to respond to perturbations, which is reflected by higher variation in the gait patterns. Their results indicate that elderly with flexed posture have impaired postural control during walking and might therefore be at increased risk of falling. Our results are in line with their findings except for the relation between flexed posture and increased TKA in OFR. In our study, larger INC, and to a lesser extent increased TKA, were significantly associated with lower score on POMA-Balance indicating decreased postural control. Possibly flexed posture, defining postural changes that place the INC in front of the plumb line, have more influence on parameters of gait than increased TKA alone, in which the centre of gravity can remain above the base of support. Kado et al. [23] found significant association between moderate hyperkyphosis (Rancho-Bernardo-Blocks-Method) and having a injurious fall in the past year when adjusting for age in men (OR = 1.73 [1.10–2.75]), but not in women. Tominaga et al. [24] found similar results, reporting significant association between severe kyphotic posture (Occiput-to-Wall distance) and falls, also only in men (OR = 2.14 [1.01–4.57]). In contrast, van der Jagt-Willems et al. [25]

Table 5
Diagnostic measures of accuracy for fall-risk.



Cp	Sn	Sp	PPV	NPV	LR +	LR-
−7.50º	95 (88–102)	2 (-2–7)	49 (38–60)	33 (-20–87)	0.97 (0.89–1.06)	2.05 (0.19–21.73)
−0.83º	70 (56–84)	61 (46–76)	64 (49–78)	68 (52–83)	1.79 (1.16–2.77)	0.49 (0.29–0.84)
6.17º	25 (12–38)	95 (89–102)	83 (62–104)	57 (45–68)	5.13 (1.20–21.94)	0.79 (0.65–0.96)



Cp	Sn	Sp	PPV	NPV	LR +	LR-
18.67º	95 (88–102)	7 (-1–15)	50 (39–61)	60 (17–103)	1.03 (0.92–1.15)	0.68 (0.12–3.88)
8.50º	70 (56–84)	73 (60–87)	72 (58–86)	71 (58–85)	2.61 (1.51–4.50)	0.41 (0.25–0.68)
3.50º	8 (-1–16)	95 (89–102)	60 (17–103)	51 (40–63)	1.54 (0.27–8.72)	0.97 (0.87–1.09)

Diagnostic measures of accuracy indicating the capacity to distinguish elderly presenting increased fall-risk (N = 40) from elderly controls (N = 41) for **(A)** Trunk inclination angle and **(B)** Sacral extension mobility; Cp = Cut point (º), Sn = Sensitivity (%), Sp = Specificity (%), PPV = Positive Predictive Value (%), NPV = Negative Predictive Value (%), LR + = Positive Likelihood Ratio (1–2 very small, 2–5 small, 5–10 moderate, > 10 large change from pre-test to post-test probability), LR- = Negative Likelihood Ratio (0.5–1 very small, 0.2–0.5 small, 0.1–0.2 moderate, < 0.1 large change from pre-test to post-test probability [30]), ROC = Receiver-Operating Characteristic, AUC = Area Under the Curve (discriminative capacity: 0.5 non, 0.7–0.79 acceptable, 0.8–0.89 excellent, 0.9–1 outstanding [16]); 95% Confidence intervals between parentheses.

found no significant relation between flexed posture (Occiput-to-Wall distance) and increased fall-risk, but found significant relation between hyperkyphosis (Cobb angle) and incidence of falls within twelve months (OR = 2.13 [1.10–4.51]). McDaniels-Davidson et al. [26] found two standing (Debrunner kyphometer/Flexicurve ruler,) and two lying (Cobb angle/Rancho-Bernardo-Blocks-Method) kyphosis measures relating to incident falls. Rancho-Bernardo-Blocks-Method showed highest correlation with incident (OR = 3.20 [1.38–7.46]) and injurious falls (OR = 2.41 [1.18–4.92]) within 12-months. Differentiating between increased thoracic kyphosis (Cobb angle/TKA) and flexed posture (Rancho-Bernardo-Blocks-Method/Occiput-to-Wall distance/INC), might be important when investigating the influence of postural alterations of the spine on parameters of gait and fall-risk in ageing.

