International Journal of Clinical and Experimental Medicine Research, 2025, 9(1), 157-172
https: //www.hillpublisher.com/journals/ijcemr/
ISSN Online: 2575-7970
ISSN Print: 2575-7989

Sitting-walking Derived from Tai Chi Gait: A Fundamental Improvement to Fall Prevention in Older Adults (Part 3)—Fall Prevention Effect of Sitting-walking

Lei Ming[1,*], **Lijia Zhang**[2]

[1]Spa of Amanfayun Resorts, Hangzhou 310013, Zhejiang, China.
[2]La Dolce Vita Spa for Wellness, Middletown, DE 19709, USA.

How to cite this paper: Lei Ming, Lijia Zhang. (2025) Sitting-walking Derived from Tai Chi Gait: A Fundamental Improvement to Fall Prevention in Older Adults (Part 3)—Fall Prevention Effect of Sitting-walking. *International Journal of Clinical and Experimental Medicine Research*, 9(1), 157-172.
DOI: 10.26855/ijcemr.2025.01.026

Received: December 30, 2024
Accepted: January 28, 2025
Published: February 27, 2025

***Corresponding author:** Lei Ming, Spa of Amanfayun Resorts, Hangzhou 310013, Zhejiang, China.

Abstract

This paper discusses the effects of sitting-walking (SW) derived from Tai Chi gait on fall prevention in older adults. Falls and instability of balance during normal walking (NW) are common problems among older adults. As independent risk factors for falls, muscle weakness, poor gait and balance (physiological factors), and fear of falls (psychological factors) are considered major obstacles to NW in older adults. The common approaches to fall prevention have focused on interventions aimed at improving the underlying problem, resulting in only a modest improvement in walking. Based on the physiological conditions of older adults, this paper focuses on reducing the risk of falls by solving the existing problems in the walk model itself. The authors believe that the problems existing in the NW (discussed in the second part) that cause unstable walking are the root cause of the falls of older adults with low physiological function and physical ability, and present a new perspective to minimize falls by changing the walking pattern itself. This paper aims to address the main problems in the NW phase, including the gait initiation and termination, and the active role of the SW mode (considered in the first part) to avoid the NW problems in older adults, thus reducing the difficulty of walking and improving walking stability.

Keywords

The risk factors of falls; physiological conditions of older adults; the root cause of falls; minimize falls; the effects of sitting-walking

Introduction

Poor balance and falls are major clinical problems in older adults [1]. Falls are common in older adults and pose a serious threat to health [2-4], leading to injuries, reducing quality of life, and threatening their ability to live independently [5]. Falls contribute to injury and death in older people and are a public health problem worldwide [6-9]. Consequently, to avoid injury, reduce medical costs, and improve quality of life, it is urgent to reduce the risk of falls among older adults [10].

Steindler [11] considers walking to be a series of narrowly avoided disasters. It shows that walking is a complex process, although this does not seem to be the case for normal people [12]. For older adults, however, walking seems to be an inevitable disaster. This is due to the problem of normal walking (NW) (see Part II), which is particularly significant in older adults with impaired physical function. Walking, as a complex task, poses requirements for the musculoskeletal, cardiopulmonary, and nervous systems [13]. In other words, walking is a full-body movement that requires internal and external coordination. The ability to walk normally depends on the free movement of joints (especially legs), the proper movement and strength of muscles, and the normal sensory input of visual, proprioceptive, and vestibular systems [1]. Many functional abilities [14], such as mobility [15], balance [16], posture control, proprioception, muscle strength, and tone and step height decline with aging, thereby reducing the ability to avoid falling [1]. This physiological decline amplifies and exaggerates the inherent problems of NW and is a key reason why older people are more likely to fall.

There are many reasons for falls in older adults, including physiological and psychological factors. Physiological factors (poor gait and balance) and psychological factors (fear of falling) are independent risk factors for falls [17]. Physiologically, the most important of these risk factors are muscle weakness and gait and balance problems [1], which are also considered the three main intrinsic fall risk factors [18]. Muscular weakness is an extremely common phenomenon among older adults, mainly due to disease or lack of activity, rather than aging itself [1]. The problem of gait may be due to changes in simple, age-related gait and balance, and to specific functional abnormalities in the nervous, muscular [1, 19], skeletal, circulatory, and respiratory systems, or the decline of function after an absence of activity [1]. Balance problems may be influenced by factors such as muscle weakness, sensory impairment, and limited movement [20]. Furthermore, in balance and falls, posture and center of mass (COM) play an important role [20]. From a psychological point of view, fear of falling is the psychological trauma caused by falling [21, 22]. A rising cycle of falls and fear leads to a reduction in physical activity, a reduction in functional abilities, and a reduction in the quality of life [23-25].

Age-related changes in neuromuscular functioning can lead to changes in gait characteristics [26]. Due to the decline of the central and peripheral nervous systems, which is influenced by age or disease, intrinsic motor or posture control during walking may be compromised, leading to a significant increase in the variability of gait [27, 28]. This makes older people's gait more rigid, less coordinated, and more precarious [1], resulting in imbalances and diminished gait performance [19]. While some functional problems with aging are inevitable, some risk factors can be modified with appropriate interventions. [1, 29, 30]. Factors such as balance and gait impairment, muscle weakness [30-35], and fear of falling [33-35] can be modified. Interventions can reduce the risk of falling due to problems with gait issues, weakness, imbalance, neurosensory issues, and behavior [36, 37].

There are large amounts of literature and technologies related to intervention issues. Common interventions for improving walking, such as strengthening, endurance, and flexibility programs, are used to improve the underlying impairments of the associated systems [38]. However, these multi-factorial impairment-based programs only slightly improved walking [39-44]. Because there is not much effective evidence-based data available for older adults, it is difficult to choose the right intervention for fall prevention [45]. There is also little evidence that interventions with intermediate effects reduce the risk of long-term ((post-intervention) falls [46]. Exercise is recommended to reduce the risk of falls in older adults, but it can cause negative consequences and injury if it is improper [47-49]. Therefore, innovative approaches should be taken to minimize falls [50]. A walking disability develops gradually and many older people with mobility problems are referred to geriatric specialists, but the causes of walking difficulties are often undetermined [13]. Interventions are also difficult to implement if the cause is unknown. Consequently, the authors believe that intervention to improve the underlying damage to the relevant system is not sufficient to prevent falls for older adults. Because of existing diagnostic and intervention problems, a different approach should be considered.

How to deal with the problem of older adults falling? Research has shown that older adults accept information that shows how to change rather than pointing out existing flaws [51].

It is better to have older adults actively participate in the intervention and help them become independent and confident. It is only through this can they achieve their independence and self-confidence. Helping older adults learn and practice new walking skills is an active intervention to replace a problematic gait pattern.

As mentioned above, the problems that exist in the NW itself are the root causes of walking instability. This instability is undoubtedly disastrous for older adults who have already weak physiological and motor abilities. It can be said that the NW mode is not suitable for older adults, and its existing problems are dangerous for them. Therefore, the solution to effectively reduce the risk of falling in older adults must begin with the solution to the existing problems in the NW. In other words, the key to solving the problem of fall prevention is to change the walking mode itself. The paper explores solutions from the perspective of the walk mode itself. The sitting-walking (SW) mode derived from Tai Chi-Gait (TCG) introduced in this paper not only avoids problems in the NW but also overcomes the negative effects of these problems in older adults and can help prevent falls. There is no academic literature on this issue to date. The methods described in this paper differ significantly from interventions based solely on improving multi-factorial injury.

Balance and proprioception in older adults are impaired, and the range of motion of joints is small, so it is difficult to apply stable or constant muscle force [52-54]. This is a common physiological condition in older adults. Improving the overall physical condition will improve the NW gait but it is not likely to return to a stable ambulation. Even for healthier older adults, have difficulty overcoming problems posed by NW. Therefore, older adults must minimize unstable factors during walking and reduce the uncontrollability of the walking process. This is like the high jump. If the height of the jump remains the same, it is still difficult for a person whose ability is not as good as before to accomplish the task only through physical and technical training. If the height is moderately reduced and training is provided in line with the physical state of the person to improve his or her ability, the success rate of performing tasks will increase greatly. Compared to NW, SW eliminates some unstable factors in NW and reduces excessive muscle strength dependence. Not only is walking relatively stable and easy, but it is also relatively easy to control body balance. For older people who have undergone physiological degenerative changes, the difficulty of walking is reduced. If supplemented with correct Tai Chi (TC) training, it can greatly improve the body's physiological functions and balance, making walking more stable. When older adults are more stable in their walking, self-confidence will be restored and the psychological problem of falling fear will be overcome. The SW posture enables the body to emphasize the role of skeletons and ligaments, decreasing overdependence on muscles, and thereby reducing muscle load and involvement. Maintaining the COM within the base of support (BOS) during SW makes balance relatively controllable. The horizontal advancing gait pattern shown by SW makes the gait quite stable. As mentioned above, SW shows great advantages over NW. These advantages not only make walking easier and more stable but significantly reduce the risk of falling due to the physiological degeneration of older adults in the NW. The following is a corresponding discussion on the main problems of older adults in the NW process according to the issues discussed earlier (Part II).

