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Investigating Interest of a Three-Stages-Single-Leg Test to Screen Adults for Postural Balance Disorders

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Abstract:

This thesis investigates postural balance acquisition and development stages to consider elaborating on an adult single-leg screening tool based on the developmental acquisition system. The three stages of the test consist of screening the ability to maintain equilibrium in a quiet position, with an active and voluntary action and then in a reactive mode. Because of involving many systems, the single-leg stance is the last somatosensory-motor skill acquired during childhood and the first primary skill to decline in adulthood. Its decline starts early, from around 32 years old. Moreover, research supports that silent and non-visible postural balance disorders in adults are often undetected until experiencing a non-contact injury such as an ankle or knee sprain, pelvic or spine pain, or musculoskeletal disorders (MSDs). The silent postural balance decline in adults also increases their risks of a sedentary lifestyle, body deconditioning, developing comorbidity factors, and, later, falls. This thesis shows that the Three-Stages-Single-Leg Screening Test is a low-cost and easy-to-use tool for postural balance screening. Its implementation by individuals or in a clinical setting seems helpful to raise balance awareness and promote a well-adjusted physical programme at the balance impairment identification and before injury-fall events occur. Identification of at risk-population includes women, obese individuals, people with comorbidity disease and athletes. Lastly, as balance is a major determinant of gait and functional mobility independence, early detection and intervention during adulthood may help public health concerns by reducing fall injuries in seniors and elders.

Keywords: *Postural balance, single-leg stance, quiet-single-leg-stance, active-single-leg stance, single-leg-stance-heel raise, adults, somatosensory-motor development strategy, vision dominant strategy.*

SUMMARY

INTRODUCTION AND GENERALES PERSPECTIVES

Considering falls on the elderly often cause injuries-based death and are a significant World Public Health concern [1] [2], keeping track of the postural balance evolution and involution during the lifespan must be a high priority for the adult population. *Howcroft* [2] and *Quijoux* [3] studies show that the deficit or the decline in balance control increases the risk of falling, injuries and death in elderlies. Seniors and elderlies [4] are widely screened, assessed and assisted for their postural balance when they report fear of falling or have had a fall. Unfortunately, the current medical practice and the lack of tests show that postural balance screening on adults does not take a great place in the medical and physical examination.

Balance is a major determinant in maintaining gait control and functional mobility performance. When turning the '60s, the body's involution signs become visible and perceptible, involving reduced vision, joint flexibility, muscle strength, coordination, proprioception and balance. As a result, many validated tests to assess static and dynamic balance in seniors and elders exist in rehabilitation, including but not limited to Time-Up-and-Go Test, the Tinetti Test, the 4-Stages-Balance Test and the Berg Balance Test. Therefore, undetected balance involution is often the first silent slide sign that can lead to a fall or an injury.

The human body is bipedal but uses the single-leg stance for mobility. Each foot has 60% ground contact and 40% off-the-ground during a paced gait in adults. The single-leg stance is a complex and high-demanding motor coordination and balancing task, and also an essential functional skill used for various activities of daily living, physical activities, work and sports. The single-leg stance requires the individual to be able to shift the weight-bearing to one leg, place the body's gravity centre (COG) on one foot, maintain the single-leg stance balance and then restore effortless posture on a broader ground base to recover stability. Active adult populations extensively use one-foot ground contact for dynamic and propulsive activities such as pushing, pulling, playing, running, jumping and kicking. However, the Single-Leg-Stance may become challenging if joints and muscles are not well-coordinated and well-controlled. In addition, it may develop compensatory patterns leading to joint and muscle overuse. *Bart Dingenen* [5] reports that difficulty maintaining a Single-Leg-Stance balance increases young adults' risk of non-contact injuries. It is also definitively a challenging task during the ageing process.

Unfortunately, screening for gait and balance disturbances in adults is not standard practice during health check-ups & medical examinations. Therefore, in my professional experience, I observed the lack of validated tools helping screen Single-Leg-Stance balance disorders in "healthy" adults. *Jaap H van Dieen* [6] also shows that hided Single-Leg-Stance disturbances often develop compensatory strategies such as joint torques, muscle synergies, use of speed and additional energy power consumption. However, these compensations are often a slow and silent process. They may exist for years, increasing the risks of progressive joint damage, muscle overuse and non-contact injuries that may lead to a less active lifestyle.

