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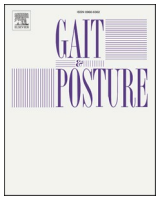

Full length article

Changes in gait and postural control after 10-day bed rest and 30-day recovery: A comparison of young vs. older adults

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ABSTRACT

Background: Prolonged bed rest is a well-established model for studying the effects of immobility on functional performance, especially gait and postural control. Understanding how these functions deteriorate and recover across age groups is essential for developing targeted rehabilitation strategies.
Research question: How does a 10-day horizontal bed rest affect gait performance and postural control in young and older adults, and to what extent do these effects differ by age?
Methods: Following a multistage screening process from a large pool of healthy male volunteers, ten older men (68.5 ± 2.6 years) and ten young men (22.9 ± 4.7 years) completed 10 days of horizontal bed rest in a controlled laboratory setting, followed by a standardized 30-day recovery program. Postural control and gait speed assessed under self-selected and brisk walking conditions were measured before bed rest, immediately after, and following a 30-day recovery program.
Results: Following bed rest, self-selected walking speed did not differ significantly from baseline in either group. In contrast, brisk walking speed significantly decreased in older (−11.4%, $p < 0.05$) and young adults (−9.9%, $p < 0.05$), with both groups returning to baseline values after recovery. Postural control deteriorated significantly in older adults (-15.5%), whereas no significant difference from baseline was observed in young adults. After baseline adjustment, postural control showed a significant group effect both after bed rest ($\eta^2 > 0.244$) and post-recovery ($\eta^2 > 0.395$).
Significance: The findings reveal clear age-related differences in responses to inactivity and recovery. Older adults experienced greater impairments and slower restoration of balance, indicating heightened vulnerability to functional decline during periods of immobilization. These findings underscore the age-dependent impact of bed rest and the importance of tailored rehabilitation strategies.

1. Introduction

Aging is a multifaceted process marked by time-dependent functional decline and represents a major risk factor for a spectrum of chronic diseases, including cardiovascular diseases, cancer, and neurodegenerative disorders [1,2]. As individuals age, degenerative changes in muscle strength [3], joint flexibility [4], and neural control mechanisms [5] contribute to significant alterations in gait patterns [6] and postural control [7], being the most affected functional abilities. Impairments in both gait and postural control are significantly implicated in an increased risk of falls [8], which can lead to morbidity, functional dependency, and, in severe cases, mortality [9]. Scientific publications highlight the rapidly growing population of older adults [10] and the concomitant rise in falls-related injuries and hospitalizations [9] posing a significant burden on healthcare systems [11]. In this context, understanding degenerative processes and developing interventions to

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mitigate the effects of aging on the motor system are crucial from medical and economic standpoints, with significant implications for social well-being.

Bed rest, utilized as a model of rapid aging, is one of the most scientifically reliable approaches to induce prolonged inactivity in a controlled, and standardized environment, allowing for the detailed examination of its physiological impacts on human functioning [12]. A recent review by Marusic et al. [13], highlighted the phenomenon of nonuniform loss of muscle mass and strength during prolonged bed rest, revealing that the decline in strength exceeds that of muscle mass and size by twofold. This disproportionate loss of strength can be attributed to neuromuscular alterations at both central and peripheral levels. Plantar flexors, the primary muscle for maintaining postural control, are the most affected by bed rest. As demonstrated by de Boer et al. [14], distal postural muscles such as the plantar flexors (e.g., soleus and gastrocnemius) deteriorate more during bed rest than proximal postural muscles (e.g., quadriceps and gluteus maximus), whereas non-postural muscles, such as upper-limb muscles (e.g., biceps brachii), are affected to a much lesser extent. Furthermore, Kouzaki et al. [15] reported in healthy young adults that plantar flexor strength training during 20 days of bed rest preserved muscle volume but did not prevent a decline in postural stability. These findings suggest that neuromuscular alterations, rather than muscle mass loss alone, play an important role in the deterioration of muscle function and mobility during prolonged inactivity. Similarly, bed rest has been associated with reduced walking performance in healthy older adults [16] and impaired postural control in healthy adults [17], while measurable deficits in both gait and balance have been reported after as little as five days of bed rest in healthy young adults [18]. Taken together, these findings indicate that bed rest adversely affects locomotor and postural control across adult populations. Given that the detrimental changes induced by bed rest are similar to those observed with aging, physical inactivity, sedentary lifestyle, and immobilization [19], a comprehensive understanding of these impacts is essential. This knowledge will facilitate the development of objective measures and effective rehabilitation strategies.

