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Review Article

Biomechanics of Gait in the Elderly: A Literature Review

Somayeh Mehrlatifan[1], Ali Fatahi[1,*] and Davood Khezri[2]
[1]Department of Sports Biomechanics, Central Tehran Branch, Islamic Azad University, Tehran, Iran
[2]Sport Sciences Reseach Institute of Iran, Tehran, Iran

[*]*Corresponding author*: Department of Sports Biomechanics, Central Tehran Branch, Islamic Azad University, Tehran, Iran. Email: ali.fatahi@iauctb.ac.ir

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Abstract

Context: Aging is associated with extensive changes in physiological and biomechanical factors, such as reduction of muscle function. Identifying and controlling the negative effects caused by these changes can help improve the quality of life of the elderly and reduce treatment costs. The objective of this research is to investigate the biomechanical changes of gates among elderly people.
Methods: All full-text articles with the keywords including elderly and walking, gait, aging, and geriatrics were considered. Data collection was done using a "Data Extraction Form" which was designed based on the purpose of the research. Articles were searched in reliable databases such as Mendeley PubMed, Science Direct, PubMed, Scopus, Google Scholar SpringerLink, and SID by searching keywords. At first, 1985 articles regarding biomechanical parameters of walking were found. Finally, 12 articles were directly related to the topic.
Results: The results of our studies showed that changes would occur in both kinetics and walking kinematics in old age due to the lack of neuromuscular and skeletal capacity and weakness in aspects of balance, coordination, and posture control. The elderly tend to perform compensatory strategies and altered movement patterns in gait, which lead to some changes in kinematic and kinetic characteristics.
Conclusions: Prevention, reduction, and treatment of movement disorders require timely diagnosis. Therefore, researches in the area of walking the elderly and assessing their risk of falling, and understanding how much age-related decline can be tolerated before creating movement restrictions are key factors.

Keywords: Elderly, Aging, Falling, Gait, Biomechanics, Kinetics, Kinematics

1. Context

Aging is a period of life that includes the chronological age of 60 years and later in developmental classifications. Today, with the advancement of science and health and the control of a large number of diseases, human life expectancy has increased. Therefore, the elderly population in developed and developing countries is increasing with the improvement of public health and the increase in life expectancy (1). According to statistics from 2002, approximately 600 million people worldwide were over the age of 60. It is projected that by 2050, this number will increase to two billion individuals (World Health Organization, 2002). Therefore, the concern related to the increase in the quality of life and the costs of this segment of society has encouraged experts to conduct more extensive research on the elderly (2). Currently, it is expected that compared to the past, in societies that are aging rapidly, more activities will be performed by the elderly (3). As individuals age, most physiological systems and bodily functions undergo gradual, progressive, and spontaneous erosive changes (4). Identifying and controlling the negative effects caused by these changes can help improve the quality of life of the elderly and reduce treatment costs. Aging is accompanied by many changes in physiological and biomechanical factors, such as the breakdown and reduction of muscle function, reduction in stride length and walking speed, reduction in the ability to maintain balance, increase in the risk of falling and tripping, reduction in the range of motion of lower body joints and changes in kinematic characteristics. There is a kinetic in the walking of people that causes this set of biomechanical changes that endangers the health of elderly people during walking (5). Therefore, it is necessary to identify and use appropriate tests to reduce the negative effects caused by these biomechanical changes in the elderly. As a basic locomotion skill, walking occupies the largest part of human daily movement activities. This skill, which is associated with problems in old age, is considered an indicator to determine the degree of independence in performing daily tasks in the elderly. Lack of control and balance during walking in the elderly is a potential cause of falls. The experience of falling causes the fear of walking and ultimately causes social isolation and a decrease in the quality of life (6).

In the researches done in the field of dynamic balance of the elderly, research has demonstrated that human physical ability tends to decline with age, and a significant contributing factor to this decline is the decrease in muscle strength. This decrease is primarily caused by the loss of muscle fibers and cross-sectional area. Muscle weakness in the thigh abductor, knee flexor, and ankle dorsiflexor muscles is related to the risk of falling during movement and walking (7). It has been reported to be expected that individuals will experience a loss of at least 30% of their muscle mass by the time they reach the age of 80 (8). This loss of mobility is greater in the lower limb than in the upper limb, and the elderly have shorter stride lengths and longer double support time, less forward power, and complete landing on the sole of the foot compared to younger individuals (9). In a study on the effects of age and walking speed on the biomechanical parameters of able-bodied elderly and young adults, their results showed that age and speed had no effect on the parameters of maximum thigh opening, the anterior tilt of the pelvis, and plantar flexion of the ankle. But ankle power was affected by different walking speeds. In the elderly, it is the sagittal thigh muscle strength that affects the period of support and balance during walking compared to younger people (10). As individuals age, their general physical functions and cognitive abilities tend to decline compared to those who are not elderly, leading to the deterioration of their muscle strength and balance (11). Therefore, it seems that in the same situation, the risk of falling in the elderly is higher than in non-elderly people (12, 13), which can lead to their death.