This thesis investigates the interest in screening postural balance disorders with a Three-Stages-Single-Leg-Stance Test during adulthood. The first part overviews the postural balance system development over the lifespan, helping us to understand its acquisition, maturation and involution. Then, the second part studies Three-Stages-Single-Leg stance Test mechanisms, including the Quiet Single-Leg Stance, Active Single-Leg Stance and Reactive Single-Heel-Raise, to demonstrate how the combination of these three progressive screening tests may interact with different aspects of the postural balance and may play a crucial role in detecting postural balance disorders during adulthood.

PART I: THE POSTURAL BALANCE SYSTEM DEVELOPMENT

Postural balance is a complex and fundamental body skill requiring the interaction of multiple body systems, combining the Central Nervous System (CNS) and Peripheral Nervous System (PNS).

Postural balance is the act of control for setting, maintaining, achieving and restoring a balanced state during a static or dynamic activity. During the gross motor acquisition skills, *Foudriat et al.* [7] reveal that postural balance control develops from a **Vision-Dominant Strategy to a Somatosensory-Motor Strategy** during childhood, then, during ageing, postural balance control declines and reverse control from a **somatosensory-motor strategy to vision strategy**. However, postural balance control is not a linear process in life and may vary on multiple factors.

A. From Vision-Dominant Strategy to Somatosensory-Motor Strategy

1. Acquisition skills

The postural balance development starts with the gross motor development and acquisition of rolling, sitting, crawling, standing and walking skills. A Vision-Dominant Strategy initiates the development of this system [9] and progresses exponentially up to 3 years old, then gradually shift to a somatosensory motor strategy.

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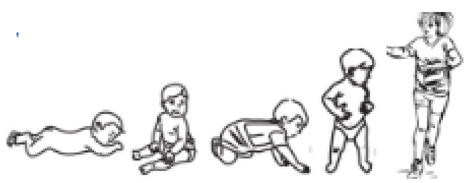


Figure 1: Gross motor development

In each newly acquired position, lying side, tummy, sitting, kneeling and standing, motor and balance acquisition skills [8] in infants develop as below:

1. The ability **to quietly maintain** a position,
2. The ability **to be voluntarily active** in this position,
3. Then finally, the ability **to be reactive to any perturbation** in this position

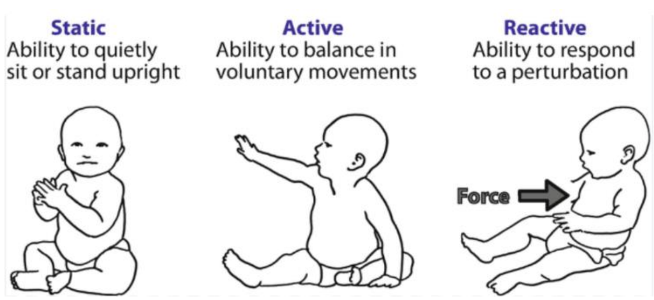


Figure 2: Balance skills development process in sitting position[16]

Initiation of the **upright standing balance control skills** starts at about 11 to 15 months old and exponentially develops during the walking acquisition stage until progressing up to 5-7 years old to well-controlled running and jumping skills. At that time, the double-leg-stance and the single-leg-stance balance skills develop through motor control and movement coordination. The previous **Visual-Dominant Strategy** progresses gradually to the **Somatosensory-Motor System Strategy.** The proprioceptive and the vestibular system also participate in that process.

2. Maturation skills

By the end of primary school, *Morioka* [7] and *Sparto* [8] shows that kids achieve a Somatosensory-Motor System, almost like adults. From a standing position and a single-leg stance, they may be able to **stand on 1 leg quietly**, **be voluntarily active and be reactive**. Children widely use these three skills for changing or adjusting walking and running directions, accelerating, decelerating, jumping over or stopping. Until adulthood, based on their living environment and personal physical experiences, teens continue mastering their skills for maintaining the body's equilibrium during dynamic and static motion. Challenging and enjoying various balance experiences during physical activities contribute to developing body strength, flexibility, coordination and balance as a part of the SomatoSensory-Motor experiences