1. Reduction of Motion Disturbances During Walking

The most common internal disturbance that occurs during walking is from the rotation, extension, and flexion of the body in different directions [55]. This problem is an activity based on dynamic posture. The problems existing in NW are the cause of these disturbances, which are particularly prominent in older adults. This is not only related to the NW gait itself but also to the walking posture and physiological decline of older adults. Therefore, by changing the walking gait pattern, adjusting the walking posture, and avoiding many problems caused by physiological decline in older adults as much as possible, the interference of NW problems in older adults can be reduced or avoided to maximize balance during walking. SW has a unique gait and posture and plays a positive practical role in solving the above-mentioned problems.

1.1 Progressing forward

The goal of walking is to move forward [56]. During NW, the progression in the forward direction begins in the pre-swing, which is related to the activity of the ankle and plantar flexor muscle. The COM of a human walker rises and decelerates in the first half of the stance phase [57, 58]. This requires the foot to flex at the ankle in preparation for the "toe off" [59]. However, studies have shown that during the terminal stance of gait in older adults, plantar flexor strength in the ankle decreases when speed is adjusted [60]. Observation shows that older adults have a decreased push-off power at the ankle compared to young people [61]. Moreover, the maximum backward tilt of the body occurs during the mid-stance [62]. This makes the transition from double support to single support unstable. The lower plantar flexor torque and strength at the ankle caused by the decrease in mobility with age [61, 63, 64] result in reduced push-off power on the back foot. Insufficient strength of the plantar flexor makes it difficult to quickly obtain enough kinetic energy (KE) to raise and move forward the COM. This leads to a longer duration of double support in NW for older adults [61, 65], causing a slower pace [66]. As a result, the slowness of older people's walking is partly due to the prolonged duration of double support [67]. Age-related gait differences may be due to differences in gait speed [60]. Therefore, muscle strength and gait speed are directly related [68, 69]. Increased stride variability in step length, speed, and double support time significantly can increase the likelihood of future falls in older adults, regardless of whether they fear falling or not [70]. In addition, the extended time of double support also slows down the transformation of the COM. The delay or deficiency of the body's COM transformation may also cause an overall loss of balance, break the weight transfer chain, and even lead to falls [66]. These are related to the strength of the plantar flexors. Compared to other muscle groups, the ankle plantar flexor in older adults has more biomechanical and physiological defects [60]. With age, the physiological and biomechanical properties of plantar flexors decrease, resulting in older people using these muscles with less torque and power during walking than younger people [60]. In short, the decline of plantar flexor strength is a unique physiological degenerative feature of older adults, making progress forward more difficult during NW.

From foot-flat to toe-off, the hip of the leg is extended [71]. In other words, when the swing foot swings forward from the toe-off, the support leg hip is in extension. The swing leg swings forward based on the support leg. In this process, the hip of the support leg should be extended to help swing the leg forward, thus achieving the forward and upward movement of the body's COM. However, the hip extension ability of older adults decreases with age, which interferes with the motion of the swing leg, thus affecting the progression in the forward direction of the gait.

During the entire SW process, whether it is the single-foot landing (SFL) phase, the double-foot landing (DFL) phase, or the transition phase between the two phases, the trunk is in a vertical state [72]. During the process of progressing forward, the body will not experience ups and downs or tilt back and forth due to the movement of the lower limbs, which makes the body stable in any state. The forward movement of the COM is accomplished by gaining KE by pushing the ground with the heel in the initial COM transformation (COMT) [72]. In this process, the COM moves stably in the BOS between the feet [72], and the velocity is easy to control. During the transition from DFL to SFL, the dependence on the plantar flexor is minimal due to the absence of the rear foot's push-off, which avoids problems caused by plantar flexor weakness and decreased ankle strength. In SW, the hip is basically in a slight flexion [72], which avoids the problem of insufficient hip extension ability in older adults.

1.2 Leaning forward

During NW, the body leans forward, causing a great disturbance in balance. The maximum forward tilt occurs before initial contact [62]. To prevent falls, it is necessary to move the foot forward to a new position to temporarily restore balance [73]. The momentum of the body leaning forward causes the body's COM to exceed the new position of the foot, forcing the other foot to take a step forward, thus achieving the body's forward progress through the successive and alternative shifts of feet [73]. During walking, the trunk moves in the sagittal plane to balance the lower limb movement [74], which is related to the support leg and trunk. For the support leg, near the terminal stance, the heel begins to rise, and the plantar flexor increases its contractile force and concentric action [75, 76]. As a result, it is possible to control the velocity at which the body leans forward and the swing leg falls. The maximum forward tilt of the body before initial contact [62] and the decline and acceleration of the COM in the second half of the stance phase [57, 58], and the fact that older people's trunks lean forward while walking [60], all cause their trunks to lean forward even more. The strength of the plantar flexor muscle in older adults is weakened, resulting in a decline in the ability to control the forward tilt of the trunk and a decrease in stability during walking. It can be said that the muscle strength of the plantar flexor is related to the stability limit of older adults [77]. As muscle strength declines further with age [78, 79], older people need to use greater muscle strength in gait, which can change time-space parameters such as stride length and speed [26].

Relatively speaking, older adults have significantly longer ground contact times and shorter flight (in the air) times [26]. The shortening of the stride length of older adults is related to the shorter time required by swinging forward [60]. The variability of stride length increases with age [80, 81]. As a result, during older adults' walking, the swing leg spends less time in the air, the front foot contacts faster, and the stride length is shorter. Studies have shown that the gait speed and stride length of older people are reduced by 17 to 20 percent compared to those of younger people [82]. This is why older adults have shorter strides, slower walking speeds, and faster heel contact than younger people [66]. In terms of the trunk, it is the ground reaction force (GRF) that causes the trunk muscles to react during gait [83].

Therefore, the GRF generated by the heel strike during walking is transmitted to the trunk through the lower limb and pelvis, moving the trunk forward as the body's COM is relatively located forward [83]. At heel strike, it seems that the activity of the back extensor muscles resists trunk flexion [83]. However, in previous studies, it was found that age and gender are associated with trunk extensor strength [84, 85]. Studies have shown that lumbar extensor strength declines by approximately 50% during the third to sixth decade of life [86]. The degeneration of back muscles in older adults reduces the ability to control the flexion of the trunk, which increases the tendency of the body to lean forward. The influence of reduced plantar flexor strength on forward-leaning, stride length, and heel-contact time is a disturbing factor that leads to the imbalance of older adults in the NW.

During SW, from the dangle phase to early DFL (i.e., heel contact), the body's COM is always located in the BOS of the support leg, and the trunk remains vertically stable without leaning forward [72]. This does not interfere with the dangle amplitude or landing time of the dangling leg. Both the heel contact without a strike and the vertical lumbar posture do not cause tension in the back extensors.

1.3 Pelvic rotation

During the NW, pelvic rotation also affects balance. The rotation of the pelvis plays an important role in prolonging the stride [87]. The increase in the pelvic transverse range of motion causes the rise of the stride length and improvement of the relative constant cadence, resulting in acceleration of the gait speed [88]. However, the degeneration of the nervous system and musculoskeletal systems increases with age, making the rotation of the trunk more rigid [89]. This reduces the horizontal rotation of the trunk. Furthermore, as previously mentioned, the lengthening of the double support time of NW also reduces the gait speed. The slow gait speed of older adults may lead to a reduction in transverse pelvic motion [90]. Reduced pelvic motion in older adults may affect gait stability [91]. Walking stability indicates not only gait stability but also the ability to cope with disturbances [92]. Older adults show less adaptability to rigid trunk rotation than younger people, who have flexible trunk movements and respond well to external perturbations [89]. As a result, older adults tend to reduce the freedom of various parts of the body while walking to maintain dynamic balance and prevent falls [93]. This indicates that the stride and stability of NW largely depend on pelvic rotational motion. It can be said that the decrease in the amplitude of pelvic rotation not only reduces the stride but also reduces stability, thus reducing the ability to combat disturbances. Additionally, the pelvic rotation in NW causes the reverse rotation in the upper and lower trunk and the body's decline to the side of the swing leg during the mid-to-terminal swing. Consequently, swinging arms is necessary to maintain balance. During NW, the pelvis rotates at each step to generate body angular momentum around the longitudinal axis, while the arms swing in the opposite direction of the lower limb movement to balance the body angular momentum [94]. Specifically, the main function of arm swing is not only to balance the rotational force in the trunk [95] but also to counterbalance the contralateral leg and pelvic movement [96]. Although the arm swings during NW do not seem to require muscle effort, their swings are caused by the combination of muscle activity and gravity [71]. This means that arm swings are not passive but driven by muscle activity [97]. Muscular activity keeps the swing between the legs and arms out of sync [98]. From this point of view, arm swings are crucial for maintaining balance during NW. The research shows that the most important factor affecting the maximum speed of the dominant arm in NW is gait speed [96]. The arm swings increase as the transverse rotation of the pelvis increases [96]. However, studies have shown that gait speed and maximum arm swing speed decrease with age in older adults [96]. That is to say, a decline in muscle strength and gait speed in older adults lead to a decrease in pelvic rotation and stride and a relative decrease in trunk rotation, resulting in a decrease in arm swing speed. However, arm swing remains an essential element in maintaining balance during NW. Therefore, the decrease in the arm swing speed of older adults has an impact on the balance of the trunk, the contralateral foot, and the pelvic movement.