Furthermore, peroneal nerve dysfunction, a peripheral neuropathy commonly observed in the elderly, can result in reduced activity or paralysis; when the tibialis anterior (TA) muscle experiences a decrease in activity or paralysis, it can result in foot drop (14). The United States has a relatively high frequency of such cases, with 30% of elderly individuals experiencing at least one fall every year (15). Such dangerous situations can occur more during brisk walking than during normal walking. Also, studies have shown that walking on different surfaces in different conditions changes its kinetic and kinematic characteristics (16, 17). The objective of this research is to investigate the biomechanical changes of gate among elderly people.

3. Methods

This review study was conducted in accordance with the PERSIST guidelines (18).

3.1. Search Strategy

Key terms used in the search strategy were based on broad terms and related synonyms targeting, including the following words: gait, OR walking, biomechanics, kinetics, kinematics, elderly OR aging, OR geriatrics, OR older adult was conducted in seven reliable databases including Google Scholar, Mendeley, PubMed, Springer Link, Scopus, Web of Science, and SID from August 2022 to December 2022. In this search, an attempt was made to evaluate the progress of research about walking without considering any spatial limitations and in a wide time period, from 1997 to 2022. Although a wide range of articles was obtained by searching for the keywords of walking changes and the elderly, the aim of the present study was only to review the researches in which the movement protocol defined for the subjects was only to examine the biomechanical changes of walking in the elderly; Therefore, the number of articles found was 1985, which after initial screening and removing duplicate studies and studies before 2018, was 833. After removing the articles that were not in English or whose full text was not available from the total number of articles found, 134 articles remained. Then, by studying the abstracts of the articles, the studies that had the most thematic connection with our target were 20 articles, which was done with the main criteria in the selection of articles including attention to the kinetic and biomechanical parameters of movement and their application in modifying the movement pattern with the aim of preventing the occurrence of imbalance and falling by reading the full text of the article. After reading the entire text of the articles by three researchers, 12 articles were selected that were most relevant to the present study and were conducted with the aim of improving the quality and efficiency of movement in various conditions in older adults, and in each case, if there was no consensus on the selection of an article between all three researchers, a survey was conducted from the fourth researcher (sieve flow chart in Figure 1). Data collection was done using the "Data Extraction Form" which was designed based on the purpose of the research (Table 1). The biomechanical characteristics of walking and their related variables were organized based on the results of relevant studies and the recommendations of experts.