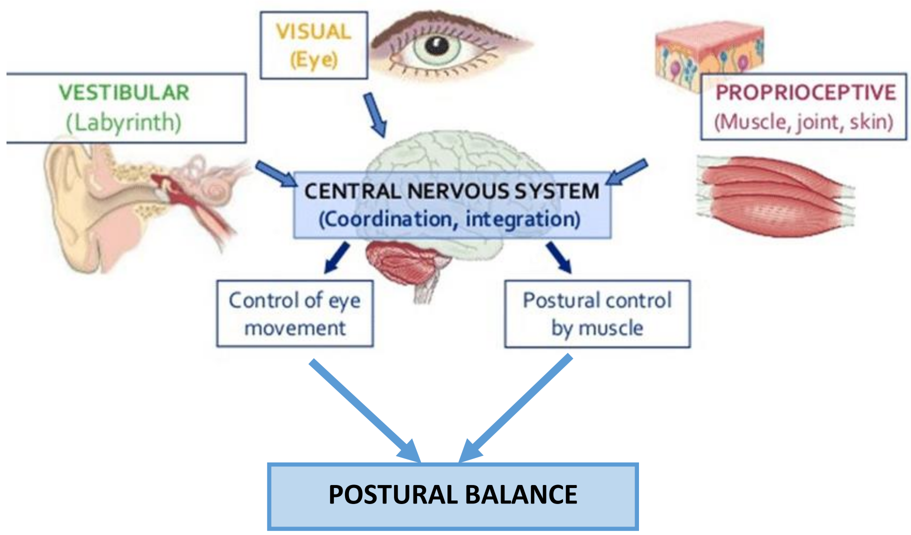


Figure 3: Postural Balance system: Somatosensory, vestibular, and visual sensory interactions [8]

Static and dynamic postural balance control on Single-Leg-Stance is one of the last balance skills developed during childhood before reaching the maturation stage in adulthood. Based on the clinical studies, *Morioka* [6] founds that the maximum value for standing time on single-leg, eyes open, was **31 years old**. It indicates that the involution of standing balance skills starts from this young age and declines silently. Over time, failure to acquire the centre of gravity alignment and reaching symmetry balance performance can accelerate the postural balance involution, reducing the variety or the number of physical activities [12] and developing the body compensation [13]. Lack of awareness of this disturbance may lead to increased risks of non-contact injuries or falls and musculoskeletal injuries

B. Postural balance involution

1. In young adults

Morioka [6] shows that the involution process for postural balance and single-leg skills is opposite to the developmental acquisition process means to **Somatosensory-Motor Strategy to Vision-Dominant Strategy**. The involution progresses linearly from 32 years old, slow at first, then much faster when turning 60.

Unfortunately, this progressive involution during the period 32-60 is primarily silent except if a specific event, such as joint pain or musculoskeletal injury, occurs. Without an event, it is often left undetected.

However, at single-leg stance training, athletes or individuals involved in intensive or regular physical and sportive activities can sometime self-detect their balance disorders and functional asymmetries. Therefore, *Bart Dingenen* [7] reports that not addressing a primary cause of single-leg stance disturbance may limit the sportive performance, diminish, affect or increase the risks of non-contact injuries such as ankle sprain or ACL injuries and develop acute or chronic injuries compromising their performance or carriers.

Additionally, *Anthea White* [8] shows that mid- and advanced-age women are more affected by postural balance disorders, non-contact injuries and falls than men. In young adults, they report that hormonal changes, especially oestrogens variation, affect muscle performance and decrease lower body strength and balance. Another factor identified during women's rehabilitation is that they present frequent sacrolumbar and pelvic functional disorders related to pregnancies, deliveries, gynaecological surgeries and menopause.

Furthermore, spine and pelvic pain are frequent among adults' most common musculoskeletal disorders [9]**.** They are often associated with acquired postural disorders, spine deviation such as scoliosis, musculoskeletal disorders (MSDs), and poor ergonomics. These disorders affect the leg's load distribution and the single-leg stance ability and performance.

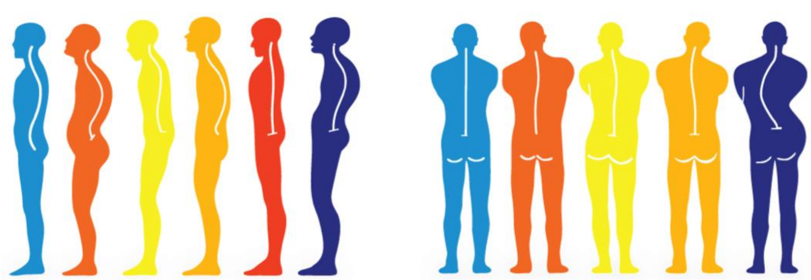


Figure 2: Different types of spine postural disorders

2. In older adults and young seniors

After the age of 55’-65’, as physical and cognitive learning experiences tend to reduce, the SomatoSensory-Motor representation in the CNS combined with all other balance control systems, tends to decline and progress back to a **Vision-Dominant system** *Poulain* studies [14]. However, as both systems, the Somatosensory-Motor system and the Vision-Dominant system accelerated their decline, this is often the time individuals observe some balance uncertainty, fear of falls, or more, they experience their 1st fall. *Muyinat Y Osoba* [10] also reports that the gait pattern tends to slow down with a shorter strike, reduced speed, reduced foot sensitivity and flexibility and increased time on a bipedal-leg stance. Daily activities requiring the single-leg stance also often reduce.