In the SW, pelvic rotation occurs only during the COMT period, and the trunk remains in a vertical position and rotates synchronously with the pelvis [72]. This prevents instability caused by the inclination of the trunk and the reversal of rotation between the upper and lower trunks. In SFL, the pelvis does not rotate, so the activity of the dangling leg is mainly related to the movement of the hip. During the dangle phase, the COM is located within the BOS of the support leg and the pelvis and trunk are facing ahead [72], making the swing leg controllable and the body stable. The physiological extension of the swing leg is achieved through pelvic tilting and hip relaxation [72]. As a result, stride and gait stability are not affected by the pelvic rotation and the swing leg movement, and body balance does not need to be maintained by arm swings. The arms swing only slightly due to inertia [72].

1.4 Lateral tilting

During NW, the interference of lateral tilt with balance is obvious. The peak of pelvic obliquity occurs exactly after the foot-off, corresponding to an early single stance [59]. Once the swing begins, the COM can be seen moving forward along the medial border of the foot [55]. Throughout the entire swing period, the body's COM is always placed outside the BOS of the support leg. This is true throughout the walk (except during the short double support period) [55]. As a result, the pelvis drops downward in the coronal plane on the opposite side of the weight-bearing limb [99], thus causing the body to tend to fall laterally. Consequently, the movement of the pelvis in the mediolateral (ML) direction is important to control lateral movement during walking, and the acceleration changes in this direction are mainly controlled by the bilateral hip joints [100]. Specifically, it is controlled by the hip abductor muscle [55]. At all stages of standing and walking, the key importance of hip abductors in balance is now obvious [55]. Especially, in recent literature, the importance of hip abductor muscle strength in maintaining mediolateral balance control is further highlighted [101-103]. This suggests that the weakening of the hip abductor muscle directly affects the mediolateral balance.

The speed at which gait initiates also affects lateral balance. Researchers have studied the effect of the speed of progression on mediolateral stability control in the gait initiation (GI), i.e., the COM's lateral fall toward the swing leg increases at high speeds compared to low and normal speeds [104]. The lateral balance of older adults during walking also varies depending on walking speed [100]. Studies have shown that older adults have a lateral instability associated with the risk of falling [105].

Furthermore, following the swing foot off, the main mechanism to restore stability in the frontal plane is the placement of the foot [106-108]. Only by safely placing the swing foot can a fall be avoided at each step [55]. Healthy young people can adjust the mediolateral foot placement well to maintain constant mediolateral stability at GI [109]. In older adults, the range of motion of the lower limb is often very small, and walking usually involves a limited range of motion of the lower limb joints [110, 111]. Balance loss in older adults is usually caused by muscle loss and weakness [112] and the inability to move the feet to an appropriate BOS position [101, 113]. Lateral stability depends on lateral control of the trunk and lateral placement of the feet [114]. In older adults, swaying the trunk from side to side may also interfere with lateral balance. Improper perception of trunk spatial orientation in older adults leads to incorrect foot position placement during walking, and inadequate stability in the frontal plane, resulting in a higher risk of falls [115]. Older adults who are prone to falls have a larger lateral displacement of the body's COM and more irregular lateral foot placement than normal people [116]. This means that the required lateral foot position increases, which requires the contraction of the hip abductor muscle in the swing leg to produce an abduction movement. Therefore, if the hip abductor muscle capacity decreases, the movement of the swing leg may be limited. Additionally, due to the decrease in swing time during walking in older adults, foot contact may occur before the swing leg reaches a suitable foot position. Normally, shortly after the heel strike, the trunk makes the greatest tilt toward the stance limb [117]. At this point, due to the COM located outside the BOS, insufficient lateral displacement and excessive lateral velocity may easily cause lateral imbalance or even a fall. The study has reported that ML dynamic stability is reduced in older adults [118].

Furthermore, with age, there is an isolated and sustained decrease in hip extension during walking, but the decrease is greater in older fallers than in older non-fallers [119]. During the initial contact at the terminal swing in NW, the hip of the hind leg needs to be extended at the same time. Therefore, a reduction in the extension of the hip can affect contact time, forefoot position, and gait.

During SW, as the COM is located at the BOS of the support leg and the trunk remains upright, the body does not tilt laterally [72]. Since the lateral displacement of the body occurs in the COMT during the DFL [72], the body remains stable during the forward and lateral movements of the COM in the horizontal plane. The relatively large pelvic obliquity significantly reduces the lateral distance between the swing foot and the support leg, thereby reducing the involvement of the hip abductor muscle. This allows the swing leg to land without interference and maintains a small lateral stride, saving energy while maintaining balance. Due to the slight flexion posture of the hip during SW, problems caused by reduced hip extension are avoided.

2. Reduction of Fall Risk During Gait Initiation and Termination

During NW, the dynamic processes of gait initiation and gait termination (GT) are complex, as the body is usually required to accelerate and decelerate, respectively, in a limited time [120]. Therefore, the skills required to maintain stability, weight transfer, foot clearance, and so on are more important in these transition stages than in steady-state conditions [121, 122]. GI and GT also pose challenges to the center of pressure (COP) and COM controls [123, 124]. Falls in older adults often occur during transitional movements, such as the GI and GT, and changes in direction [125, 126]. These requirements become even more important in older adults who have inherent difficulties with postural stability and gait [127, 128]. The transitional movement causes difficulties for older adults and disabled people [129, 130]. Among all these tasks, balance is challenged when transitioning from one static or dynamic stable motion mode to another [124]. From this, it can be seen that there are also significant stability problems with the GI and GT in the NW. The difficulty of completing it is greater than stepping and poses a great risk of falling for older adults with physiological degradation. Similarly, solving this problem also requires starting with gait and posture, while attempting to avoid the shortcomings of the physiological aspects of older adults. Adopting the SW mode can also effectively get rid of the problems caused by the GI and GT in NW. For older adults with physical problems, the difficulty of walking and the risk of falling are also greatly reduced with SW.

2.1 Gait initiation

The transitional movement from upright standing to stepping or walking is a common motion task [131]. This transitional movement, commonly known as GI, involves composite and synergistic neuromuscular control and coordination [132, 133]. The GI demands the neuromuscular system more than steady-state walking due to the complex integration of neural mechanisms, muscle activity, and the required biomechanical force [134]. GI is a transitional state between quiet standing (QS) and steady-state gait, which healthy people can easily pass through [135]. But it is also a task to that challenges the balance control system [134, 136]. Both aging and disease cause changes in the nervous system, muscular system, skeleton, and other systems of the body, affecting balance control [136]. This may affect the activity and stability of the GI in older adults. In NW, the movement begins with leaning forward [73]. This leaning forward indicates a forward and downward trend of the COM, which activates the movement of walking [72]. This initiation, with the trunk leaning forward, is similar to a controlled fall [137]. Due to the large weight of the trunk relative to the entire body [55], controlling the tilt of the trunk at the GI seems challenging [138]. The GI is first achieved by lowering the body's COM, while the lower limb repositions under the body to establish a new BOS to prevent the actual fall [139]. Studies have found that it is difficult for older adults to decelerate the COM downward speed [140]. That is, it is difficult for older adults to perform active vertical braking, which can lead to postural instability [109]. This is particularly true for older adults [136], who typically exhibit atypical trunk postures [141] and have a high risk of falling at the GI [142].

In addition, indicators of balance and postural control are often presented as COP [143]. The force produced by COP displacement is less in the anteroposterior (AP) and mediolateral (ML) directions in older adults [123, 142, 144, 145]. Reduced COP sway in the AP or ML direction may indicate either instability or the use of another form of postural control, which may generate inefficient momentum for the GI [144, 146]. The COP is required to precisely control the COM during the transition between the relatively stable quasi-static double support and the challenging and dynamic single support [123, 136, 147-149]. This control relies on the integrity of sensory and motor functions in the lower limbs and trunk [124, 150, 151]. In the sagittal plane, the COP at the GI, or the origin of the GRF vector, is controlled by the interaction of antagonistic muscles at the ankle [152-154]. The forward progression of COP at the stance foot is controlled by the plantar-flexor activity of the stance limb ankle [147]. Therefore, during GI, lower limb muscle activity plays an important role in controlling the displacement trajectories of COM and COP [131]. Normal GI is characterized by COM and COP displacement caused by consistent patterns of lower limb muscle activity [131]. There is no doubt that the decreased strength of lower limb muscles and plantar flexors in older adults is extremely unfavorable to the control of COP and COM.

The GI of SW is different from that of NW. At the GI during SW, the COM is located in the BOS of the support leg, the trunk remains upright, and the body does not tilt forward or laterally when swinging a leg. A significant pelvic obliquity and hip muscle relaxation create a physiologic extension of the swing leg, making it easy to achieve a foot landing while maintaining an upright trunk. The COM does not move during the dangle phase. Therefore, there is almost no displacement of COP in the AP and ML directions, and both COP and COM are within BOS. The characteristics of SW effectively avoid the problem of over-reliance on lower limb muscles at the GI during NW. The use of SW can not only reduce the difficulty of GI but also improve stability.