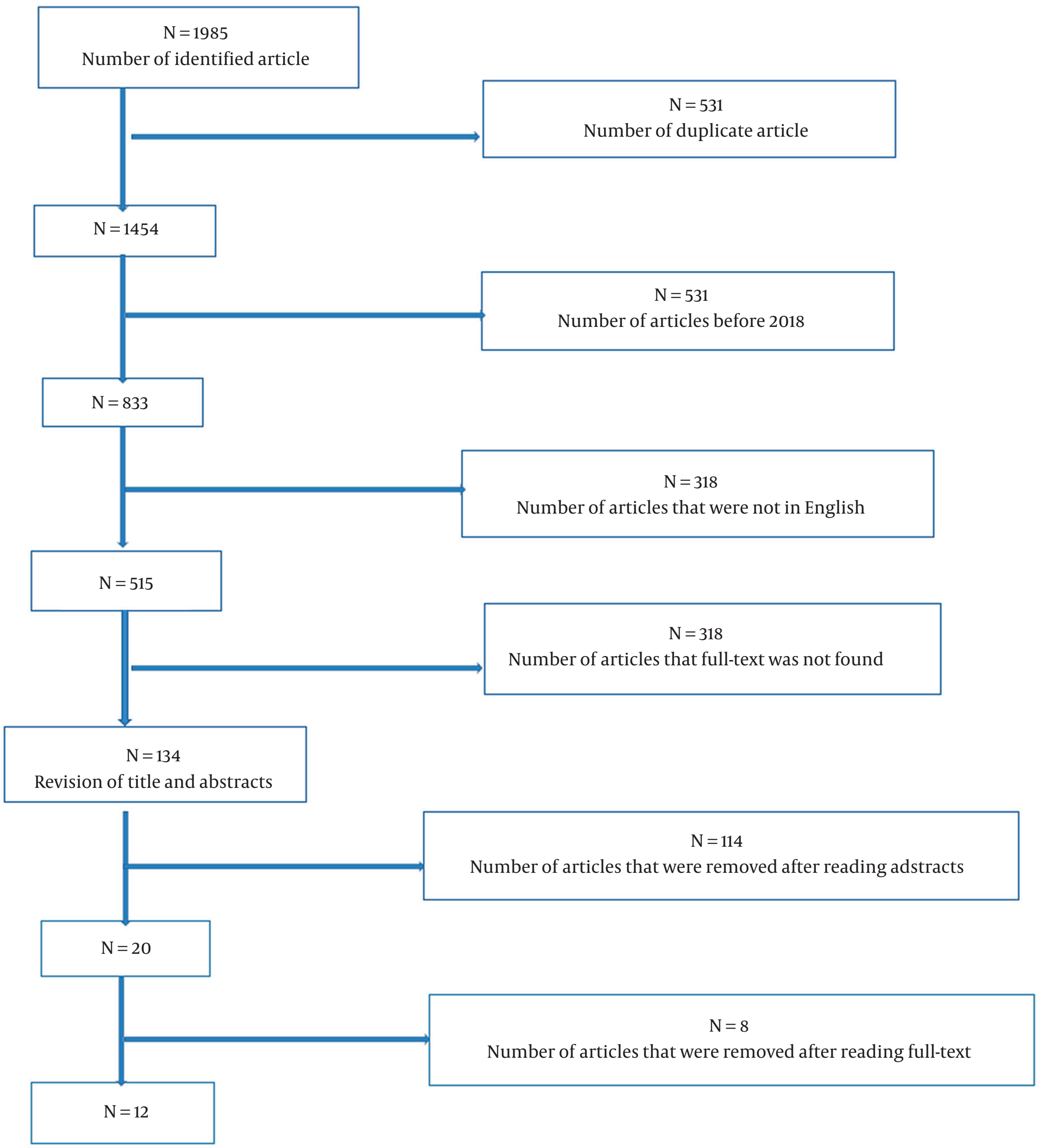

Figure 1. Flow chart of the study selection process

3.2. Eligibility Criteria

Articles published in magazines were required to be in English or Farsi. Studies in the field of bone fracture problems and burns, investigation of drug effects, diseases, or limb amputations, as well as in the field of cognitive and perceptual disorders or memory disorders. Studies that dealt with the biomechanical changes of walking and balance of the elderly and their improvement and the risk of falling while walking. Articles that were approved by both researchers.

3.3. Exclusion Criteria

Articles that were not in the field of elderly walking. Articles that were not in English or Farsi or their full text was not available. The articles that were based on the data extraction form that was designed based on the purpose of the study did not match. Studies were in the field of bone fractures and burns, diseases, and investigation of drug effects or limb amputation, as well as in the field of cognitive and perceptual disorders or memory disorders. Articles that were before 2018. Articles that were not agreed upon by the two researchers.

3.4. Study Selection

To minimize bias or errors in study selection, all three reviewers (SM, AF, DKH) independently screened study titles, abstracts, and full texts based on the inclusion criteria. In cases where there were disagreements, the reviewers discussed and reached a consensus.

3.5. Quality Assessment

A modified Downs and Black checklist was used for the assessment of the methodological quality of both randomized and non-randomized studies. It was used to evaluate the quality of articles (31). All included studies used 15 items extracted from the revised version of the Downs and black quality index (32). Three researchers independently evaluated each study. One researcher extracted the data from the included articles (S M), and the data was confirmed by the next researchers (A F, D KH). One point was given for each question. The average score was 9.91 (refer to Appendix 1 in Supplementary File).

3.6. Data Collection

All relevant data from the included articles were extracted by one author (SM). To minimize bias or errors in the data extraction, AF and DKH verified all the data.

