

Biomechanical characteristics of the picking-up task related to balance and mobility among community-dwelling older adults

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Research Article

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Abstract

Background

Picking up objects is a common daily activity among older adults that may increase the risk of falls and is a leading cause of disability and mortality. This study aimed to investigate the associations between balance and mobility and biomechanical characteristics during a picking-up task and to identify biomechanical characteristics of poor balance and mobility in older adults.

Methods

Volunteers were assessed via the Community Balance and Mobility Scale (CB&M). Motion analysis was performed via a three-dimensional optical motion capture system. Spearman's rank correlation was used to examine associations, and binary logistic regression was conducted to identify characteristics of poor balance and mobility.

Results

During reaching down, CB&M scores were negatively correlated with the height of the right acromion and C7 and positively correlated with the bilateral squatting angle and right eccentric hip extensor power. At the start of lifting, scores were negatively correlated with C7 height and positively correlated with the vertical acceleration of the bilateral acromia, C7, T12, right elbow, right wrist, and center of mass. During lifting, the scores were negatively correlated with the vertical acceleration of C7. Logistic regression revealed that the right squatting angle (odds ratio [OR] = 0.83, 95% confidence interval [CI]: 0.71–0.97, $p = 0.022$) and right eccentric hip extensor power (OR = 0.19, 95% CI: 0.04–0.85, $p = 0.030$) during reaching down were significant biomechanical characteristics correlated with poor B&M.

Conclusions

The maintenance of an upright trunk posture with reduced hip control movement during reaching down may represent important biomechanical considerations for balance and mobility interventions in older adults.

Background

The proportion of older adults (OAs) in the global population is increasing at an unprecedented rate. According to the United Nations Department of Economic and Social Affairs, 728 million individuals (9.00%) were aged 65 years or older in 2020, a figure that is projected to more than double to 1.55 billion (16.00%) by 2050 [1]. In 2017, Japan reported the highest proportion of OAs worldwide (27.05%),

followed by Italy and Portugal [2]. These demographic shifts have raised concerns about age-related health issues, particularly those affecting balance and mobility (B&M) and fall risk.

Aging is accompanied by progressive changes in the musculoskeletal system, including reductions in muscle mass (sarcopenia), bone density (osteoporosis), and joint flexibility [3]. These changes are strongly associated with impaired B&M, which in turn increases susceptibility to falls and related injuries. Globally, the prevalence of falls among OAs is estimated to be 26.50%, with the highest rates observed in Oceania, followed by the Americas and Asia [4]. Notably, fall-related mortality is also increasing. In 2017, falls accounted for 695,771 deaths worldwide [5], with mortality risk increasing sharply with advancing age, particularly among those aged 85 years and older [6].

The risk factors for falls among OAs include a history of previous falls, impaired B&M, lower-limb weakness, chronic diseases, and cognitive decline [7]. Among daily activities, picking up (PU) objects from the floor has been identified as a common trigger for falls. A study in China reported that 4.80% of OAs living in urban areas and 7.00% of OAs living in rural areas experienced a fall during PU tasks [8]. Such falls often result in serious consequences, including fractures, hospitalization, long-term disability, and reduced quality of life [5, 9].

The Community B&M Scale (CB&M) is an assessment tool designed to evaluate B&M in higher-functioning OAs. It incorporates tasks that challenge dynamic balance, coordination, and postural control. Previous studies conducted in Europe reported mean CB&M scores ranging from 64.70–66.40 among community-dwelling OAs [10–12]. Although the clinical utility of the CB&M is well established, the specific biomechanical factors underlying performance on this scale remain insufficiently explored.

Previous research has demonstrated that OAs perform PU tasks differently from younger adults [13]. Age-related changes contribute to slower movement speed, reduced hip and knee flexion, and limited postural adaptability during task execution. OAs are also more likely to adopt conservative strategies, such as minimizing crouching and relying more heavily on the upper body. Moreover, alterations in center of pressure (CoP) control have been observed in this population. These biomechanical characteristics may serve as markers of functional decline. However, their relationships with standardized measures of B&M remain unclear.

To date, few studies have investigated the relationships between biomechanical factors during PU tasks and B&M in OAs. Accordingly, this study aimed to investigate the associations between B&M and biomechanical characteristics during PU tasks and to identify the biomechanical characteristics of poor B&M. These findings are expected to support the development of targeted strategies for fall risk assessment and mobility promotion among community-dwelling OAs.

Methods

Participants

The sample size was determined via G*Power (version 3.1.9.7) for correlation analysis. On the basis of an assumed correlation coefficient (ρ) of 0.37 derived from a previous study reporting the relationship between the CB&M and the Functional Reach Test [14], with an α level of 0.05 and a power of 0.95, the minimum required sample size was calculated as 89 participants.