2.2 Gait termination

GT is a common transitional movement in daily life [147, 155, 156], which poses a huge challenge to the body as the nervous system must effectively transition the body from a dynamic state to a static state [157]. GT is achieved by a series of postural adjustments to control the body's forward movement and dissipate all KE generated by walking motion [156]. This means that GT is closely related to posture. Compared to stepping, GT requires greater control of postural stability and complex integration and collaboration of the neuromuscular system [158]. GT involves complex sensory, vestibular, and proprioceptive integration [124]. As a result, problems may arise when older adults, including those with disabilities or neurological conditions, attempt to terminate their gait [55, 159]. The GT process from dynamic walking to static standing is characterized by an increase in the front foot brake force and a decrease in the back foot push-off at the last step [160, 161]. The main difference between GT and gait movement is that the propulsive phase is less [124, 155]. Compared to normal gait, the braking force during GT increases in the final support phase, making it difficult for older adults to maintain stability due to their relatively low muscle strength [162, 163]. Undoubtedly, GT is a significant stability challenge for older adults, including those with balance disorders, especially in the case of unplanned gait termination (UGT) [124]. In the event of an unexpected attempt to terminate the gait, the last step's walking speed will decrease by about 90% [163], which results in a significant change in position, causing older adults to lose balance and even fall [164].

In addition, to avoid colliding with unexpected obstacles while walking, a person must stop moving or change direction, both of which require reducing the momentum of the forward movement of the COM and controlling it within the BOS in the body [165]. Sudden changes in COM reduce stability and may lead to falls [149, 166]. These changes require rapid deceleration of the COM in unexpected situations, thus increasing the risk of falls and other injuries [167]. To avoid unexpected falls or collisions, knee joints can be used to quickly stop the body to improve body control, which is achieved through the active movement of the knee extensor to increase the knee extension torque [165]. However, the knee stretching torque of older adults is lower due to aging [163, 168]. Moreover, the plantar flexion torque of the ankle helps support the body [169]. However, the decline of the plantar flexor in older adults also weakens this function.

During NW, there are three main ways of GT: 1) reducing the acceleration of the body's COM through the synergistic effect of the hind leg flexors and 2) increasing the deceleration of the whole body's COM through the synergistic action of the forelimb extensor muscles [155, 156], as well as 3) transferring energy or momentum through a toe raise [155] or transferring momentum to another motion plane [159]. No matter what method is used to achieve GT, muscle synergy is required. The decrease in lower limb muscle strength in older adults is not conducive to fulfilling such tasks. Due to the decrease in muscle strength of the lower limbs with age, older adults may experience falls when performing very simple actions and are more likely to lose balance when changing positions [124]. This indicates that the decrease in lower limb muscle strength is closely related to falls [165]. Studies have shown a high rate of falls during GT in older adults as well as in several neurological disorders [170, 171]. Together, these age-induced muscle weaknesses make GT a significant risk factor for older adults.

In response to the above-mentioned problems, by adopting unique postures and gait during the SW process, the risk of falling is reduced, thereby effectively avoiding physiological problems in older adults. First, keeping the trunk vertically is the most prominent feature. Active control of the body's perpendicularity in the sagittal and frontal planes stabilizes the head containing visual and vestibular sensory references [172]. The regulatory "center point" of vestibular system activity is based on the vertically upright posture of the body [173]. In cases where older adults often exhibit muscle weakness and reduced capacity to organize muscle strength, maintaining a vertical trunk may improve balance and reduce falls [172]. Secondly, the GT process during SW is also based on the smooth transition of the COM during the COMT period. The change in COM velocity depends on the push force of the hindfoot in the initial COMT, but this has no direct effect on the stability of the body. Thirdly, since GT does not involve front foot brake or rear foot propulsion, it is also less dependent on lower muscles than NW. Compared with NW, both PGT and UGT are relatively controllable.

3. Conclusion

In NW, the problems existing in progressing forward, leaning forward, pelvic rotation, and lateral tilting during stepping cause gait movement problems, while the problems existing in the activities during the GI and GT bring the risk of falls to the gait. These factors make walking more difficult, especially in older adults who already have declining physiological function and increase the risk of falling. Therefore, the solution to the problem of fall prevention is to reduce the difficulty of walking and improve body stability, thereby reducing the risk of imbalance and falling. The SW pattern can effectively avoid the problems existing in the NW and reduce the difficulty of walking. This reduces the risk of relying on an impaired neuromuscular system, balance, and muscle strength for gait stability and the improved walking stability with SW offers a fundamental improvement in fall prevention in older adults.

Acknowledgments

We thank Dr. Paul Martin for his professional suggestions and practical feedback on the content of the paper, as well as the revision of the English text.

Funding Statement

This study received no specific grants from any funding agency in the public, commercial, or not-for-profit sectors.

Ethical Compliance

Not applicable.

Conflict of Interest

The authors declare that they have no conflicts of interest.

Author Contributions

LM, as the creator of sitting-walking, contributed to the design, implementation, and establishment of the theoretical system, as well as the conceptualization and writing of the manuscript. LJZ was involved in the overall practical operation and experience and provided technical suggestions on the manuscript content. All authors (LM and LJZ) have read and approved the manuscript.

References

[1] Rubenstein LZ. Falls in older people: epidemiology, risk factors and strategies for prevention. Age Ageing. 2006;35(Suppl 2):ii37-ii41. doi:10.1093/ageing/afl084.

[2] Howcroft J, Kofman J, Lemaire ED. Review of fall risk assessment in geriatric populations using inertial sensors. J Neuroeng Rehabil. 2013;10(1):91. doi:10.1186/1743-0003-10-91.

[3] Huang Z, Feng Y, Li Y, Lv C. Systematic review and meta-analysis: Tai Chi for preventing falls in older adults. BMJ Open. 2017;7(2):e013661. doi:10.1136/bmjopen-2016-013661.

[4] Rao SS. Prevention of falls in older patients. Am Fam Physician. 2005;72(1):81-88. Available from: https://pubmed.ncbi.nlm.nih.gov/16035686.

[5] CDC. Older Adult Fall Prevention. 2023 Apr 12. Available from: https://www.cdc.gov/falls/index.html.

[6] Bergen G, Stevens MR, Burns ER. Falls and fall injuries among adults aged ≥65 years — United States, 2014. MMWR Morb Mortal Wkly Rep. 2016;65(37):993-998. doi:10.15585/mmwr.mm6537a2.

[7] Khanuja K, Joki J, Bachmann G, Cuccurullo S. Gait and balance in the aging population: Fall prevention using innovation and technology. Maturitas. 2018;110:51-56. doi:10.1016/j.maturitas.2018.01.021.

[8] Cigolle CT, Ha J, Min LC, Lee PG, Gure TR, Alexander NB, Blaum CS. The epidemiologic data on falls, 1998-2010: more older Americans report falling. JAMA Intern Med. 2015;175(3):443-445. doi:10.1001/jamainternmed.2014.7533.

[9] Zhong D-L, Xiao Q-W, He M-X, Li Y-X, Ye J, Zheng H, Xia L-N, Zhang C, Liang F-R, Li J, Jin R-J. Tai Chi for improving balance and reducing falls. Medicine. 2019;98(17):e15225. doi:10.1097/md.0000000000015225.

[10] Chen Y, Ringdahl D, Trelstad-Porter R, Gurvich OV. Feasibility of implementing a Tai chi program in an assisted living facility: reducing fall risks and improving quality of life. J Clin Med. 2021;10(6):1277. doi:10.3390/jcm10061277.

[11] Steindler A. A historical review of the studies and investigations made in relation to human gait. J Bone Joint Surg Am. 1953;35-A(3):540-542.

[12] Elders LR, Greenwald HL, Sartor CA. A Preliminary Study of Trunk Kinematics during Walking in Normal Subjects. Masters Theses. 1997;322. Available from: https://scholarworks.gvsu.edu/theses/322.

[13] Ferrucci L, Bandinelli S, Benvenuti E, Di Iorio A, Macchi C, Harris TB, Guralnik JM. Subsystems contributing to the decline in ability to walk: Bridging the gap between epidemiology and geriatric practice in the InCHIANTI study. J Am Geriatr Soc. 2000;48(12):1618-1625. doi:10.1111/j.1532-5415.2000.tb03873.x.

[14] Guirguis-Blake JM, Michael YL, Perdue LA, Coppola EL, Beil TL, Thompson JH. Interventions to Prevent Falls in Community-Dwelling Older Adults: A Systematic Review for the U.S. Preventive Services Task Force. Agency for Healthcare Research and Quality (US), 2018.

[15] Zhong R, Rau PP, Yan X. Application of smart bracelet to monitor frailty-related gait parameters of older Chinese adults: A preliminary study. Geriatr Gerontol Int. 2018;18(9):1366-1371. doi:10.1111/ggi.13492.

[16] Neyens J, Dijcks B, Twisk JWR, Schols JMG A, Van Haastregt JCM, Van Den Heuvel W, De Witte L. A multifactorial intervention for the prevention of falls in psychogeriatric nursing home patients, a randomised controlled trial (RCT). Age Ageing. 2008;38(2):194-199. doi:10.1093/ageing/afn297.

[17] Delbaere K, Close JCT, Brodaty H, Sachdev PS, Lord SR. Determinants of disparities between perceived and physiological risk of falling among elderly people: cohort study. BMJ. 2010;341(Aug18 4):c4165. doi:10.1136/bmj.c4165.

[18] Gschwind YJ, Kressig RW, Lacroix A, Muehlbauer T, Pfenninger B, Granacher U. A best practice fall prevention exercise

program to improve balance, strength / power, and psychosocial health in older adults: study protocol for a randomized controlled trial. BMC Geriatr. 2013;13(1). doi:10.1186/1471-2318-13-105.

[19] Granacher U, Muehlbauer T, Gruber M. A Qualitative review of balance and strength performance in healthy Older Adults: Impact for testing and training. J Aging Res. 2012;2012:1-16. doi:10.1155/2012/708905.