Our study had some limitations and results may have been biased due to the criteria used for fall-risk assignment as described previously [2]. Several subjects in YC or OC may have presented hidden gait abnormality, which did not become apparent on the clinical evaluation, but accompanied with altered instrumented gait analysis outcomes. To limit possible cross contamination, all participants were screened using three different fall-risk criteria [12]. Secondly, assessment of spinal posture and mobility by SpinalMouse® provides only surface-based measures of the curvature of the spine in the frontal and sagittal plane, but it has proven to be reliable [13], feasible, and responsive [27] and is non-invasive. Measurements in the transverse plane of the spine regarding trunk rotations would have made a valuable contribution as it is an important factor in maintaining normal gait patterns [5]. Thirdly, direct measures of muscle function of the spine and lower extremity also could have made a valuable contribution to the results, clarifying possible relations between muscle function and gait. Fourthly, the cross-sectional design limits us to provide only an explanatory model

for the relationship between spinal posture and mobility, gait and fall-risk in the elderly and although significant the reported effect-sizes are relatively small. Strong points of our study are the relatively high sample size stratified by gender, age and fall-risk. Another strength is the use of instrumented assessment of spinal posture and mobility as well as gait analysis. Finally, we were able to identify aspects of spinal posture and mobility that can be targeted in exercise interventions (e.g. posture correction, range of motion of the hip/spine, core strength training of stabilising muscles of the hip/spine such as the abdominals, paraspinals, glutes and hip girdle) for improving posture and gait and decrease fall-risk in ageing, which are feasible, safe and effective [5,28]. Based on our results we can recommend integrating the evaluation of spinal posture and mobility in fall-risk assessment in elderly persons, further research is needed to establish the prognostic and therapeutic value.

In conclusion, our results showed that larger trunk inclination and smaller sacral extension mobility (i.e. hip extension mobility) are moderately related to increased fall-risk, gait alterations, lower muscle performance, and worse functional mobility in ageing. Contrary to our hypothesis, thoracic kyphosis showed no relation with parameters of gait and/or fall-risk. INC and sacral extension mobility have fair discriminative power to distinguish older persons with increased fall-risk from those without and might be considered as therapeutic targets.

Conflict of interest

All authors declare that they have no conflicts of interest.