A total of 151 community-dwelling OAs volunteers were recruited via the Silver Human Resources Center in Hirakata city between 2021 and 2023. The exclusion criteria included left-handed, severe missing marker data, unusually long total movement time, musculoskeletal disorders, neurological deficits, and any condition requiring assistance with PU objects. Thirteen left-handed participants, one participant with severe missing marker data, and two participants with an unusually long total movement time (mean = 4.64 s/mBH) were excluded from the analysis. A total of 135 right-handed community-dwelling OAs aged 60 years and older were recruited. All participants provided written informed consent after receiving a detailed explanation of the study procedures and potential risks. The study protocol was approved by the Ethics Committee of Kansai Medical University (2020294) and conducted in accordance with the principles outlined in the Declaration of Helsinki.

Research instruments

This study assessed B&M in OAs via the CB&M [15], which comprises 13 challenging tasks that reflect the motor skills required for community functioning. These tasks include a unilateral stance, a tandem walk, a 180° tandem pivot, lateral foot scooting, hopping forward, crouching and walking, lateral dodging, walking and looking, running with a controlled stop, forward-to-backward walking, walking-looking-and-carrying, stair descent, and step-ups. Each task is scored on a 6-point scale (0–5), yielding a maximum total score of 96. The CB&M has been widely applied to assess B&M not only in healthy adults but also in people with traumatic brain injury, Parkinson's disease, and stroke [16–19]. Moreover, several studies have specifically employed CB&M in community-dwelling OAs [10–12]. A cutoff score of 59 points has been proposed to distinguish between OAs with good and poor B&M [20].

Motion analysis

In this study, a three-dimensional (3D) optical motion capture system (Locus 3D MA-3000, Anima Corporation, Chofu, Japan) comprising 12 infrared cameras with a sampling rate of 100 Hz along two force plates (MG-1190, Anima Corporation, Chofu, Japan; 120 cm × 60 cm) with a sampling rate of 1,000 Hz was used. The setup followed a protocol described in a previous study [21, 22]. Marker trajectories and ground reaction forces (GRF) were filtered using second-order Butterworth low-pass filters with cut-off frequencies of 10 and 20 Hz, respectively [21]. Missing marker trajectories were reconstructed via spline interpolation. This method estimates the position of a missing marker by assuming that its relative position with respect to the three nearest markers remains unchanged. External joint moments at the foot, knee, hip, and trunk were calculated using inverse dynamics based on each segment's local coordinate system [21]. Joint angles during the picking-up task were calculated from the positions of

adjacent joint centers according to the recommendations of the International Society of Biomechanics for defining joint coordinate systems using Euler angles [21, 22].

A total of 30 retroreflective markers were placed at anatomical landmarks, including the spinous processes of C7 and T12, bilateral acromion processes, lateral humeral epicondyles, radial styloid processes, iliac crests, anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), greater trochanters, medial and lateral femoral epicondyles, medial and lateral malleoli, first and fifth metatarsal heads, and calcaneal tuberosities. The biomechanical parameters analyzed included the following: 1) distances of body landmarks from the origin of the coordinate system (acromion, ASIS, PSIS, iliac crest, greater trochanter, C7, T12, elbow, wrist, hip, knee, ankle, metatarsal joints, and center of mass [CoM]) in the medio-lateral, antero-posterior, and vertical directions; 2) joint angles of the hip, knee, ankle, and trunk, which were calculated via Euler angles in the sagittal, frontal, and transverse planes; and 3) special angle such as a novel squatting angle (SA), defined as the angle between the vertical axis and the vector formed between the greater trochanter and the fifth metatarsal head in the sagittal plane, which is based on the concept of the leading limb angle [23] (Fig. 1). In addition, GRF parameters, including total body weight, load on each foot, and CoP displacement, were examined. Joint kinetics (moment and power at the ankle, knee, and hip in the sagittal, frontal, and transverse planes) were also assessed, along with linear accelerations of body landmarks and angular accelerations of joint angles. The distances of the body landmarks and GRF data were normalized to the body height and body weight, respectively, whereas the joint moment and power were normalized to the body weight multiplied by the body height. The intraclass correlation coefficients (ICCs [3, K]) of the critical biomechanical parameters in this study ranged from 0.70 to 0.92, indicating acceptable to excellent reliability.