[20] Usami K, Aimoto K, Oyabu M, Hashimoto K, Owaki S, Tozawa N, Kondo I. Maximum inter-foot distance during leg-crossing movement depends on whether the dominant or non-dominant leg is in front. Prog Rehabil Med. 2017;2(0):n/a. doi:10.2490/prm.20170010.

[21] Tinetti ME, Speechley M. Prevention of Falls among the Elderly. N Engl J Med. 1989;320(16):1055-1059. doi:10.1056/nejm198904203201606.

[22] Hindmarsh JJ, Estes EH Jr. Falls in older persons. Causes and interventions. Arch Intern Med. 1989;149(10):2217-2222.

[23] Friedman SM, Munoz B, West SK, Rubin GS, Fried LP. Falls and fear of falling: Which comes first? A longitudinal prediction model suggests strategies for primary and secondary prevention. J Am Geriatr Soc. 2002;50(8):1329-1335. doi:10.1046/j.1532-5415.2002.50352.x.

[24] Cumming RG, Salkeld G, Thomas MH, Szonyi G. Prospective study of the impact of fear of falling on activities of daily living, SF-36 scores, and nursing home admission. J Gerontol A Biol Sci Med Sci. 2000;55(5):M299-M305. doi:10.1093/gerona/55.5.m299.

[25] Murphy SL, Williams CS, Gill TM. Characteristics Associated with Fear of Falling and Activity Restriction in Community-Living Older Persons. J Am Geriatr Soc. 2002;50(3):516-520. doi:10.1046/j.1532-5415.2002.50119.x.

[26] Butler EE, Druzin M, Sullivan EV. Gait Adaptations in Adulthood: Pregnancy, Aging, and Alcoholism. In: Rose J, Gamble JG, eds. Human Walking. 3rd ed. Philadelphia: Lippincott Williams & Wilkins; 2006:131-148.

[27] Callisaya ML, Blizzard L, Schmidt MD, McGinley J, Srikanth V. Ageing and gait variability--a population-based study of older people. Age Ageing. 2010;39(2):191-197. doi:10.1093/ageing/afp250.

[28] Brach JS, Studenski SA, Perera S, VanSwearingen JM, Newman AB. Stance time and step width variability have unique contributing impairments in older persons. Gait Posture. 2008;27(3):431-439. doi:10.1016/j.gaitpost.2007.05.016.

[29] Lord SR, Sherrington C, Menz H, Close J. Falls in older people risk factors and strategies for prevention. 2nd ed. Cambridge: Cambridge University Press; 2007.

[30] American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention. Guideline for the prevention of falls in older persons. J Am Geriatr Soc. 2001;49(5):664-672. doi:10.1046/j.1532-5415.2001.49115.x.

[31] Rubenstein LZ, Josephson KR. The epidemiology of falls and syncope. Clin Geriatr Med. 2002;18(2):141-158. doi:10.1016/s0749-0690(02)00002-2.

[32] Granacher U, Muehlbauer T, Zahner L, Gollhofer A, Kressig RW. Comparison of traditional and recent approaches in the promotion of balance and strength in older adults. Sports Med. 2011;41(5):377-400. doi:10.2165/11539920-000000000-00000.

[33] Cruz-Díaz D, Martínez-Amat A, De La Torre-Cruz MJ, Casuso RA, De Guevara NML, Hita-Contreras F. Effects of a six-week Pilates intervention on balance and fear of falling in women aged over 65 with chronic low-back pain: A randomized controlled trial. Maturitas. 2015;82(4):371-376. doi:10.1016/j.maturitas.2015.07.022.

[34] Hita-Contreras F, Martínez-Amat A, Cruz-Díaz D, Pérez-López FR. Osteosarcopenic obesity and fall prevention strategies. Maturitas. 2015;80(2):126-132. doi:10.1016/j.maturitas.2014.11.009.

[35] Shariat A, Cleland JA, Danaee M, Kargarfard M, Sangelaji B, Tamrin SBM. Effects of stretching exercise training and ergonomic modifications on musculoskeletal discomforts of office workers: a randomized controlled trial. Braz J Phys Ther. 2018;22(2):144-153. doi:10.1016/j.bjpt.2017.09.003.

[36] Phelan EA, Mahoney J, Voit J, Stevens JA. Assessment and Management of Fall Risk in Primary Care Settings. Med Clin North Am. 2015;99(2):281-293. doi:10.1016/j.mcna.2014.11.004.

[37] Ambrose AF, Paul G, Hausdorff JM. Risk factors for falls among older adults: A review of the literature. Maturitas. 2013;75(1):51-61. doi:10.1016/j.maturitas.2013.02.009.

[38] Brach JS, VanSwearingen JM. Interventions to Improve Walking in Older Adults. Curr Transl Geriatr Exp Gerontol Rep. 2013;2(4):230-238. doi:10.1007/s13670-013-0059-0.

[39] Judge JO, Underwood M, Gennosa T. Exercise to improve gait velocity in older persons. PubMed. 1993;74(4):400-406. Available from: https://pubmed.ncbi.nlm.nih.gov/8466422.

[40] Bean JF, Herman S, Kiely DK, Frey I, Leveille SG, Fielding RA, Frontera WR. Increased Velocity Exercise Specific to Task (INVEST) Training: A pilot study exploring effects on leg power, balance, and mobility in Community-Dwelling Older women. J Am Geriatr Soc. 2004;52(5):799-804. doi:10.1111/j.1532-5415.2004.52222.x.

[41] Buchner DM, Cress ME, De Lateur BJ, Esselman PC, Margherita AJ, Price R, Wagner EH. The effect of strength and endurance training on GAIT, balance, fall risk, and health services use in Community-Living Older Adults. J Gerontol A Biol Sci Med Sci. 1997;52A(4):M218-M224. doi:10.1093/gerona/52a.4.m218.

[42] Helbostad JL, Sletvold O, Moe-Nilssen R. Home training with and without additional group training in physically frail old people living at home: effect on health-related quality of life and ambulation. Clin Rehabil. 2004;18(5):498-508. doi:10.1191/02692 15504cr761oa.

[43] Wolf SL, O'Grady MJ, Easley KA, Guo Y, Kressig RW, Kutner M. The influence of intense tai chi training on physical performance and hemodynamic outcomes in transitionally frail, older adults. J Gerontol A Biol Sci Med Sci. 2006;61(2):184-189. doi:10.1093/gerona/61.2.184.

[44] Manini TM, Marko M, VanArnam T, Cook SB, Fernhall B, Burke JR, Ploutz-Snyder LL. Efficacy of resistance and Task-Specific exercise in older adults who modify tasks of everyday life. J Gerontol A Biol Sci Med Sci. 2007;62(6):616-623. doi:10.1093/gerona/62.6.616.

[45] Li F, Eckstrom E, Harmer P, Fitzgerald K, Voit J, Cameron KA. Exercise and fall Prevention: Narrowing the Research-to-Practice gap and enhancing integration of clinical and community practice. J Am Geriatr Soc. 2016;64(2):425-431. doi:10.1111/jgs.13925.

[46] Tricco AC, Thomas SM, Veroniki AA, Hamid JS, Cogo E, Strifler L, Khan PA, Robson R, Sibley KM, MacDonald H, Riva JJ, Thavorn K, Wilson C, Holroyd-Leduc J, Kerr GD, Feldman F, Majumdar SR, Jaglal SB, Hui W, Straus SE. Comparisons of Interventions for Preventing Falls in Older Adults: A Systematic Review and Meta-analysis. JAMA. 2017;318(17):1687-1699. doi:10.1001/jama.2017.15006.

[47] Low SP, Ang LW, Goh KS, Chew SK. A systematic review of the effectiveness of Tai Chi on fall reduction among the elderly. Arch Gerontol Geriatr. 2009;48(3):325-331. doi:10.1016/j.archger.2008.02.018.

[48] Wolfson L, Whipple R, Derby CA, Judge JO, King MB, Amerman P, et al. Balance and strength training in older adults: intervention gains and Tai chi maintenance. J Am Geriatr Soc. 1996;44(5):498-506. doi:10.1111/j.1532-5415.1996.tb01433.x.

[49] Sherrington C, Whitney J, Lord SR, Herbert RD, Cumming RG, Close JC. Effective Exercise for the Prevention of Falls: A Systematic Review and Meta-Analysis. J Am Geriatr Soc. 2008;56(12):2234-2243. doi:10.1111/j.1532-5415.2008.02014.x.

[50] Wolf SL, Sattin RW, Kutner M, O'Grady MJ, Greenspan AI, Gregor RJ. Intense tai chi exercise training and fall occurrences in older, transitionally frail adults: a randomized, controlled trial. J Am Geriatr Soc. 2003;51(12):1693-1701. doi:10.1046/j.1532-5415.2003.51552.x.

[51] Yardley L, Donovan-Hall M, Francis K, Todd C. Older people's views of advice about falls prevention: a qualitative study. Health Educ Res. 2006;21(4):508-517. doi:10.1093/her/cyh077.

[52] Enoka RM. Neural strategies in the control of muscle force. Muscle Nerve. 1997;20(S5):66-69. doi:10.1002/(sici)1097-4598(1997)5.

[53] Galganski ME, Fuglevand AJ, Enoka RM. Reduced control of motor output in a human hand muscle of elderly subjects during submaximal contractions. J Neurophysiol. 1993;69(6):2108-2115. doi:10.1152/jn.1993.69.6.2108.