Despite the large number of studies on this topic, there remains a critical need for comparative analyses of gait and postural control between young and older adults during bed rest. Such comparisons have yet to be comprehensively performed and are essential for identifying age-specific effects and potential interventions. Therefore, this study aimed to determine whether short-term bed rest induces different magnitudes of decline in gait and postural control performance between young and older adults, and whether these changes are fully reversible after a 30-day recovery period. We hypothesized that older adults would exhibit greater impairments in postural control and gait performance after bed rest and a slower recovery compared with younger adults. Addressing these questions is essential to deepen our understanding of age-related differences in neuromuscular adaptation to inactivity and to guide the development of targeted rehabilitation strategies aimed at preserving functional capacity in older adults.

2. Methods

Data were collected from two separate bed rest studies conducted in MARS PRE bed rest study (2019, young participants; ClinicalTrials.gov identifier: NCT04081467) and bed rest SBI 2023 study (2023, older participants; ClinicalTrials.gov identifier: NCT06141291), both carried out in controlled medical environments at the General Hospital in Izola, Slovenia. Both studies adhered to the standards set by the latest revision of the Declaration of Helsinki and were approved by the National Ethical Committee of the Slovenian Ministry of Health on 17 July 2019 and 21 June 2023, with reference numbers 0120–304/2019/9 and 0120–123/2023/9, respectively. Participants received comprehensive information about experimental procedures through interviews, information sheets, kinesiological and medical examinations. Upon signing the consent form, participants were enrolled in the study with the option to withdraw at any stage.

2.1. Participants

In 2019, ninety-three young adults applied for the bed rest study. Forty-six were interviewed, and sixteen met all inclusion/exclusion criteria and passed the initial medical examination (see Supplementary Table S1 for detailed criteria and assessments used in the 2019 and 2023 bed rest studies). Subsequently, ten participants (aged 18–33 years; average age 22.9 ± 4.7 years; body mass 77.5 ± 10 kg; body height 181.2 ± 3.9 cm) were selected based on homogeneity (age, body composition, aerobic performance) and underwent additional assessments, including kinesiological and medical examinations, a physical activity questionnaire (GPAQ), body composition analysis, resting and exercise electrocardiography with blood pressure assessment, medical questionnaires, functional movement assessment, and a nutrition interview. Excluded were participants with a history of smoking, regular alcohol consumption, presence of ferromagnetic implants, history of deep vein thrombosis with D-dimer levels exceeding 500 μg L^{-1}, acute or chronic skeletal, neuromuscular, metabolic, or cardiovascular diseases, as well as a history of pulmonary embolism.

In 2023, a total of 41 older adults applied to participate in the bed rest study. Following telephone screening and medical interviews, 16 candidates met the predefined inclusion and exclusion criteria and passed the initial medical examination. The final step involved selecting ten eligible participants (aged 64–71 years, average age 68.9 ± 2.7 years; body mass 83.8 ± 11.8 kg; body height 177.8 ± 6.9 cm), resulting in a relatively homogeneous sample with respect to age and anthropometric characteristics. These participants subsequently underwent the same assessments as conducted in 2019. The exclusion criteria included a history of regular alcohol consumption, ferromagnetic implants, history of deep vein thrombosis with D-dimer exceeding 500 μg L^{-1}, donation of a large quantity of blood (more than 300 ml) in the three months prior to the start of the project, poor orthostatic tolerance, arterial hypertension (>140/90 mm Hg), diabetes, acute or chronic skeletal, neuromuscular, metabolic, or cardiovascular diseases, as well as a history of pulmonary embolism. Participants were informed of the purpose, procedures and potential risks of the study before signing the informed consent. The sample size (n = 10 per group) is consistent with previous bed-rest investigations. Owing to the high operational cost and logistical complexity associated with prolonged bed-rest experiments conducted under strictly controlled medical conditions, studies in this field typically include relatively small cohorts [20].