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References

[1] L.P. Fried, C.M. Tangen, J. Walston, A.B. Newman, C. Hirsch, J. Gottdiener, et al., Frailty in older adults: evidence for a phenotype, J. Gerontol. A Biol. Sci. Med. Sci. 56 (2001) M146–56.
[2] I. Bautmans, B. Jansen, B. Van Keymolen, T. Mets, Reliability and clinical correlates of 3D-accelerometry based gait analysis outcomes according to age and fall-risk, Gait Posture 33 (2011) 366–372.
[3] S. Studenski, S. Perera, K. Patel, C. Rosano, K. Faulkner, M. Inzitari, et al., Gait speed and survival in older adults, JAMA. 305 (2011) 50–58.
[4] A.L. Simon, B. Ilharreborde, P. Souchet, K.R. Kaufman, Dynamic balance assessment during gait in spinal pathologies - a literature review, Orthop. Traumatol. Surg. Res. 101 (2015) 235–246.
[5] R.A. Merchant, S. Banerji, G. Singh, E. Chew, C.L. Poh, S.C. Tapawan, et al., Is trunk posture in walking a better marker than gait speed in predicting decline in function and subsequent frailty? J. Am. Med. Dir. Assoc. 17 (2016) 65–70.
[6] D.M. Kado, K. Prenovost, C. Crandall, Narrative review: hyperkyphosis in older persons, Ann. Intern. Med. 147 (2007) 330–338.
[7] L.Z. Rubenstein, Falls in older people: epidemiology, risk factors and strategies for prevention, Age Ageing 35 (Suppl 2) (2006) ii37–ii41.
[8] S.K. Inouye, S. Studenski, M.E. Tinetti, G.A. Kuchel, Geriatric syndromes: clinical, research, and policy implications of a core geriatric concept, J. Am. Geriatr. Soc. 55 (2007) 780–791.
[9] L. Alcock, N. Vanicek, T.D. O'Brien, Alterations in gait speed and age do not fully explain the changes in gait mechanics associated with healthy older women, Gait Posture 37 (2013) 586–592.
[10] H.G. Kang, J.B. Dingwell, Separating the effects of age and walking speed on gait variability, Gait Posture 27 (2008) 572–577.
[11] I. Bautmans, E. Gorus, R. Njemini, T. Mets, Handgrip performance in relation to self-perceived fatigue, physical functioning and circulating IL-6 in elderly persons without inflammation, BMC Geriatr. 7 (2007) 5.
[12] C.C. Persad, S. Cook, B. Giordani, Assessing falls in the elderly: should we use simple screening tests or a comprehensive fall risk evaluation? Eur. J. Phys. Rehabil. Med. 46 (2010) 249–259.
[13] T. Roghani, M. Khalkhali Zavieh, A. Rahimi, S. Talebian, F. Dehghan Manshadi, A. Akbarzadeh Baghban, et al., The reliability of standing sagittal measurements of spinal curvature and range of motion in older women with and without hyperkyphosis using a skin-surface device, J. Manipul. Physiol. Ther. 40 (2017) 685–691.
[14] S. Yanagisawa, N. Sato, M. Shimizu, K. Saito, A. Yamamoto, K. Takagishi, Relation among the knee, sagittal spinal alignment, and the spinal range of motion: investigation in local medical check-ups using the SpinalMouse, Asia Pac. J. Sports Med. Arthrosc. Rehabil. Technol. 2 (2015) 68–71.
[15] M. Yousefi, S. Ilbeigi, N. Mehrshad, M.E. Afzalpour, S.E. Naghibi, Comparing the validity of non-invasive methods in measuring thoracic kyphosis and lumbar lordosis, Zahedan J. Res. Med. Sci. 14 (2012) 37–42.
[16] D. Hosmer, S. Lemeshow, Applied Logistic Regression, 2nd ed. ed., John Wiley and Sons, New York, NY, 2000.
[17] Y. Kasukawa, N. Miyakoshi, M. Hongo, Y. Ishikawa, H. Noguchi, K. Kamo, et al., Relationships between falls, spinal curvature, spinal mobility and back extensor strength in elderly people, J. Bone Miner. Metab. 28 (2010) 82–87.
[18] S. Imagama, Z. Ito, N. Wakao, T. Seki, K. Hirano, A. Muramoto, et al., Influence of spinal sagittal alignment, body balance, muscle strength, and physical ability on falling of middle-aged and elderly males, Eur. Spine J. 22 (2013) 1346–1353.
[19] Y. Ishikawa, N. Miyakoshi, Y. Kasukawa, M. Hongo, Y. Shimada, Spinal sagittal contour affecting falls: cut-off value of the lumbar spine for falls, Gait Posture 38 (2013) 260–263.
[20] A. Muramoto, S. Imagama, Z. Ito, K. Hirano, N. Ishiguro, Y. Hasegawa, Spinal sagittal balance substantially influences locomotive syndrome and physical performance in community-living middle-aged and elderly women, J. Orthop. Sci. 21 (2016) 216–221.
[21] Y. Ishikawa, N. Miyakoshi, M. Hongo, Y. Kasukawa, D. Kudo, Y. Shimada, Relationships among spinal mobility and sagittal alignment of spine and lower extremity to quality of life and risk of falls, Gait Posture 53 (2017) 98–103.
[22] M.H. de Groot, H.C. van der Jagt-Willems, J.P. van Campen, W.F. Lems, J.H. Beijnen, C.J. Lamoth, A flexed posture in elderly patients is associated with impairments in postural control during walking, Gait Posture 39 (2014) 767–772.
[23] D.M. Kado, M.H. Huang, C.B. Nguyen, E. Barrett-Connor, G.A. Greendale, Hyperkyphotic posture and risk of injurious falls in older persons: the Rancho Bernardo Study, J. Gerontol. A Biol. Sci. Med. Sci. 62 (2007) 652–657.
[24] R. Tominaga, S. Fukuma, S. Yamazaki, M. Sekiguchi, K. Otani, S. Kikuchi, et al., Relationship between kyphotic posture and falls in community-dwelling men and women: the locomotive syndrome and health outcome in aizu cohort study, Spine (Phila Pa 1976) (41) (2016) 1232–1238.
[25] H.C. van der Jagt-Willems, M.H. de Groot, J.P. van Campen, C.J. Lamoth, W.F. Lems, Associations between vertebral fractures, increased thoracic kyphosis, a flexed posture and falls in older adults: a prospective cohort study, BMC Geriatr. 15 (2015) 34.
[26] C. McDaniels-Davidson, A. Davis, D. Wing, C. Macera, S.P. Lindsay, J.T. Schousboe, et al., Kyphosis and incident falls among community-dwelling older adults, Osteoporos. Int. 29 (2018) 163–169.
[27] I. Bautmans, J. Van Arken, M. Van Mackelenberg, T. Mets, Rehabilitation using manual mobilization for thoracic kyphosis in elderly postmenopausal patients with osteoporosis, J. Rehabil. Med. 42 (2010) 129–135.
[28] U. Granacher, A. Gollhofer, T. Hortobagyi, R.W. Kressig, T. Muehlbauer, The importance of trunk muscle strength for balance, functional performance, and fall prevention in seniors: a systematic review, Sports Med. 43 (2013) 627–641.
[29] J.D. Evans, Straightforward Statistics for the Behavioral Sciences. Pacific Grove, Thomson Brooks/Cole Publishing Co., CA, US, 1996.
[30] R. Jaeschke, G.H. Guyatt, D.L. Sackett, Users' guides to the medical literature. III. How to use an article about a diagnostic test. B. What are the results and will they help me in caring for my patients? The Evidence-Based Medicine Working Group, JAMA. 271 (1994) 703–707.