[54] Gu M, Schultz AB, Shepard NT, Alexander NB. Postural control in young and elderly adults when stance is perturbed: Dynamics. J Biomech. 1996;29(3):319-329. doi:10.1016/0021-9290(95)00052-6.

[55] Winter DA. Human balance and posture control during standing and walking. Gait Posture. 1995;3(4):193-214. doi:10.1016/0966-6362(96)82849-9.

[56] Waters RL, Mulroy SJ. The energy expenditure of normal and pathologic gait. Gait Posture. 1999;9(3):207-231. doi:10.1016/s0966-6362(99)00009-0.

[57] Lee CR, Farley CT. Determinants of the center of mass trajectory in human walking and running. J Exp Biol. 1998;201(21):2935-2944. doi:10.1242/jeb.201.21.2935.

[58] Minetti AE, Capelli C, Zamparo P, di Prampero PE, Saibene F. Effects of stride frequency on mechanical power and energy expenditure of walking. Med Sci Sports Exerc. 1995;27(8):1194-1202.

[59] Kaufman KR, Sutherland DH. Kinematics of Normal Human Walking. In: Rose J, Gamble JG, eds. Human Walking. 3rd ed. Philadelphia: Lippincott Williams & Wilkins; 2006:33-52.

[60] DeVita P, Hortobágyi T. Age causes a redistribution of joint torques and powers during gait. J Appl Physiol. 2000;88(5):1804-1811. doi:10.1152/jappl.2000.88.5.1804.

[61] Winter D, Patla AE, Frank JS, Walt SE. Biomechanical walking pattern changes in the fit and healthy elderly. Phys Ther. 1990;70(6):340-347. doi:10.1093/ptj/70.6.340.

[62] Elders LR, Greenwald HL, Sartor CA. A Preliminary Study of Trunk Kinematics during Walking in Normal Subjects. Masters Theses. 1997;322. Available from: https://scholarworks.gvsu.edu/theses/322.

[63] JudgeRoy JO, Davis B, Õunpuu S. Step Length reductions in Advanced Age: The role of ankle and hip kinetics. J Gerontol A Biol Sci Med Sci. 1996;51A(6):M303-M312. doi:10.1093/gerona/51a.6.m303.

[64] Kerrigan DC, Todd MK, Della Croce U, Lipsitz LA, Collins JJ. Biomechanical gait alterations independent of speed in the healthy elderly: Evidence for specific limiting impairments. Arch Phys Med Rehabil. 1998;79(3):317-322. doi:10.1016/s0003-9993(98)90013-2.

[65] Imms FJ, Edholm OG. The assessment of gait and mobility in the elderly. Age Ageing. 1979;8(4):261-267. doi:10.1093/ageing/8.4.261.

[66] Lockhart TE, Woldstad JC, Smith JL. Effects of age-related gait changes on the biomechanics of slips and falls. Ergonomics. 2003;46(12):1136-1160. doi:10.1080/0014013031000139491.

[67] Kimura T, Kobayashi H, Nakayama E, Hanaoka M. Effects of aging on gait patterns in the healthy elderly. Anthropol Sci. 2007;115(1):67-72. doi:10.1537/ase.060309.

[68] Bassey EJ, Bendall MJ, Pearson M. Muscle strength in the triceps surae and objectively measured customary walking activity in men and women over 65 years of age. Clin Sci (Lond). 1988;74(1):85-89. doi:10.1042/cs0740085.

[69] Ito H, Nagasaki H, Maruyama H, Hashizume K, Nakamura R. Age related changes of the walking cycle during fastest walking in healthy male subjects. Jpn J Geriatr. 1989;26(4):347-352. doi:10.3143/geriatrics.26.347.

[70] Maki BE. GAIT changes in older adults: predictors of falls or indicators of fear? J Am Geriatr Soc. 1997;45(3):313-320. doi:10.1111/j.1532-5415.1997.tb00946.x.

[71] Hamilton N, Weimar W, Luttgens K. Kinesiology: Scientific Basis of Human Motion. 11th ed. New York: McGraw-Hill; 2007.

[72] Ming L. Tai Chi Medication: Methodology of Internal Equilibrium Re - creation for the Musculoskeletal System. Unpublished.

[73] Simoneau GG. Chapter 15: Kinesiology of Walking. In: Neumann DA, ed. Kinesiology of the musculoskeletal system: foundations for rehabilitation. 2nd ed. St. Louis: Mosby/Elsevier; 2010:627-681.

[74] Chung CY, Park MS, Lee SH, Kong SJ, Lee KM. Kinematic aspects of trunk motion and gender effect in normal adults. J Neuroeng Rehabil. 2010;7(1). doi:10.1186/1743-0003-7-9.

[75] Sutherland DH, Cooper L, Daniel D. The role of the ankle plantar flexors in normal walking. J Bone Joint Surg Am. 1980;62(3):354-363. doi:10.2106/00004623-198062030-00005.

[76] Sutherland DH. An electromyographic study of the plantar flexors of the ankle in normal walking on the level. J Bone Joint Surg Am. 1966;48(1):66-71. doi:10.2106/00004623-196648010-00005.

[77] Melzer I, Benjuya N, Kaplanski J, Alexander NB. Association between ankle muscle strength and limit of stability in older adults. Age Ageing. 2008;38(1):119-123. doi:10.1093/ageing/afn249.

[78] Doherty TJ. Invited review: Invited Review: Aging and sarcopenia. J Appl Physiol (1985). 2003;95(4):1717-1727. doi:10.1152/japplphysiol.00347.2003.

[79] Frontera WR, Hughes V, Fielding RA, Fiatarone MA, Evans WJ, Roubenoff R. Aging of skeletal muscle: a 12 - yr longitudinal study. J Appl Physiol. 2000;88(4):1321-1326. doi:10.1152/jappl.2000.88.4.1321.

[80] Brach JS, Berthold R, Craik RL, VanSwearingen JM, Newman AB. GAIT Variability in Community - Dwelling Older Adults. J Am Geriatr Soc. 2001;49(12):1646-1650. doi:10.1111/j.1532-5415.2001.49274.x.

[81] Grabiner PC, Biswas S, Grabiner MD. Age-related changes in spatial and temporal gait variables. Arch Phys Med Rehabil. 2001;82(1):31-35. doi:10.1053/apmr.2001.18219.

[82] Elble RJ, Thomas S, Higgins C, Colliver JA. Stride - dependent changes in gait of older people. J Neurol. 1991;238(1):1-5. doi:10.1007/bf00319700.

[83] Waters RL, Morris JM. Electrical activity of muscles of the trunk during walking. J Anat. 1972;111(Pt 2):191-199.

[84] Eagan MS, Sedlock DA. Kyphosis in active and sedentary postmenopausal women. Med Sci Sports Exerc. 2001;688-695. doi:10.1097/00005768-200105000-00002.

[85] Keller A, Johansen JG, Hellesnes J, Brox JI. Predictors of isokinetic back muscle strength in patients with low back pain. Spine (Phila Pa 1976). 1999;24(3):275-280. doi:10.1097/00007632-199902010-00016.

[86] Limburg PJ, Sinaki M, Rogers JW, Caskey PE, Pierskalla B. A useful technique for measurement of back strength in osteoporotic and elderly patients. Mayo Clin Proc. 1991;66(1):39-44. doi:10.1016/s0025-6196(12)61173-2.

[87] Aoyama H, Yonenobu K, Ogawa K, Jeong S. Effect of upper extremity load on pelvic movements during wheeled upright walker use. J Phys Ther Sci. 2022;34(4):269-274. doi:10.1589/jpts.34.269.

[88] Nottrodt JW, Charteris J, Wall JC. The effects of speed on pelvic oscillations in the horizontal plane during level walking. J Hum Mov Stud. 1982;8(1):27-40.

[89] Van Emmerik RE, McDermott WJ, Haddad JM, Van Wegen EEH. Age - related changes in upper body adaptation to walking speed in human locomotion. Gait Posture. 2005;22(3):233-239. doi:10.1016/j.gaitpost.2004.09.006.

[90] Bötzel K, Olivares A, Cunha JPS, Sáez JM, Weiss R, Plate A. Quantification of gait parameters with inertial sensors and inverse

kinematics. J Biomech. 2018;72:207-214. doi:10.1016/j.jbiomech.2018.03.012.

[91] Saunders J, Inman VT, Eberhart HD. THE MAJOR DETERMINANTS IN NORMAL AND PATHOLOGICAL GAIT. J Bone Joint Surg Am. 1953;35(3):543-558. doi:10.2106/00004623-195335030-00003.

[92] Meyns P, Bruijn SM, Duysens J. The how and why of arm swing during human walking. Gait Posture. 2013;38(4):555-562. doi:10.1016/j.gaitpost.2013.02.006.

[93] Shishov N, Gimmon Y, Rashed H, Kurz I, Riemer R, Shapiro A, et al. Old adult fallers display reduced flexibility of arm and trunk movements when challenged with different walking speeds. Gait Posture. 2017;52:280-286. doi:10.1016/j.gait-post.2016.12.004.

[94] Bruijn SM, Meijer OG, Van Dieën JH, Kingma I, Lamoth CJC. Coordination of leg swing, thorax rotations, and pelvis rotations during gait: The organisation of total body angular momentum. Gait Posture. 2008;27(3):455-462. doi:10.1016/j.gait-post.2007.05.017.