Basic anthropometric parameters of the two groups are reported in Table 1.

2.2. Study design

In both the 2019 and 2023 bed rest studies, the protocol included three days of familiarization with the environment, data collection before bed rest (BDC), data collection post bed rest (BR10), and data collection following thirty days of recovery (R+30). The post-bed rest recovery program consisted of ten supervised training sessions performed on a cycle ergometer under the guidance of a personal trainer. The sessions were equally distributed across the 30-day recovery period to allow gradual reconditioning following bed rest.

Table 1
Baseline anthropometric characteristics for young and older adult participants.

	YOUNG	OLD	*p*
N	10	10	
Age, yr	22.9 ± 4.7	68.9 ± 2.7	< 0.001
Body height, cm	181.2 ± 3.9	177.8 ± 6.9	0.006
Body mass, kg	77.5 ± 10.0	83.8 ± 11.8	0.117
Body mass index kg/m^2	23.6 ± 2.5	26.5 ± 4.3	0.003

Each session followed a structured interval-based protocol combining anaerobic and aerobic exercise modalities. Training intensity was prescribed relative to each participant's maximal power output determined on a cycle ergometer. Specifically, each session included:

(i) A 15-minute warm-up session,
(ii) Anaerobic exercise modality: 4 sets of 15-second maximal effort intervals with 45 s of rest between sets,
(iii) Six blocks of aerobic cycling performed at approximately 20% of maximal power output, interspersed with short higher-intensity intervals reaching approximately 65% of maximal power output. Exercise intensity was progressively increased throughout the recovery period within these relative intensity targets, in accordance with interval-training principles shown to promote mitochondrial and neuromuscular adaptations [21].

At BDC, BR10, and R+ 30, participants underwent assessments of single-task postural control and gait speed.

2.3. Assessment

During the postural single-task condition, participants stood on a force plate (Balance Tracking Systems Inc., CA, USA) with their arms positioned on their hips and their gaze fixed on a black dot located approximately one meter in front of them at eye level. Each assessment consisted of three, 30-second trials. The average total sway distance was calculated to quantify the displacements of the center of pressure (COP) in both the medio-lateral and antero-posterior directions during quiet standing. COP-derived parameters are commonly used to quantify postural control in force-platform posturography, and different COP variables provide complementary information about postural stability. Because no single COP parameter is considered universally optimal, total sway distance was selected as a global descriptor of COP displacement during the standing task [22].

In 2019, gait speed was measured using the OptoGait system (Microgate, Bolzano, Italy) under two 1-minute conditions presented in randomized order: walking at a preferred self-selected speed and brisk walking at the fastest sustainable speed. Data were sampled at 1 kHz and analyzed using OptoGait software, version 1.12.15. In 2023, gait speed at both preferred self-selected speed and brisk walking was assessed over an 8-meter distance using a kinematic suit (Motion Workshop, Friday Harbor, USA) equipped with Vive Pro trackers and cameras (HTC Corporation, Taiwan). Data were sampled at 100 Hz and analyzed using MATLAB software. While the two systems differ in hardware and sampling frequency, both approaches are well-established for gait assessment and overlapping pilot trials were used to cross-check outputs and verify consistency of results.

2.4. Bed rest protocol

Participants underwent a 10-day horizontal bed rest protocol in standard air-conditioned hospital rooms, under continuous video surveillance and 24-hour medical supervision. During bed rest, participants were instructed to maintain a horizontal lying position at all times, abstaining from any physical or muscle contraction activity. All volunteers adhered to a eucaloric diet throughout their hospital stay, receiving three standardized meals per day. Dietary energy requirements for each participant were calculated by multiplying their resting energy expenditure by 1.4 during the three days familiarization period and by 1.2 during the bed rest period [23]. The macronutrient distribution was standardized to 60% carbohydrates, 25% fats, and 15% proteins. Participants' sleep schedule was set from 22:00–07:00.