4. Results

From the total of 12 articles that were included in this study, five articles were related to the investigations of both kinematics and kinetics of walking in the elderly (19, 21, 22, 29, 30), five articles of kinematic investigations (24-28), and two articles also included a kinetic study of the walking of the elderly (20, 23), three studies on shoes and types of surfaces (20, 24, 29), two articles on electromyographic studies on lower limbs while walking (23, 28), three articles on maintaining postural stability and balance and falling during elderly walking (22, 27, 30), one article about speed and balance (19), one article about the impact on walking parameters in the elderly (26), and two articles about the characteristics of lower limb joints during walking (21, 25).

4.1. Speed and Gait Biomechanics in the Elderly

Roh (19) investigated the effect of walking speed on the ground reaction forces and also on balance during walking of the elderly and observed that as a result of increasing the walking speed, the elderly face a decrease in balance. During normal walking, compared to the maximum walking speed, the increase in walking speed is accompanied by an increase in physical movements, and as a result, maintaining balance is difficult. According to this issue, when designing exercise programs for elderly individuals, greater emphasis should be placed on strengthening variables related to balance, with particular attention given to maintaining balance during increases in walking speed.

4.2. Footwear and Gait Biomechanics in the Elderly

Footwear strongly affects gait stability and variability in both older adults and the elderly. The conditions of walking barefoot and inside the building compared to outside conditions show the high compatibility of these parameters with different experimental conditions (20). Hida et al. (24) investigated the effect of different types of shoes on gait variables and reported the variations in the hip. This study examined the lower limb joint angles throughout the entire walking cycle in elderly individuals under different shoe conditions: large changes in joint angles in the knee and ankle in the sagittal plane during walking were detected, which emphasized the characteristics of a less fixed posture, and it was found that walking with less stable shoes may lead to increased variability in knee and ankle joint angles, which may, in turn, increase the risk of falling. Ren et al. (29), by examining walking with bare feet and with shoes in the elderly with the help of human body analysis software, found that walking with bare feet may be better than walking with shoes for balance training based on impairment in the elderly.

4.3. Center of Mass Changes, Muscle Activation Related to Gait Biomechanics in Elderly

Decreased COM compressive strength appears to be more related to walking speed than biological age. Thus, the findings suggest that age-related decline in COM compressive strength in able-bodied adults begins at age 70, which precedes changes in kinematics, emphasizing gaining a better understanding of the causes of age-related decline in older adults (23). Regional neuromuscular activation of the RF muscle is not associated with joint movements of the lower limb and toes during walking in the elderly (28).

4.4. Biomechanical Changes of Gait Related to Biological Age vs. Chronological Age

In examining the functional ability of the elderly, they found significant clinical differences between functional ability with a decreasing gradient from strong, moderate to weak in most walking parameters, and also the discriminating power of stratifications by SPPB is the highest. Classification by functional ability (biological age) shows a greater range of differentiation than chronological age (25). Kinematic and kinetic characteristics of the lower leg, knee, and thigh joints in two groups were explored and compared. The discoveries were as follows: up to 5 kinematic characteristics and 5 active characteristics on the lower leg, knee, and thigh joints were explored in the young and elderly population. A small variety in kinematic and kinetic characteristics not related to age was recognized in two bunches, which incorporate lower leg minute, knee point, hip flexion point, and hip adduction. Kinematics and energy of strolling, the nearness or nonappearance of certain pointers, instead of age, is pivotal in determining normal walking. This can be a key figure in evaluating the versatility and, by and large, useful capacity of more seasoned people (21).

4.5. Gait Changes Associated with Falls and Sex

In a 6-month follow-up, it was observed that elderly people who fell had lower performance in walking and showed less physical activity than non-fallers. They show more fear of falling and more limited movement (26). In research that was conducted in order to investigate the relationship between spine position and mobility with 3D accelerometry-based gait analysis, performance, and risk of falling in old age, it was shown that increasing (INC: trunk inclination angle) and decreasing hip extension mobility both play a role in increasing the risk of falling and are therapeutic targets to reduce the risk of falling in the elderly (27). In a study on postural mechanisms of gait initiation following unexpected perturbations, according to reports, young individuals were observed to possess a longer duration for adapting their anticipatory biomechanical response to perturbations during walking, compared to their older adult counterparts. This behavior was demonstrated in an effort to achieve balance maintenance. By way of contrast, the elderly cohort demonstrated an incapacity to adapt their anticipatory configurations in the presence of disturbance and instead heavily leaned on compensatory mechanisms that endeavored to uphold stability via a prudently executed stepping approach (22). Also, elderly women are more at risk of falling than their male counterparts. The study of uphill and downhill walking conditions determined that all walking characteristics were significantly different from walking conditions on the slope, and elderly women walked with a longer middle stance phase and loading response. Also, walking on an incline caused a longer standing phase (30).