[95] Elftman H. The function of the arms in walking. Hum Biol. 1939;11:529-535. Available from: https://ci.nii.ac.jp/naid/10018856541.

[96] Fang X, Jiang Z. Three - dimensional thoracic and pelvic kinematics and arm swing maximum velocity in older adults using inertial sensor system. PeerJ. 2020;8:e9329. doi:10.7717/peerj.9329.

[97] Ballesteros ML, Buchthal F, Rosenfalck P. The pattern of muscular activity during the arm swing of natural walking. Acta Physiol Scand. 1965;63(3):296-310. doi:10.1111/j.1748-1716.1965.tb04069.x.

[98] Kuhtz-Buschbeck JP, Jing B. Activity of upper limb muscles during human walking. J Electromyogr Kinesiol. 2012;22(2):199-206. doi:10.1016/j.jelekin.2011.08.014.

[99] Inman VT, Ralston HJ, Todd F, Childress DS, Gard SA. Human Locomotion. In: Rose J, Gamble JG, eds. Human Walking. 3rd ed. Philadelphia: Lippincott Williams & Wilkins; 2006:1-18.

[100] Toda H, Nagano A, Luo Z. Analysis of walking variability through simultaneous evaluation of the head, lumbar, and lower-extremity acceleration in healthy youth. J Phys Ther Sci. 2016;28(6):1801-1805. doi:10.1589/jpts.28.1801.

[101] Hilliard MJ, Martinez K, Janssen I, Edwards BJ, Mille M, Zhang Y, et al. Lateral balance factors predict future falls in Community-Living older adults. Arch Phys Med Rehabil. 2008;89(9):1708-1713. doi:10.1016/j.apmr.2008.01.023.

[102] Arvin M, Van Dieën JH, Faber GS, Pijnappels M, Hoozemans M, Verschueren S. Hip abductor neuromuscular capacity: A limiting factor in mediolateral balance control in older adults? Clin Biomech (Bristol, Avon). 2016;37:27-33. doi:10.1016/j.clinbiomech.2016.05.015.

[103] Arvin M, Hoozemans M, Burger BJ, Rispens SM, Verschueren S, Van Dieën JH, et al. Effects of hip abductor muscle fatigue on gait control and hip position sense in healthy older adults. Gait Posture. 2015;42(4):545-549. doi:10.1016/j.gaitpost.2015.08.011.

[104] Caderby T, Yiou E, Peyrot N, Begon M, Dalleau G. Influence of gait speed on the control of mediolateral dynamic stability during gait initiation. J Biomech. 2014;47(2):417-423. doi:10.1016/j.jbiomech.2013.11.011.

[105] Rogers MW, Mille M. Lateral stability and falls in older people. Exerc Sport Sci Rev. 2003;31(4):182-187. doi:10.1097/00003677-200310000-00005.

[106] MacKinnon CD, Winter D. Control of whole body balance in the frontal plane during human walking. J Biomech. 1993;26(6):633-644. doi:10.1016/0021-9290(93)90027-c.

[107] Townsend M. Biped gait stabilization via foot placement. J Biomech. 1985;18(1):21-38. doi:10.1016/0021-9290(85)90042-9.

[108] Kuo AD. Stabilization of lateral motion in passive dynamic walking. Int J Robot Res. 1999;18(9):917-930. doi:10.1177/02783649922066655.

[109] Yiou E, Caderby T, Delafontaine A, Fourcade P, Honeine J. Balance control during gait initiation: State-of-the-art and research perspectives. World J Orthop. 2017;8(11):815-828. doi:10.5312/wjo.v8.i11.815.

[110] Kerrigan DC, Todd MK, Della Croce U, Lipsitz LA, Collins JJ. Biomechanical gait alterations independent of speed in the healthy elderly: Evidence for specific limiting impairments. Arch Phys Med Rehabil. 1998;79(3):317-322. doi:10.1016/s0003-9993(98)90013-2.

[111] McGibbon CA. Toward a better understanding of gait changes with age and disablement: neuromuscular adaptation. Exerc Sport Sci Rev. 2003;31(2):102-108. doi:10.1097/00003677-200304000-00009.

[112] Landi F, Liperoti R, Russo A, Giovannini S, Tosato M, Capoluongo E, Bernabei R, Onder G. Sarcopenia as a risk factor for falls in elderly individuals: results from the ilSIRENTE study. Clin Nutr. 2012;31(5):652-658. doi:10.1016/j.clnu.2012.02.007.

[113] Nakamura H, Tsuchida T, Mano Y. The assessment of posture control in the elderly using the displacement of the center of pressure after forward platform translation. J Electromyogr Kinesiol. 2001;11(6):395-403. doi:10.1016/s1050-6411(01)00016-5.

[114] Bauby CE, Kuo AD. Active control of lateral balance in human walking. J Biomech. 2000;33(11):1433-1440. doi:10.1016/s0021-9290(00)00101-9.

[115] Hurt CP, Rosenblatt NJ, Crenshaw JR, Grabiner MD. Variation in trunk kinematics influences variation in step width during treadmill walking by older and younger adults. Gait Posture. 2010;31(4):461-464. doi:10.1016/j.gaitpost.2010.02.001.

[116] François P, Corriveau H, Hébert R, Winter D. Gait in the elderly. Gait Posture. 1997;5(2):128-135. doi:10.1016/s0966-6362(97)01118-1.

[117] Braune W, Fischer O. The Human Gait. Berlin: Springer Verlag; 1987. pp.1-116.

[118] Terrier P, Reynard F. Effect of age on the variability and stability of gait: A cross - sectional treadmill study in healthy individuals between 20 and 69 years of age. Gait Posture. 2015;41(1):170-174. doi:10.1016/j.gaitpost.2014.09.024.

[119] Kerrigan DC, Lee LW, Collins JJ, Riley PO, Lipsitz LA. Reduced hip extension during walking: Healthy elderly and fallers versus young adults. Arch Phys Med Rehabil. 2001;82(1):26-30. doi:10.1053/apmr.2001.18584.

[120] Cimolin V, Cau N, Galli M, Santovito C, Grugni G, Capodaglio P. Gait initiation and termination strategies in patients with Prader - Willi syndrome. J Neuroeng Rehabil. 2017;14(1). doi:10.1186/s12984-017-0257-7.

[121] Miller CA, Verstraete MC. A mechanical energy analysis of gait initiation. Gait Posture. 1999;9(3):158-166. doi:10.1016/s0966-6362(99)00008-9.

[122] Brunt D, De Carvalho Santos V, Kim HD, Light KE, Levy CE. Initiation of movement from quiet stance: comparison of gait and stepping in elderly subjects of different levels of functional ability. Gait Posture. 2005;21(3):297-302. doi:10.1016/j.gait-post.2004.03.003.

[123] Chang H, Krebs DE. Dynamic balance control in elders: gait initiation assessment as a screening tool. Arch Phys Med Rehabil. 1999;80(5):490-494. doi:10.1016/s0003-9993(99)90187-9.

[124] Sparrow W, Tirosh O. Gait termination: a review of experimental methods and the effects of ageing and gait pathologies. Gait Posture. 2005;22(4):362-371. doi:10.1016/j.gaitpost.2004.11.005.

[125] Ashley MJ, Gryfe CI, Amies A. A Longitudinal Study of Falls in an Elderly Population II. Some Circumstances of Falling. Age Ageing. 1977;6(4):211-220. doi:10.1093/ageing/6.4.211.

[126] Tinetti ME, Doucette J, Claus EB. The contribution of predisposing and situational risk factors to serious fall injuries. J Am Geriatr Soc. 1995;43(11):1207-1213. doi:10.1111/j.1532-5415.1995.tb07395.x.

[127] Liu S, Brunt D, Bauer J. Principles underlying the organization of gait initiation and stepping. Gait Posture. 1998;7(2):173. doi:10.1016/s0966-6362(98)90257-0.

[128] Elble RJ, Cousins R, Leffler K, Hughes LF. Gait initiation by patients with lower - half parkinsonism. Brain. 1996;119(5):1705-1716. doi:10.1093/brain/119.5.1705.

[129] Tinetti ME, Baker DI, McAvay G, Claus EB, Garrett P, Gottschalk M, Koch ML, Trainor KM, Horwitz RI. A Multifactorial Intervention to Reduce the Risk of Falling among Elderly People Living in the Community. N Engl J Med. 1994;331(13):821-827. doi:10.1056/nejm199409293311301.

[130] Imms FJ, Edholm OG. Studies of GAIT and mobility in the elderly. Age Ageing. 1981;10(3):147-156. doi:10.1093/age-ing/10.3.147.

[131] Jones S, Twigg PC, Scally AJ, Buckley J. The gait initiation process in unilateral lower-limb amputees when stepping up and stepping down to a new level. Clin Biomech. 2005;20(4):405-413. doi:10.1016/j.clinbiomech.2004.11.018.

[132] Dichgans J, Diener H. The contribution of vestibulo-spinal mechanisms to the maintenance of human upright posture. Acta Oto-Laryngol. 1989;107(5-6):338-345. doi:10.3109/00016488909127518.

[133] Paulus W, Straube A, Brandt T. Visual stabilization of posture. Physiological stimulus characteristics and clinical aspects. Brain. 1984;107(4):1143-1163. doi:10.1093/brain/107.4.1143.