Data collection

General demographic information, including age and sex, was obtained through interviews, and body height and weight were subsequently measured. The participants then completed the 13 tasks of the CB&M. Afterward, 30 retroreflective markers were attached to anatomical landmarks, and each participant was instructed to stand and pick up a sponge ball (diameter of 6.50 cm and weight of 85.00 g) from the floor using the right hand. The ball was positioned diagonally on the lateral side of the right foot, 15 cm lateral and 15 cm anterior to the tip of the little toe. The starting point was defined as the frame immediately before the C7 anterior was displaced more than 1 cm from its initial coordinate, and the endpoint was defined as the frame at the right wrist that reached its maximum vertical height after the ball was lifted. Each participant performed the task three times, and all trials were recorded via the 3D optical motion capture system. Three trials were collected for each participant, and the mean of the remaining valid trials (minimum of two trials) was used for statistical analyses. Trials with marker loss, technical failure, or other measurement artifacts were excluded. Data were collected for three key events (Fig. 1): 1) the midpoint of the reaching-down phase (P_1), defined as the midpoint of the vertical height of the right wrist from the ground at the starting point; 2) the start of the lifting phase (P_2), defined as the frame immediately before the ball was vertically displaced more than 1 cm from its initial coordinate;

and 3) the midpoint of the lifting phase (P_3), defined as the midpoint of the vertical height of the right wrist from the ground at the end point.

Statistical analysis

IBM SPSS Statistics (version 28.0.0.0) and R (version 4.6.1) were used for the statistical analyses. The demographic characteristics are reported as the means $\pm$ standard deviations. The normality of the data was assessed via the Shapiro-Wilk test. Variables with a normal distribution were compared between groups via the independent samples t test, whereas variables with a nonnormal distribution were analyzed via the Mann-Whitney U test. Group differences in acceleration were examined via analysis of covariance (ANCOVA), adjusting for total movement time (movement duration) as a covariate. Pearson's chi-square test was used to examine the associations between sex and the B&M group. Spearman's rank correlation was applied to examine the associations between CB&M scores and biomechanical parameters. Binary logistic regression analysis was performed to identify biomechanical factors of poor B&M. Prior to model development, multicollinearity among significantly Spearman-correlated parameters and confounding factors was assessed via the variance inflation factor (VIF), with values < 5 considered acceptable. The final model was developed via the forward stepwise likelihood ratio method, with entry and removal criteria set at p values of 0.05 and 0.10, respectively. Model performance was evaluated via a confusion matrix to calculate accuracy, sensitivity, and specificity. Model fit was assessed via the Hosmer-Lemeshow test, Cox-Snell R^2 , and Nagelkerke R^2 . The discriminatory ability of the model was further evaluated via the area under the receiver operating characteristic curve (AUC). The number of candidate predictors entered into the logistic regression model and the events-per-variable (EPV) ratio were reported. Internal validation was performed using bootstrap validation with 1,000 resampling iterations. To control for type I error inflation due to multiple testing, the Bonferroni correction was applied to all correlation analyses and between-group comparisons. A total of 1,005 tests were included in each analysis family, and statistical significance was set at an adjusted p value threshold of < 0.00005 .

Results

Demographic and biomechanical characteristics

The mean age of community-dwelling OAs was 73.04 ± 6.13 years, with 51.11% males and 48.89% females. The mean body height, body weight, body mass index (BMI), and CB&M score were 1.59 ± 0.10 m, 58.87 ± 11.80 kg, 23.09 ± 3.46 kg/m², and 65.25 ± 18.70 , respectively. The mean durations for total movement, reaching down, and lifting were 1.49 ± 0.37 , 0.84 ± 0.26 , and 0.65 ± 0.15 s/m of body height, respectively. The demographic characteristics of the good and poor B&M groups are presented in Table 1. Comparisons of the biomechanical characteristics during the picking-up task between the good and poor B&M groups are presented in Table 2.

Table 1
Demographic characteristics of community-dwelling older adults.

Characteristic		Total (n = 135)	Group		<i>p</i> value
			Good balance and mobility (n = 91)	Poor balance and mobility (n = 44)	
Age (y)		73.04 ± 6.13	71.27 ± 5.03	76.70 ± 6.62	< 0.001 ^a
Sex	Male (%)	69 (51.11%)	49 (36.30%)	20 (14.81%)	0.36 ^b
	Female (%)	66 (48.89%)	42 (31.11%)	24 (17.78%)	
Body height (m)		1.59 ± 0.10	1.61 ± 0.10	1.55 ± 0.09	0.001 ^c
Body weight (kg)		58.87 ± 11.80	59.06 ± 12.31	58.47 ± 10.79	0.81 ^c
Body mass index (kg/m ²)		23.09 ± 3.46	22.47 ± 3.09	24.36 ± 3.85	0.010 ^c
Community Balance and Mobility Scale		65.25 ± 18.70	75.85 ± 9.50	43.34 ± 13.12	< 0.001 ^c
Total movement time (s/mBH)		1.49 ± 0.37	1.34 ± 0.26	1.78 ± 0.41	< 0.001 ^a
Reaching down time (s/mBH)		0.84 ± 0.26	0.75 ± 0.16	1.03 ± 0.31	< 0.001 ^c
Lifting time (s/mBH)		0.65 ± 0.15	0.60 ± 0.12	0.75 ± 0.16	< 0.001 ^a
The data are presented as the means ± standard deviations, except for sex, which is presented as the frequency. ^a Independent sample t test, ^b Pearson's chi-square test, ^c Mann-Whitney U test. mBH = m of body height.					