2.5. Statistical analysis

All data analyses were performed using SPSS version 28.0 (IBM, Chicago, USA), with results reported as mean and standard deviation. Normal distribution was evaluated using histograms and Q-Q plots and confirmed by the Shapiro-Wilk test. Anthropometric characteristics and baseline measures were compared using independent *t*-test. The identified differences in gait speed and postural control values at baseline led to further investigation of the main group effect using univariate analyses of covariances (UNIANCOVA). In this analysis, post-bed rest assessment and post-bed rest recovery served as the dependent variable, group as a fixed factor and pre-assessment as a covariate. The effect size for each analysis was assessed using the eta-squared statistic (partial η^2) and interpreted as proposed by Cohen [24]: < 0.01 = small, 0.01 – 0.06 = medium, > 0.14 = large. In addition, a dependent *t*-test and the percentage of change between each data collection periods were calculated. Statistical significance for all analyses was set at $\alpha = 0.05$.

3. Results

All participants fully adhered to the study protocol with no dropouts or medical complications in both bed rest studies.

Expected differences (all $p \leq 0.001$) at BDC between older and young adults were observed in self-selected and brisk walking at the fastest sustainable speed, as well as in postural control (Table 2). The temporal evolution of these variables across the three time points is illustrated in Fig. 1. Among the three assessed variables, gait at self-selected speed was the only one not affected by bed rest in either group. At R+ 30, both young and older adults increased their self-selected gait speed by 14.5% ($p = 0.006$) and 16.1% ($p = 0.025$), respectively. UNIANCOVA revealed no group effects at BDC ($F = 0.415$; $df = 1$; $p = 0.528$) and at R+ 30 ($F = 1.681$; $df = 1$; $p = 0.212$).

Brisk walking at the fastest sustainable speed was affected by bed rest in both young and older adults, with respective decreases of 9.9% ($p = 0.009$) and 11.4% ($p = 0.003$). Following the recovery program, both groups successfully restored their gait speed, with increases of 11.1% ($p = 0.005$) in young and 13.3% ($p = 0.033$) in older adults, respectively. No group effect was observed at BDC ($F = 0.468$; $df = 1$; $p = 0.503$) and R+ 30 ($F = 2.512$; $df = 1$; $p = 0.131$).

Postural control was affected by bed rest only in the older adult group, showing a 15.5% deterioration in COP ($p = 0.036$). Conversely, the recovery period improved postural control in both young and older adults, with improvements of 7.6% ($p = 0.047$) and 7.5% ($p = 0.043$), respectively. UNIANCOVA showed a large group effect at both BDC ($F = 5.491$; $df = 1$; $p = 0.032$; $\eta^2 = 0.244$) and R+ 30 ($F = 11.087$; $df = 1$; $p = 0.004$; $\eta^2 = 0.395$).

4. Discussion

Our results showed that 10 days of horizontal bed rest reduced gait performance at the fastest sustainable speed but not at the self-selected pace in both young and older adults. The recovery period effectively restored performance in both gait conditions. In contrast, postural control was significantly affected only in older adults, indicating a greater susceptibility of balance regulation to inactivity with advancing age. Although postural stability improved after recovery in both groups, older adults continued to exhibit inferior balance performance compared to younger participants. These findings suggest that the decline in postural control among older adults likely arises from combined alterations in afferent and efferent pathways. On the afferent side, bed rest may exacerbate the age-related deterioration of proprioceptive, vestibular, and visual inputs essential for balance maintenance. On the efferent side, reduced motor unit recruitment, impaired neuromuscular junction transmission, and lower muscle strength may further compromise stability. Together, these mechanisms may account for the greater postural instability observed in older adults following bed rest. These findings are consistent with recent evidence that age-related neural system degeneration increases gait variability and shifts locomotor control toward greater cognitive demand, a process further amplified by

Table 2
UNIANCOVA of group effects with baseline data (BDC) as a covariate.