5. Discussion

This study aims to conduct a comprehensive analysis of the biomechanics underlying the gait of elderly individuals and its changes related to aging and the risks caused by these changes, including falling while walking. The results of our studies showed that changes would occur in both kinetics (19-23, 29, 30) and walking kinematics (19, 21, 22, 24, 28-30) in old age.

Due to the lack of neuromuscular and skeletal capacities and weakness in balance, they tend to perform compensatory strategies and change movement patterns in walking (22), which itself causes some changes such as balance disturbance and falling, and costs are caused by it. It is important to consider the characteristics of different surfaces, such as the slope of the surfaces and the use of different types of shoes. Choosing shoes that don't cover the foot completely or don't fasten enough increases the risk of falling in the elderly by increasing the angle changes of the knee and ankle joints while walking (24). If the walking conditions and levels of the elderly are not safe, they will lead to an increase in the risk of falling by making changes in walking parameters and disrupting balance, and affecting postural stability (19). Elderly people are more at risk of falling outdoors (33) due to more exposure to high-risk items such as choosing inappropriate shoes, uneven surfaces, obstacles, and more possibility of balance disturbance.

From a biomechanical perspective, the concept of dynamic balance is characterized by the interplay between the individual's center of mass and base of support, response time in terms of spatial-marginal stability, and available response time. Therefore, preventive measures aimed at reducing falls ought to concentrate on the management of MFC (minimum two-foot distance), COF, and dynamic balance. The utilization of biomechanical concepts proves to be a practical approach in diverse day-to-day scenarios for the prevention of falls amid the aging demographic (34). Walking on steep surfaces due to the increase (INC: torso inclination angle) and decrease in hip extension mobility contribute to the increase in the risk of falling and are useful as therapeutic goals to reduce the risk of falling in the elderly.

The inability to increase walking speed has been identified as an important factor in disturbing the balance of the elderly while walking. In the elderly, chronological age cannot always be a complete guide for trainers and caregivers in the direction of physical assessment and care and exercise programs for the elderly, but in addition, it will be necessary to personalize the assessments based on individual characteristics. Kinematics and kinetics of age-independent factors of walking serve as fundamental guidelines for ambulating with routine functionality and are critical in evaluating the mobility and functional capacity of older adults (21). The preservation of an individual's ability to avoid falls holds a critical significance for fostering optimal life expectancy and promoting sustainable healthcare systems. It is recommended that older adults engage in active outdoor walking as a means of achieving adequate exercise; however, it is noteworthy that falls resulting from issues with balance and slips account for a predominant portion of severe injuries (34). Prevention, reduction, and treatment of movement disorders require timely diagnosis and identification (24). Periodic evaluations will provide this possibility for elderly caregivers. Therefore, research in the field of walking of the elderly and evaluation of movement disorders and predictions in the field of falling risk, as well as understanding how much age-related decline can be tolerated before creating movement restrictions, are key (25).

According to what was stated in this research, regular evaluation and periodic evaluation of walking in the elderly in order to inform the elderly and their caregivers about the changes that may occur in the walking of the elderly will be useful in order to prevent falls, take the necessary measures to prevent the fall. Like preventing an elderly from being in a situation where he has to suddenly increase his walking speed or check the slope of the surfaces that the elderly person is going to walk on. Practical intervention strategies include shoe modification (i.e., sole shoe geometry and slip-resistant soles), exercise (i.e., ankle dorsiflexion and central stabilizers), and technological rehabilitation (i.e., electrical stimulators and active exoskeletons) (34). And in the context of physical fitness for senior citizens, it is recommended that exercise regimens prioritize the enhancement of balance-related factors. Specifically, there exists a need to prioritize the maintenance of balance during periods of increased walking speed (19). Also, today, the use of assistive instruments with new technologies helps to increase the stability of walking for the elderly. Arefin et al. suggested using a smart cane as an assistive instrument with different design variations as per user requirements (35).