Correlations between CB&M scores and biomechanical characteristics

The results of the correlation analysis between CB&M scores and biomechanical characteristics during PU tasks are presented in Table 3. During P₁, CB&M scores were negatively correlated with the height of the right acromion and C7. Positive correlations were observed between the bilateral SA and right eccentric hip extensor power (EHEP). In P₂, CB&M scores were negatively correlated with the height of C7 and positively correlated with the vertical acceleration (VA) of the acromia, C7, T12, right elbow, right wrist, and CoM. During P₃, CB&M scores were negatively correlated with the VA of C7.

Table 3
Correlation analysis between the Community Balance and Mobility Scale and biomechanical characteristics

Picking up task	Parameter	Mean	ρ (95% CI)	<i>p</i> value
P_1	Right acromion height (cm/cmBH)	0.58 ± 0.07	-0.41 (-0.54 – -0.25)	< 0.00005
	C7 height (cm/cmBH)	0.66 ± 0.07	-0.43 (-0.57 – -0.27)	< 0.00005
	Left squatting angle (degree)	12.97 ± 3.21	0.47 (0.30–0.60)	< 0.00005
	Right squatting angle (degree)	16.58 ± 3.65	0.49 (0.33–0.62)	< 0.00005
	Right eccentric hip extensor power (W/kg*m)	0.77 ± 0.42	0.44 (0.30–0.56)	< 0.00005
P_2	C7 height (cm/cmBH)	0.53 ± 0.03	-0.42 (-0.55 – -0.26)	< 0.00005
	Vertical acceleration of left acromion (cm/s ²)	298.91 ± 111.76	0.45 (0.30–0.57)	< 0.00005
	Vertical acceleration of right acromion (cm/s ²)	351.74 ± 145.53	0.43 (0.27–0.56)	< 0.00005
	Vertical acceleration of C7 (cm/s ²)	325.93 ± 124.91	0.46 (0.31–0.59)	< 0.00005
	Vertical acceleration of T12 (cm/s ²)	198.41 ± 92.93	0.40 (0.23–0.55)	< 0.00005
	Vertical acceleration of right elbow (cm/s ²)	349.97 ± 146.79	0.44 (0.31–0.57)	< 0.00005
	Vertical acceleration of right wrist (cm/s ²)	349.23 ± 141.96	0.41 (0.26–0.54)	< 0.00005
	Vertical acceleration of center of mass (cm/s ²)	191.82 ± 82.06	0.43 (0.27–0.56)	< 0.00005
P_3	Vertical acceleration of C7 (cm/s ²)	-292.82 ± 158.83	-0.42 (-0.56 – -0.25)	< 0.00005

The data are presented as the means $\pm$ standard deviations. Anatomical landmark height data were normalized to body height, whereas joint power was normalized to body weight multiplied by body height. ρ = Spearman's rank correlation coefficient, CI = confidence interval, cmBH = cm of body height, P_1 = the midpoint of the reaching-down phase, P_2 = the start of the lifting phase, P_3 = the midpoint of the lifting phase. Bonferroni correction was applied for 1,005 correlation analyses, with statistical significance set at $p < 0.00005$.

Binary logistic regression analysis

As shown in Table 1, age, body height, and BMI differed significantly between the good and poor B&M groups. Therefore, age, body height, BMI, and sex were considered potential confounding variables and included in the multivariable analysis. Multicollinearity was evaluated among the 14 biomechanical variables that were significantly correlated with CB&M in the Spearman correlation analysis (Table 3) and the four potential confounding variables. After multicollinearity assessment, the left SA at P₁, right SA at P₁, right EHEP at P₁, C7 height at P₂, VA of C7 at P₃, age, body height, BMI, and sex showed VIF values < 5 and were retained for further analysis. The final logistic regression model was developed using these nine variables with the forward stepwise likelihood ratio method. During the forward stepwise likelihood ratio procedure, the left SA at P₁, C7 height at P₂, VA of C7 at P₃, and sex were excluded from the model. The final model identified right SA at P₁, right EHEP at P₁, age, and BMI were significant characteristics of poor B&M (Table 4). A total of nine candidate parameters were entered into the model, resulting in an EPV ratio of 4.89. Bootstrap validation with 1,000 resampling iterations showed an apparent AUC of 0.872, a mean optimism of 0.017, and an optimism-corrected AUC of 0.856. We ran separate binary logistic regression models via the enter method with the left SA at P₁, right EHEP at P₁, age, body height, BMI. We found an AUC of 0.87 (95% CI = 0.80–0.94). The left SA at P₁ was a significant characteristic (OR = 0.81, 95% CI: 0.67–0.98, p = 0.030).