[134] Rossi SA, Doyle W, Skinner HB. Gait initiation of persons with below-knee amputation: the characterization and comparison of force profiles. J Rehabil Res Dev. 1995;32 (2):120-127.

[135] Smith AW, Wong DP. Sagittal and frontal plane GAIT initiation kinetics in healthy, young subjects. J Hum Kinet. 2019;67(1):85-100. doi:10.2478/hukin-2018-0087.

[136] Halliday SE, Winter DA, Frank JS, Patla AE, Prince F. The initiation of gait in young, elderly, and Parkinson’s disease subjects. Gait Posture. 1998;8(1):8-14. doi:10.1016/S0966-6362(98)00020-4.

[137] Mann RA, Hagy JL, White V, Liddell D. The initiation of gait. J Bone Joint Surg Am. 1979;61(2):232-239. doi:10.2106/00004623-197961020-00011.

[138] Leteneur S, Simoneau E, Gillet C, Dessery Y, Barbier F. Trunk's natural inclination influences stance limb kinetics, but not body kinematics, during gait initiation in able men. PLoS One. 2013;8(1):e55256. doi:10.1371/journal.pone.0055256.

[139] Adrian MJ, Cooper JM. Biomechanics of Human Movement. Indianapolis: Benchmark Press; 1989. pp.279-291.

[140] Chong R, Chastan N, Welter ML, Cuong M. Age-related changes in the center of mass velocity control during walking. Neurosci

Lett. 2009;458(1):23-27. doi:10.1016/j.neulet.2009.04.022.

[141] Hirose D, Ishida K, Nagano Y, Takahashi T, Yamamoto H. Posture of the trunk in the sagittal plane is associated with gait in community-dwelling elderly population. Clin Biomech (Bristol, Avon). 2004;19(1):57-63. doi:10.1016/j.clinbiomech.2003.08.005.

[142] Polcyn AF, Lipsitz LA, Kerrigan DC, Collins JJ. Age-related changes in the initiation of gait: Degradation of central mechanisms for momentum generation. Arch Phys Med Rehabil. 1998;79(12):1582-1589. doi:10.1016/s0003-9993(98)90425-7.

[143] Doyle RJ, Hsiao-Wecksler ET, Ragan BG, Rosengren KS. Generalizability of center of pressure measures of quiet standing. Gait Posture. 2007;25(2):166-171. doi:10.1016/j.gaitpost.2006.03.004.

[144] Martin MJ, Shinberg M, Kuchibhatla M, Ray L, Carollo J, Schenkman M. GAIT Initiation in Community-Dwelling Adults with Parkinson Disease: Comparison with older and Younger adults without the disease. Phys Ther. 2002;82(6):566-577. doi:10.1093/ptj/82.6.566.

[145] Kim H. Age-Related Changes in the Center of Pressure Trajectory during Obstacle Crossing. J Phys Ther Sci. 2009. doi:10.1589/jpts.21.75.

[146] Hass CJ, Gregor RJ, Waddell DE, Oliver A, Smith DW, Fleming RP, Wolf SL. The influence of Tai Chi training on the center of pressure trajectory during gait initiation in older adults. Arch Phys Med Rehabil. 2004;85(10):1593-1598. doi:10.1016/j.apmr.2004.01.020.

[147] Jian Y, Winter D, Ishac M, Gilchrist L. Trajectory of the body COG and COP during initiation and termination of gait. Gait Posture. 1993;1(1):9-22. doi:10.1016/0966-6362(93)90038-3.

[148] Van Keeken H, Vrieling AH, Hof AL, Postema K, Otten B. Controlling horizontal deceleration during gait termination in trans-femoral amputees: Measurements and simulations. Med Eng Phys. 2013. doi:10.1016/j.medengphy.2012.07.002.

[149] Viton J, Timsit M, Mesure S, Massion J, Franceschi J, Delarque A. Asymmetry of gait initiation in patients with unilateral knee arthritis. Arch Phys Med Rehabil. 2000;81(2):194-200. doi:10.1016/s0003-9993(00)90140-0.

[150] Mickelborough J, Van Der Linden M, Tallis R, Ennos AR. Muscle activity during gait initiation in normal elderly people. Gait Posture. 2004;19(1):50-57. doi:10.1016/s0966-6362(03)00016-x.

[151] Remelius JG, Hamill J, Kent-Braun JA, Van Emmerik RE. GAIT initiation in multiple sclerosis. Motor Control. 2008;12(2):93-108. doi:10.1123/mcj.12.2.93.

[152] Brenière Y, Do MC. Control of gait initiation. J Motor Behav. 1991;23(4):235-240. doi:10.1080/00222895.1991.9942034

[153] Brunt D, Lafferty MJ, McKeon AB, Goode B, Mulhausen C, Polk P. Invariant characteristics of gait initiation. Am J Phys Med Rehabil. 1991;70(4):206-212. doi:10.1097/00002060-199108000-00009.

[154] Rogers MW, Pai Y. Dynamic transitions in stance support accompanying leg flexion movements in man. Exp Brain Res. 1990;81(2). doi:10.1007/bf00228132.

[155] Jaeger RJ, Vanitchatchavan P. Ground reaction forces during termination of human gait. J Biomech. 1992;25(10):1233-1236. doi:10.1016/0021-9290(92)90080-k.

[156] Hase K, Stein RB. Analysis of rapid stopping during human walking. J Neurophysiol. 1998;80(1):255-261. doi:10.1152/jn.1998.80.1.255.

[157] Oates A, Patla AE, Frank JS, Greig M. Control of Dynamic Stability During Gait Termination on a Slippery Surface. J Neurophysiol. 2005;93(1):64-70. doi:10.1152/jn.00423.2004.

[158] Meier MR, Desrosiers J, Bourassa P, Błaszczyk JW. Effect of Type II diabetic peripheral neuropathy on gait termination in the elderly. Diabetologia. 2001;44(5):585-592. doi:10.1007/s001250051664.

[159] O'Kane FW, McGibbon CA, Krebs DE. Kinetic analysis of planned gait termination in healthy subjects and patients with balance disorders. Gait Posture. 2003;17(2):170-179. doi:10.1016/s0966-6362(02)00104-2.

[160] Novak D, Rebersek P, Beravs T, Podobnik J, Munih M, De Rossi SM, Donati M, Lenzi T, Vitiello N, Carrozza MC. Early recognition of gait initiation and termination using wearable sensors. 2012 4th IEEE RAS & EMBS International Conference on Biomedical Robotics and Biomechatronics (BioRob). 2012:1937-1942. doi:10.1109/BioRob.2012.6290277.

[161] Novak D, Rebersek P, De Rossi SMM, Donati M, Podobnik J, Beravs T, Lenzi T, Vitiello N, Carrozza MC, Munih M. Automated detection of gait initiation and termination using wearable sensors. Med Eng Phys. 2013;35(12):1713-1720. doi:10.1016/j.medengphy.2013.07.003.

[162] Bishop MD, Brunt D, Pathare N, Patel B. The interaction between leading and trailing limbs during stopping in humans. Neurosci Lett. 2002;323(1):1-4. doi:10.1016/s0304-3940(01)02525-3.

[163] Bishop M, Brunt D, Pathare N, Patel B. The effect of velocity on the strategies used during gait termination. Gait Posture. 2004;20(2):134-139. doi:10.1016/j.gaitpost.2003.07.004.

[164] Alexander NB. Postural control in older adults. J Am Geriatr Soc. 1994;42(1):93-108. doi:10.1111/j.1532-5415.1994.tb06081.x.

[165] Jung S, Yi J, Song C. Biomechanical alterations of gait termination in middle-aged and elderly women. J Phys Ther Sci. 2016;28(3):861-867. doi:10.1589/jpts.28.861.

[166] Braun BL. Knowledge and perception of Fall-Related risk factors and Fall-Reduction Techniques among Community-Dwelling elderly individuals. Phys Ther. 1998;78(12):1262-1276. doi:10.1093/ptj/78.12.1262.

[167] Cao C, Ashton-Miller JA, Schultz AB, Alexander NB. Effects of age, available response time and gender on ability to stop suddenly when walking. Gait Posture. 1998;8(2):103-109. doi:10.1016/s0966-6362(98)00029-0.

[168] Riley PO, Della Croce U, Kerrigan DC. Effect of age on lower extremity joint moment contributions to gait speed. Gait Posture. 2001;14(3):264-270. doi:10.1016/s0966-6362(01)00133-3.

[169] Kepple TM, Siegel KL, Stanhope SJ. Relative contributions of the lower extremity joint moments to forward progression and support during gait. Gait Posture. 1997;6(1):1-8. doi:10.1016/s0966-6362(96)01094-6.

[170] Gryfe CI, Amies A, Ashley MJ. A longitudinal study of falls in an elderly population: I. Incidence and morbidity. Age Ageing. 1977;6(4):201-210. doi:10.1093/ageing/6.4.201.

[171] Stolze H, Klebe S, Zechlin C, Baecker C, Friege L, Deuschl G. Falls in frequent neurological diseases--prevalence, risk factors and aetiology. J Neurol. 2004;251(1):79-84. doi:10.1007/s00415-004-0276-8.

[172] Gatts S. A Tai Chi Chuan training model to improve balance control in older adults. Curr Aging Sci. 2008;1(1):68-70. doi:10.2174/1874609810801010068.

[173] Llinás R. Qualia from a neuronal point of view. I of the Vortex. Westwood: MIT Press; 2002. p. 216.