5.1. Conclusions

Our results show that the stability and variety of walking are strongly related to changes in the environment and experimental conditions and physical and individual characteristics of the elderly. From the point of view of prevention and treatment, we need to create training conditions based on the conditions of the elderly to improve and improve general walking skills. It seems that a training program that combines strength and balance programs is useful for improving the walking readiness of the elderly. Elderly people suffer from balance disorders and fall due to weakness and sudden increases in speed while walking. Studies concerning facility standards derived from the walking attributes of elderly individuals are essential to mitigate potential accidents that may arise during ambulation.

Supplementary Material

Supplementary material(s) is available here [To read supplementary materials, please refer to the journal website and open PDF/HTML].

Footnotes

Authors' Contribution: All the authors participated equally in all stages of the research.

Conflict of Interests: There was no conflict of interest in this study. The article is taken from a master's thesis regarding gait and challenges in elderly people. The first author is a researcher (student), the second author is a supervisor, and the third one is an advisor.

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Table 1. Data Extraction Form

Authors	Aims	Sample Size	Study Design	Statistic Method	Subjects	Method	Tool	Results
Roh (19)	Physical exercise through the analysis of kinetic & motor variables of fast walking - results	62	Cross-sectional	No report	The study included healthy elderly individuals (> 70 years old and without any diseases) and young adults (aged 19 - 29 years) as the control group	To analyze motion during normal and maximum walking, pedestrian passages were organized. The pedestrian passage was 10 meters in length and 3 meters in width, allowing for straight-line walking and remaining unaffected by the surrounding.	The study utilized a motion capture system composed of Raptor-3 and Eagle-4 and a ground reaction force plate to produce motion analysis.	The elderly experienced a decrease in walking speed of approximately 5% during maximum walking compared to normal walking. Variables related to balance were measured up to 12%.
Hollander et al. (20)	Parameters of gait stability & variability affected by shoed versus	74	RCT	No report	The study consisted of 32 young participants (17 women, 15 men; age: 30 ± 4 years) and 42 elderly participants (24 women, 18 men; age: 71 ± 4 years)	The subjects participated in the randomized within-subject study design. Participants conducted consecutive 25 m walking trials barefoot and with standardized footwear inside and outside. Inertial measurement units were mounted on the participant's foot and used to calculate local dynamic stability (LDS), velocity and minimal toe clearance (MTC), stride length, and stride time, including variabilities for these parameters. Linear mixed models were calculated.	The study utilized wireless inertial sensors (MTw2, Xsens Technologies B.V., Enschede, The Netherlands) with an angular velocity measurement range of ±1200°/s and a sampling rate of 100 Hz. The sensors were attached to the front of the right leg using tape.	Footwear strongly affects gait stability and variability in both older and younger adults. The study found that walking barefoot and inside a building, compared to outside conditions, demonstrated high compatibility of these parameters with different experimental conditions.
Liang et al. (21)	Investigate the kinematics and kinetics of walking unrelated to age	20	Cross-sectional	k-means clustering and Elbow Method	12 healthy young people and 8 healthy elderly people.	The study conducted gait analysis at a self-paced speed. Kinematic and kinetic features of the ankle, knee, and hip joints were analyzed and compared between the two groups. The degree of variation between the young and elderly in each feature was calculated using pattern distance and percentage of significant difference. K-means clustering and the Elbow Method were used to select and validate non-age-related features. The study also plotted average waveforms with standard deviation to compare the results.	Special motion recording cameras and two power screens	The study detected minor differences in the kinetic characteristics of movement between the young and elderly, which were unrelated to age. These differences included ankle moment, knee angle, hip flexion angle, and hip adduction moment. Kinematics and kinetics of walking that are not related to age are important indicators for normal walking function. These indicators are essential in evaluating the mobility and functional ability of the elderly and can be combined with other data of the present device.