Table 4
Logistic regression model to identify variables associated with poor balance and mobility.

Parameter	B	S.E.	Wald	p value	OR (95% CI)
Right squatting angle at P ₁	-0.19	0.08	5.21	0.022	0.83 (0.71–0.97)
Right eccentric hip extensor power at P ₁	-1.66	0.77	4.69	0.030	0.19 (0.04–0.85)
Age	0.14	0.05	8.76	0.003	1.15 (1.05–1.27)
Body height	-5.15	2.62	3.86	0.050	0.01 (0.00–0.99)
Body mass index	0.16	0.08	4.03	0.045	1.17 (1.00–1.37)
Constant	-2.34	6.40	0.13	0.71	0.10
B = logistic regression coefficient, S.E. = standard error, Wald = Wald chi-square statistic, OR = odds ratio, CI = confidence interval, P ₁ = the midpoint of the reaching-down phase, Hosmer-Lemeshow test ($\chi^2 = 7.93$, p value = 0.44), area under the receiver operating characteristic curve (AUC) = 0.87 (95% CI: 0.80–0.94), accuracy = 0.87, sensitivity = 0.75, specificity = 0.92, Cox-Snell R ² = 0.37, and Nagelkerke R ² = 0.51. Internal validation: bootstrap validation (1,000 resampling iterations); apparent AUC = 0.872; mean optimism = 0.017; optimism-corrected AUC = 0.856.					

Discussion

Reaching-down phase

During the reaching-down phase, the OAs demonstrated coordinated hip and knee flexion. This movement pattern reflects a typical postural strategy used to position the right hand to grasp objects located at the floor level [24, 25]. A key strength of this study is the analysis of biomechanical parameters at P₁, a time point that has not been examined in previous studies, which have focused primarily on the instant at which an object is grasped at the floor level [26].

At P₁, CB&M scores were negatively correlated with the height of C7 and the right acromion and positively correlated with the bilateral SA. These findings indicate that OAs with good B&M adopted a deeper squat posture characterized by greater hip and knee flexion (Fig. 2A). Biomechanically, adopting a deep squat reduces the vertical distance between the hand and the object, thereby facilitating safety while grasping the object. This interpretation is consistent with previous findings emphasizing the importance of squat-like strategies during reaching-down tasks in individuals with good B&M [24]. In contrast, OAs with poor B&M demonstrated reduced hip and knee flexion and smaller SA, indicating their limited ability to achieve sufficient squat depth (Fig. 2D). This more upright limb posture likely results from reduced postural stability and greater difficulty in controlling descent. Previous studies have

reported similar findings, showing that OAs exhibit reduced lower-limb flexion compared with younger adults, resulting in a more upright limb posture during object retrieval [13]. However, these studies primarily examined static postures at the moment of grasping. In contrast, the present study extended the current knowledge by analyzing dynamic movement at P_1 and identifying biomechanical parameters associated with B&M performance during the descent phase.

Additionally, right EHEP at P_1 was positively associated with CB&M scores and emerged as a significantly associated with poor CB&M classification in the regression model. Each 1 W/kg*m increase in right EHEP was associated with an 81% reduction in the odds of poor B&M. Moreover, binary logistic regression demonstrated that right SA at P_1 also emerged as a significantly associated with poor CB&M classification, with each 1° increase associated with a 17% reduction in the odds of poor B&M. According to separate binary logistic regression models, left SA at P_1 also emerged as a significant factor associated with poor CB&M classification, with each 1° increase associated with a 19% reduction in the odds of poor B&M. These findings related to coordinated weight transfer and maintenance of postural stability during unilateral reaching-down movement in OAs can be interpreted within the framework of the right lower limb functioning as both a loading and control limb, whereas the left lower limb functions as a control limb only. Specifically, the greater right EHEP and SA observed at P_1 , which was identified as a protective factor for B&M, was accompanied by a significantly greater vertical ground reaction force (vGRF) on the right foot in the good B&M group [Supplementary materials]. This pattern suggests that OAs with good B&M capacity are able to control eccentric activation of the hip extensors to facilitate efficient and stable loading onto the right lower limb. Moving into a deeper squat on the right side reduces the distance between the right hand and the object on the floor. From a biomechanical perspective, these findings support the role of the right lower limb as both a loading and control limb, responsible for accepting body weight and initiating the controlled descent of the CoM, whereas the left lower limb functions as a control limb only [28, 29]. Importantly, right EHEP activity only contributes to force absorption and regulates CoM displacement by bilateral SA for precise neuromuscular coordination in OAs with good B&M.