Outcome	Study Groups	BDC	BR10	R+ 30	p_{BR10} group (η^2)	p_{R+30} group (η^2)
COP (cm)	YOUNG	30.1 ± 8.0	31.7 ± 7.4	29.1 ± 6.3**	0.032 (0.244)	0.004 (0.395)
	OLD	61.4 ± 12.8	70.4 ± 13.9*	63.9 ± 10.8**		
Gait self-selected speed (m/s)	YOUNG	1.29 ± 0.08	1.22 ± 0.16	1.38 ± 0.14**	0.528	0.212
	OLD	1.11 ± 0.12	1.05 ± 0.15	1.20 ± 0.17**		
Gait fast speed (m/s)	YOUNG	1.96 ± 0.17	1.76 ± 0.24*	1.94 ± 0.17**	0.503	0.131
	OLD	1.55 ± 0.12	1.37 ± 0.14*	1.54 ± 0.23**		

COP…The displacement of the center of pressure; BR10…after the bed rest; R+ 30…after the 30-day recovery; *different from BDC; ** different from BR10

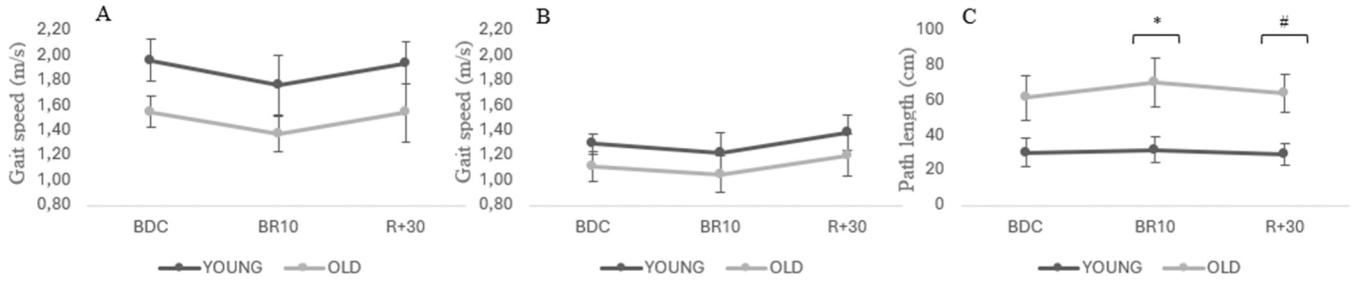

Fig. 1. Changes in gait speed and postural control across the study period. A… self-selected gait speed; B… brisk gait speed; C… postural control (average total sway distance); *… significant difference between YOUNG and OLD at BR10 after adjusting for BDC values as a covariate; #… Significant difference between YOUNG and OLD at R+ 30 after adjusting for BDC values as a covariate.

disuse [25,26].

The association between reduced muscle strength, particularly in the lower extremities, and slower gait speed [27], impaired postural control [28] and increased risk of falls [29] in older adults is well documented. Because gait speed depends on lower-limb force production (push-off, swing phase, stability), a decline in muscle strength is indeed expected to contribute to slower gait [30].

In addition, declines in muscle mass and strength are critical determinants of functional capacity in older age [31] and represent key contributors to age-related sarcopenia [32]. Previous studies have consistently shown that gait speed is closely associated with lower-limb muscle strength [33] and that muscle weakness systematically reduces gait performance and postural stability [34]. Bed rest, as a well-controlled model of accelerated aging, offers valuable insights into the structural and functional adaptations that accompany disuse. Pišot et al. [35] identified distinct responses to a 14-day horizontal bed rest between older (55–64 years) and young adults, with older adults exhibiting greater quadriceps muscle atrophy and a pronounced reduction in force and power output. Moreover, older participants showed slower recovery following a 14-day rehabilitation program compared with their younger counterparts. This accelerated muscle atrophy, reduced force-generating capacity, and delayed recovery may collectively explain the impaired postural control and reduced gait speed observed in the older adults of our study following bed rest.

However, recent evidence indicates that bed rest can also induce neuromotor adaptations, including reduced corticospinal excitability, altered sensorimotor integration, and increased reliance on visual input, which collectively contribute to greater postural sway and instability [36]. Such changes may exacerbate balance deficits in older adults, who often present age-related declines in proprioceptive and vestibular function [7], thereby providing a complementary explanation for the pronounced postural control deterioration observed in this group. The reduced postural balance after bed rest in the older group may also represent a greater risk for falls, one of the most serious consequences of reduced postural balance and strength in the older population [37,38].