Laudani et al. (22)	Comparing the ability to develop postural responses and maintain stability in response to external perturbations at the start of walking	20	Cross-sectional	Shapiro–Wilk test and with z-score transform (ANOVA), RMS, Mauchly's test, Greenhouse-Ge adjustment was applied on repeated measures, linear regressions, partial correlation analysis	10 young people and 10 old people	The study involved participants performing ten walking start trials followed by 48 unperturbed trials and 12 perturbed trials in random order. Mechanical parameters were quantified using a stereophotogrammetric system and three force platforms during the preparatory and stepping phases. Parameters included time and amplitude of postural adjustments, step characteristics, and dynamic stability. The study also analyzed the activation patterns of lower leg muscles.	The study utilized a stereophotogrammetric system and three force platforms to quantify mechanical parameters during the preparatory phase (e.g., time and amplitude of postural adjustments) and stepping phase (e.g., step characteristics and dynamic stability). The activation patterns of lower leg muscles were analyzed using surface electromyography.	Older participants showed smaller increases in both magnitude ($P < 0.001$; $\eta^2 p = 0.62$) and duration ($P = 0.001$; $\eta^2 p = 0.39$) of preparation parameters and shorter plantar muscle activity ($P < 0.001$; $\eta^2 p = 0.59$) and lower ($P < 0.001$; $\eta^2 p = 0.43$) compared to young participants when responding to perturbation. Interestingly, younger participants showed higher correlations between preparatory phase parameters and first-phase dynamic stability than older participants (mean r -0.40 and -0.06, respectively).
Sloot et al. (23)	Investigate age-related changes in leg work on the center of mass compressive strength during walking	138	Cross-sectional	(ANOVA), correlations and multiple regression analysis.	138 Adults 20 to 86 years old	Motion, ground reaction forces, and gastrocnemius muscle activity were documented in 138 adults while they walked overground at a self-selected pace. To analyze age-related differences in variables between decades, an ANOVA was employed. The relationship between COM push-off power and joint kinetic variables, as well as walking speed and biological age, was assessed using correlation and multiple regression analysis.	Force plate and (EMG) electromyography	An age-related decline in foot strike-off strength in able-bodied adults begins at age 70, which precedes changes in kinematics, and this decline in foot strike-off strength is more related to walking speed rather than biological age, which emphasizes the need to better understand the cause of deceleration in older adults.
Hida et al. (24)	Determining distinct differences in joint angle changes between different conditions in the use of different shoes	20	Cross-sectional	(ANOVA)	Healthy adults	In this study, 3D spatiotemporal data of hip and lower extremity joint angles were collected from 20 healthy adults during walking while wearing shoes under different conditions. The data was analyzed using Principal Component Analysis (PCA), and experiments were conducted in a room with a 10-meter straight and unobstructed path for participants to walk in shoes, slippers, and barefoot. Kinematic waveforms were reconstructed from the PCA data to identify significant differences in joint angle changes between the various shoe conditions.	The study utilized a 3D motion imaging system (VICON MX, Oxford, UK) to obtain three-dimensional position data at a sampling rate of 200 Hz. To ensure accurate marker placement, Visual 3D software (C-motion Inc., Germantown, MD, USA) was used to attach 57 reflective markers. Ground reaction forces (GRF) were also measured using a six-force plate (AMTI, Watertown, MA, USA) located at the center of the testing area and sampled at 1000 Hz. To process the data, a fourth-order zero-lag sphere-value filter was applied with a cut-off frequency of 10 Hz for marker trajectories and 56 Hz for GRFs.	This study aimed to investigate the impact of shoe fixation on joint angle changes in elderly individuals during walking. Results indicated that there was an increase in knee and ankle joint angle changes when walking with less fixed shoes. It can be a risk factor for falls.

Dapp et al. (25)	To contribute to the reference values of walking parameters based on functional ability	642	Cross-sectional	Chi2-test, *t*-test, (ANOVA)	642 participants living in the community (age 78.5 ± 4.8 years; 233 men, 409 women)	3 different established frameworks were visualized and combined that assess gait characteristics. An approach was based on eight gait parameters	Including the LUCAS functional ability index (FAI), the short physical performance battery (SPPB), and geriatric gait assessments using an objective system called GAITRite.	The study involved 642 participants who were classified into three groups based on their scores: strong (11 - 12 points) at 27.1%, moderate (8 - 10 points) at 44.2%, and weak (0 - 7 points) at 28.7%. Overall, the results demonstrated that functional ability was a better indicator of gait decline than chronological age, as indicated by a wide range of functional decline in all gait parameters examined. This suggests that classification based on functional ability (i.e., biological age) provides greater differentiation than chronological age alone.
Park et al. (26)	The potential impact of falls on several parameters of gait in elderly people.	163	Cohort (6-month follow-up)	Shapiro-Wilk, test, U Mann-Whitney, A one-way ANOVA, chi-square test, Cohen's d, measuring outcomes in two-time points, multiple pairwise comparisons were conducted using the least significant difference method	163 elderly people (age 76.5 ± 70.7 years) participated and were followed up for six months.	Participants were categorized as fallers or non-fallers based on their history of falls within the previous year. Objective assessments of gait, balance, and physical activity were conducted on all participants using wearable sensors at baseline and again at the 6-month follow-up.	Timed Up and Go test Additional assessments included psychosocial concerns (depression and fear of falling) and movement.	People who fell had lower performance in walking and showed less physical activity. Lower depression level, more fear of falling, and lower motor capacity compared to people who do not fall (in the beginning and in 6-month follow-up). Results also showed an acceleration in physical activity and decreased motor capacity (compared to non-fallers at a 6-month follow-up.)