In OAs with poor B&M, an impaired right loading and bilateral control limbs function may result in insufficient weight transfer, a reduced vGRF on the loading limb, and a diminished capacity of the bilateral control limb to regulate the CoM, leading to less efficient and more conservative movement strategies, such as reduced weight shift and increased reliance on upper body compensation.

Lifting phase

The present study examined both the initiation (P_2) and midpoint (P_3) of the lifting phase, capturing the transition from a static squat posture to a dynamic upward movement. This phase is biomechanically demanding and requires coordinated lower-limb extension, trunk stabilization, and object control. During the lifting phase, the OAs demonstrated coordinated hip and knee extension, whereas the trunk transitioned to a more neutral upright posture.

At P_2 , defined as the initiation of upward movement, no biomechanical variables independently associated with poor B&M. However, CB&M scores were negatively correlated with C7 height, indicating that individuals with good B&M maintained a deeper squat posture at the onset of lifting (Fig. 2B). In contrast, OAs with poor B&M exhibited a more flexed trunk posture (Fig. 2E), suggesting insufficient carryover from the reaching-down phase. This higher CoM position at lift initiation may reduce postural stability and increase fall risk [13].

In addition, CB&M scores were positively correlated with the VA of C7, T12, the right upper limb, and the CoM at P_2 . This suggests that individuals with good B&M are able to generate greater upward acceleration, facilitating efficient momentum transfer while maintaining stability. Similar patterns have been observed in sit-to-stand tasks, where individuals with better functional performance generate greater vertical momentum and demonstrate more effective lower-limb extension [30]. In contrast, OAs with poor B&M may have insufficient lower-limb strength, limiting their ability to generate adequate acceleration and initiate upward movement efficiently [30–32].

At P_3 , defined as the midpoint of the lifting phase, CB&M scores were negatively correlated with C7 VA, OAs with good B&M demonstrated more controlled trunk acceleration, indicating a more regulated lifting strategy characterized by smoother intersegmental coordination. This interpretation aligns with previous findings showing that controlled movement strategies, including the modulation of acceleration, are important for maintaining stability during functional tasks such as lifting and sit-to-stand transitions [33, 34]. In contrast, poorly controlled acceleration in OAs with poor B&M may increase postural instability during task execution.

The observed associations between the PU task and CB&M should be interpreted with caution. Because the CB&M assesses multiple aspects of dynamic B&M, the biomechanical parameters identified during the PU task may reflect shared underlying functional capacities, such as lower-limb strength, flexibility, movement speed, and dynamic postural control, rather than an entirely independent functional domain.

Although the EPV ratio of 4.89 was below the traditional recommendation of 10, previous research has suggested that the 10 EPV rule is not an absolute requirement [35, 36], bootstrap validation with 1,000 resampling iterations demonstrated a mean optimism of 0.017, and an optimism-corrected AUC of 0.856, suggesting that the model had limited overfitting [37].

Clinical implications

These findings have notable practical implications. First, compared with standard assessments alone, clinical assessments of squatting ability and EHEP may enable the more precise detection of balance impairments. Second, interventions targeting right EHEP and bilateral squatting ability during the reaching-down phase may have the potential to enhance balance and mobility in OAs. Third, this approach may also facilitate the future development of simplified clinical assessment systems using wearable sensors or markerless motion-analysis technologies. Further studies are required to validate

the proposed classification thresholds in independent populations and to determine the feasibility, reliability, and clinical utility of these technologies in routine clinical practice.

Limitations

This study has several limitations that should be acknowledged. First, this study was limited by its cross-sectional design and the lack of fall history and cognitive screening. Second, the sample consisted exclusively of community-dwelling OAs with preserved functional abilities, which may limit the generalizability of the findings to frailer populations. Third, all participants were right-handed and were instructed to PU a sponge ball positioned diagonally anterolateral to the right foot using the right hand. Although this standardized the experimental condition, it may limit the generalizability of the findings. Different task conditions, such as using the left hand or the non-dominant hand, reaching toward the midline, lifting objects from different heights, or handling objects with different weights, may require different postural control strategies. Therefore, the present findings should be interpreted as specific to a right-handed, right-sided, low-load, floor-level picking-up task and should not be generalized to all types of picking-up tasks.

Conclusions

The results of this study suggest that greater squatting ability and right EHEP during the reaching-down phase of PU by right hand may be associated with a reduced likelihood of poor B&M classification among community-dwelling OAs.