Interestingly, these neuromuscular and sensory alterations did not manifest as measurable impairments in gait at the self-selected walking speed. In both groups, responses to inactivity and subsequent recovery were nearly identical, with only minimal (< 2%) variation in performance across assessments. In contrast to our results, Di Girolamo et al. [12], in their meta-analysis, reported a significant decline in self-selected gait speed in older adults following a 10-day or longer bed rest, with an average decrease of approximately 8%. In our study, the decline was slightly less than 6% and non-significant in both young and older adults. This disparity may be attributed to differences in testing protocols. For instance, Coker et al. [16] and Kortebein et al. [39] utilized a 5-minute walking test, which is physically more demanding, with a strong aerobic component, compared to our assessment. Furthermore, the other studies included in the meta-analysis that followed a 10-day bed rest protocol did not assess gait speed. Notably, in Marušič et al. [40] the 14-day bed rest period induced no changes in the self-selected and fast walking speed of older adults. The authors assessed gait speed using 1-minute conditions, which aligns with the methodology used in the present study.

Our findings demonstrate that only the most demanding gait condition, brisk walking at the fastest sustainable speed, was significantly impaired following bed rest, whereas self-selected walking speed remained unaffected. In other words, short-term inactivity mainly diminishes one's physiological reserve for high-intensity locomotor tasks without substantially affecting basic walking ability. This pattern is consistent with previous bed rest findings indicating that short-term inactivity reduces the ability to perform at maximal effort, whereas routine walking at a self-selected pace is relatively unaffected. For instance, 10 days of bed rest in healthy older adults led to marked losses in leg strength, power, and aerobic capacity (~12–14% declines), yet usual walking speed and other routine performance measures showed no significant change [39]. Similarly, in a five-day bed rest study, Reidy et al. [41] reported significant declines in peak knee extension power, whereas performance in a six-minute walking test remained unchanged. These findings support that short-term inactivity predominantly impairs maximal muscular performance, while functional abilities required for everyday walking are maintained. Encouragingly, brisk walking at the fastest sustainable speed was fully restored after the 30-day rehabilitation period in our participants, suggesting that these impairments were reversible and primarily attributable to deconditioning rather than structural damage. This aligns with recent findings demonstrating complete recovery of muscle power and walking performance following short-term immobilization and retraining in both young and older adults

[42].

From a clinical perspective, the present findings indicate that short-term bed rest primarily affects postural control and higher-demand locomotor performance, while basic gait function at a self-selected pace remains relatively preserved. This suggests that, following periods of immobilization, rehabilitation should not focus solely on restoring habitual walking ability, but should also target balance and higher-intensity locomotor capacity. In particular, the persistence of reduced postural control relative to younger adults after the recovery period indicates that balance deficits may not be resolved with standard recovery alone and may require specific and potentially prolonged intervention. Therefore, rehabilitation programs for older patients should incorporate targeted balance training and exercises aimed at restoring neuromuscular control and functional reserve, in order to reduce the risk of instability and falls despite apparent recovery of basic gait function. Future studies should investigate optimized rehabilitation strategies that more effectively address these deficits in older populations following inactivity.

The main limitation of this study lies in the inability to directly examine the mechanisms underlying the observed functional declines and age-related differences. Moreover, the use of two different gait assessment systems across study phases may have introduced minor methodological variability; however, cross-checking of outputs indicated no systematic bias in gait speed measurements. Future research should aim to integrate neurophysiological assessments to elucidate the cortical and sensorimotor processes contributing to balance and gait adaptations following inactivity. The application of advanced techniques such as mobile brain/body imaging (MoBI) [43–46] could provide a more comprehensive understanding of the neural mechanisms and physiological determinants underlying these effects. Such knowledge would not only advance current insights into the neuromotor consequences of bed rest but also inform the design of targeted interventions to promote functional recovery and preserve mobility in aging populations.

CRediT authorship contribution statement

Uros Marusic: Writing – review & editing, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Rado Pišot:** Writing – review & editing, Project administration, Methodology, Investigation, Conceptualization. **Marco V. Narici:** Writing – review & editing, Project administration, Methodology, Conceptualization. **Luka Šlosar:** Writing – review & editing, Writing – original draft, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Manca Peskar:** Writing – review & editing, Project administration, Data curation. **Boštjan Šimunič:** Writing – review & editing, Project administration, Methodology, Investigation, Data curation, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this work the authors used ChatGPT-5 in order to improve language and readability of the text. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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Declaration of Competing Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gaitpost.2026.110203.

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