Demarteau et al. (27)	Investigating the relationship between posture and mobility of the spine and fall risk in old age	121	RCT	—	Adults, old and young	40 elderlies with increased risk of falls (OFR, 80.6 ± 5.4 years), 41 old controls (OC, 79.1 ± 4.9 years), and 40 young controls (YC, 21.6 ± 1.4 years) were evaluated for spinal condition and mobility.	Spinal Mouse®), gait analysis (DynaPort MiniMod), and functional testing (grip strength, hand grip, timed test, get-up-and-go, performance-based motor assessment).	Compared to the OC group, the OFR group demonstrated significantly (P < 0.05) greater trunk inclination angle (INC), decreased sacral extension mobility, slower walking speed, and lower step regularity and mediolateral stepping. However, the thoracic kyphosis angle (TKA) was similar between the two groups. Of all the gait parameters examined, INC and sacral extension mobility exhibited the strongest correlation with gait speed, functional performance, and fall risk. Both INC (OR = 1.14) and sacral extension mobility (OR = 1.12) were able to differentiate OFR from OC, although they had low diagnostic values in predicting fall risk. The best possible cut-off values were determined to be -0.83 degrees for INC (sensitivity = 70%, specificity = 61%, PPV = 64%, NPV = 68%, LR+ = 1.79, LR- = 0.49, AUC = 0.71) and 8.5 degrees for sacral extension mobility (sensitivity = 70%, specificity = 73%, PPV = 72%, NPV = 71%, LR + = 2.61, LR - = 0.41) in middle-aged participants, AUC = 0.71.
Ullauri et al. (28)	The relationship between specific area electromyographic response (EMG) of the rectus femoris muscle (RF) and lower limb kinematics in the swing phase of walking	13	Cross-sectional	Two-tailed paired *t*-test and Bonferroni method.	13 elderly men (age: mean 71.3 years, standard deviation 5.7 years),	During normal treadmill walking, multi-channel surface EMG and lower limb kinematics were measured, specifically from the proximal to distal rectus femoris (RF) muscle. The relationship between central place activation (CLA), which reflects the spatial distribution of surface EMG along the RF muscle, and lower joint kinematics was calculated at the point of minimum leg distance during the swing phase.	EMG electromyography	The regional neuromuscular activation of the RF rectus femoris muscle is not related to lower limb joint movements and toe clearance strategy during walking in the elderly.
Ren et al. (29)	Investigating whether shoed or barefoot walking is more appropriate for impairment-based balance training	14	Cross-sectional	(ANOVA)	14 healthy elderly people aged: 68.29 ± 3.41 years	Performed normal and slip-like perturbed walking tests with barefoot and barefoot (shoes. Real-time analysis interactive lab.	Treadmill Human Body Model Software	The effect of shoe position (P = 0.0310) and walking pattern by shoe position interaction effect (P = 0.0055) were observed only in the variability of rotation time. Effects of gait pattern were detected in all four outcomes of gait variability

Kwon et al. (30)	Investigating the walking characteristics of elderly women in the conditions of the ground and the slope of the sidewalk	30	Cross-sectional	(ANOVA)	30 elderly women (15 young, elderly women and 15 older women)	The participants walked along a linear path that included three different walking conditions: on-ground, ascent, and descent.	Force Plate Business Motion Analysis Software	In older women, the loading response and mid-stance phase during landing gait were found to be longer compared to younger women. Walking uphill resulted in a longer end-stance phase in all participants. Additionally, significant interaction effects between age and walking condition were observed in the vertical ground reaction force (GRF), with older women exhibiting higher values than younger women during uphill walking ($P < 0.01$) and descending walking conditions ($P = 0.05$).