Abbreviations

CB&M	Community Balance and Mobility Scale
C7	7th cervical vertebra
T12	12th thoracic vertebra
OR	Odds ratio
CI	Confidence interval
OAs	Older adults
B&M	Balance and mobility
PU	Picking up
CoP	Center of pressure
ρ	Spearman’s rank correlation coefficient

3D	Three-dimensional
Hz	Hertz
ASIS	Anterior superior iliac spine
PSIS	Posterior superior iliac spine
CoM	Center of mass
SA	Squatting angle
ICCs	Intraclass correlation coefficients
P_1	The midpoint of the reaching-down phase
P_2	The start of the lifting phase
P_3	The midpoint of the lifting phase
VIF	Variance inflation factor
AUC	Area under the receiver operating characteristic curve
BMI	Body mass index
EHEP	Eccentric hip extensor power
VA	Vertical acceleration
r	Pearson correlation coefficient
vGRF	Vertical ground reaction force
mBH	Meter of body height
B	Logistic regression coefficient
S.E.	Standard error

Declarations

Ethics approval and consent to participate

All participants provided written informed consent after receiving a detailed explanation of the study procedures and potential risks. The study protocol was approved by the Ethics Committee of Kansai

Medical University (2020294) and conducted in accordance with the principles outlined in the Declaration of Helsinki.

Consent for publication

Not applicable.

Availability of data and materials

The data used and analyzed during the current study are available from the corresponding author upon reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Kolip Payanglee: Formal analysis, investigation, writing – original draft, and visualization. Kimitaka Hase: Conceptualization, validation, investigation, resources, writing – review and editing, supervision, project administration, and funding acquisition. Meguru Taguchi: Methodology, software, investigation, data curation, and supervision. Takanari Kubo: Methodology, software, investigation, data curation, and supervision. Kimihiko Mori: Methodology, software, investigation, data curation, writing – review and editing, and supervision. All the authors read and approved the final manuscript.

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Table 2

Table 2 is available in the Supplementary Files section.

Figures

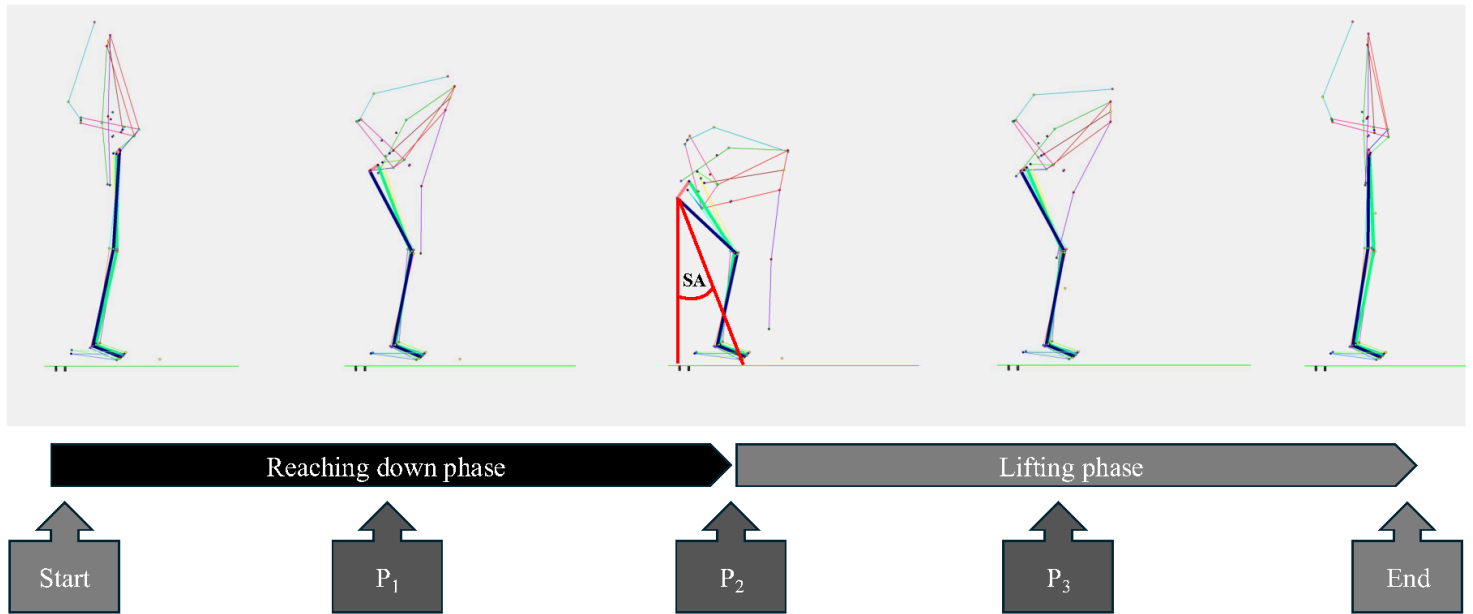


Figure 1

Standing and picking up task. Illustration of the movement sequence for standing and picking up an object from the floor among community-dwelling older adults, as assessed during motion analysis. P₁ = the midpoint of the reaching-down phase, P₂ = the start of the lifting phase, P₃ = the midpoint of the lifting phase, and SA = the squatting angle.

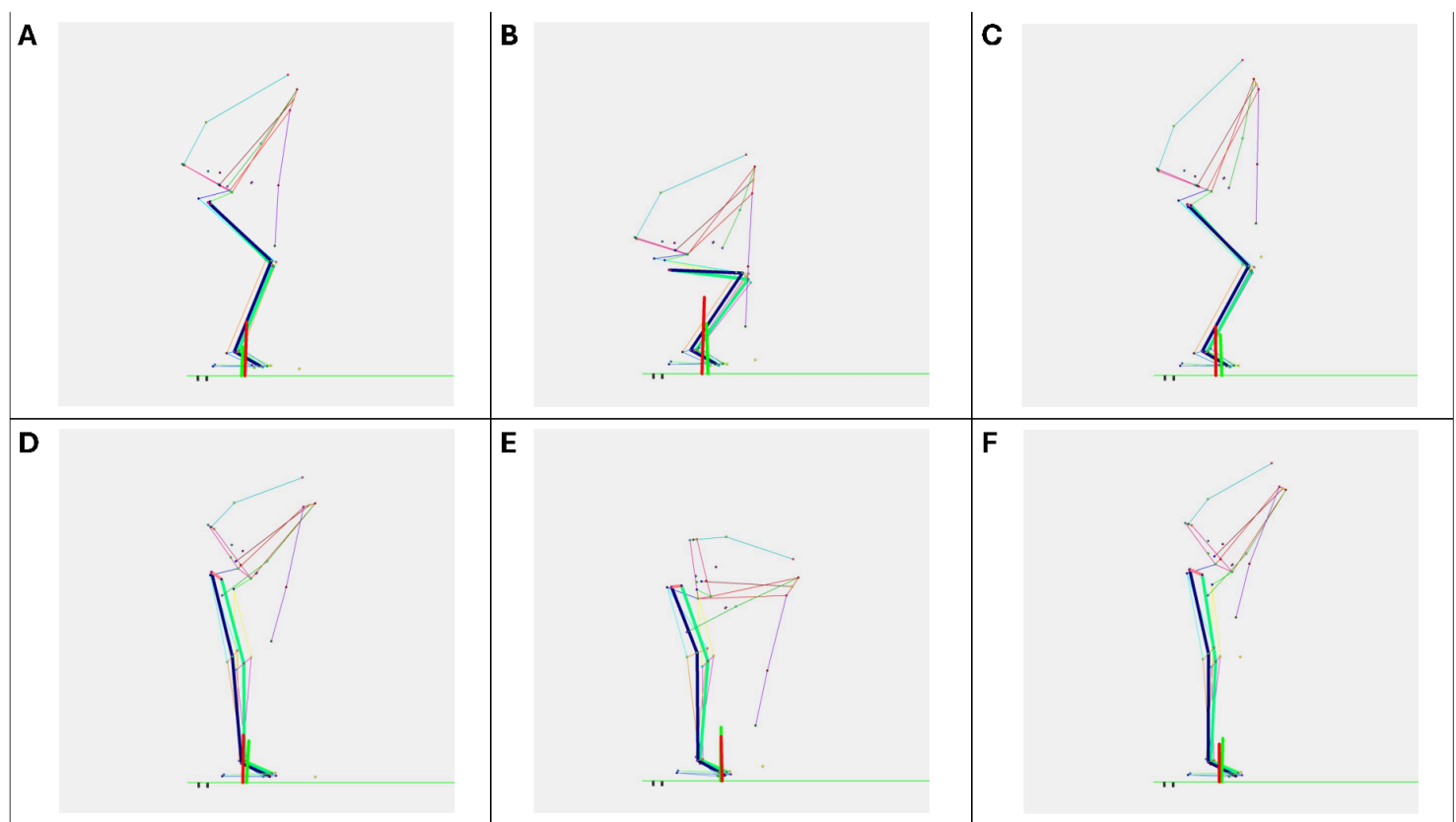


Figure 2

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Movement characteristics of older adults during the picking-up task.

(A–C) Older adults with good balance and mobility: (A) midpoint of the reaching-down phase, (B) initiation of the lifting phase, and (C) midpoint of the lifting phase. (D–F) Older adults with poor balance and mobility: (D) midpoint of the reaching-down phase, (E) initiation of the lifting phase, and (F) midpoint of the lifting phase.

Supplementary Files

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