This period is also the time vision decline, muscle strength and joint flexibility decline, muscle synergies are slow or impaired, and reactive coordination starts to be challenging. Additionally, age-related body changes such as osteoarthritis, neurodegenerative diseases, and metabolic or cardiovascular diseases tend to develop, reducing the confidence and the ability to move or use a single-leg stance confidently,

All these contributing factors lead to the development of comorbidities factors such as obesity, metabolic disease and osteoarthritis, then later on to potential premature death.

When degenerative changes appear in elderlies, validated tools to assess the standing postural balance are extensively used [18], such as the Tinetti test, Time-Up and Go Test and 4-Stage-Balance Test and the single-leg stance. However, there is a lack of studies and health screening for the early detection of postural balance disorders and, more specifically, single-leg stance abilities in adults.

PART II: THE SINGLE-LEG STANCE BIOMECHANICS AND CHALLENGES

Holding a single-leg stance position is a primary skill consisting of supporting the entire body on one leg. The other leg is unsupported and not in contact with any support. Taking this position requires the complete integrity of the postural balance system and the integrity of the musculoskeletal system from the CNS and PNS. The maintenance of the equilibrium, the control of the postural sway and the anatomical-functional integrity of the ankle-foot and lumbopelvic complexes are the key factors in reacting to variable forces and maintaining a single-leg stance.

In addition, the single-leg stance is a simple primary skill that can become challenging for completing basic or complex tasks of daily living, such as walking on uneven surfaces, pivoting, climbing stairs or physical activities such as running and jumping. Therefore, the general body balance performance depends on symmetry and equality of the postural balance on each leg.

Based on the 1st paragraph study, we saw that the balance control in one static position is acquired and matured in three progressive stages:

1. Being able to hold a quiet position,
2. Being able to engage the body in a voluntary active motion
3. And being able to be reactive to internal or external stimulation,

The following paragraph uses the above balance acquisition model to investigate three single-leg stance mechanisms in an upright standing, with eyes open. First, the study investigates and describes the Quiet Single-Leg Stance, then the Active Single-Leg Stance and finally, the Reactive Single-Heel-Raise.

A. The Quiet Single-Leg Stance

The Quiet Single-Leg Stance is an effortless, sustained position that maintains the body upright on one leg with the other foot off the ground and unsupported. It engages mainly the equilibrium and the postural sway control systems, which means engaging the visual and vestibular systems. In addition, the motor and proprioceptive system also contributes to adjusting the equilibrium and minimising the postural sway.

The postural equilibrium is the micro-movement coordination stabilising the centre of gravity over the foot ground surface.

The postural sway describes the body fluctuation and minor multidirectional reactive movements to maintain the Centre Of Pressure (COP) in the base support. The postural sway helps to detect position and motion in the space.

The Quiet Single-Leg Stance helps to screen the **general performance, coordination and symmetry of the different body systems in managing equilibrium and sway**.

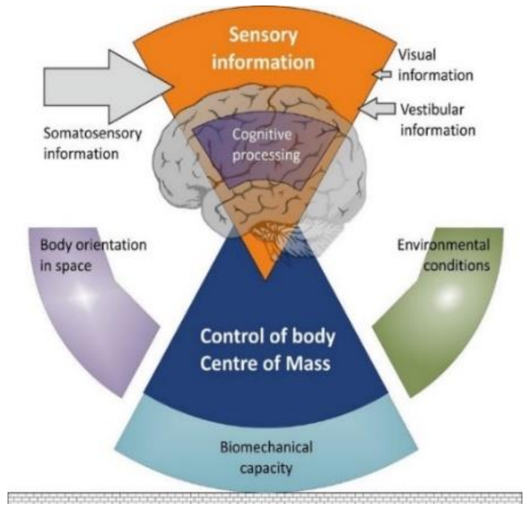


Figure 3: Control of the postural balance [23]

The sensory role of the ankle-foot complex in collecting disturbance information is the **first activation strategy to maintain a quiet single-leg stance** [21].

Any deficit or delay in the postural stability system affects the postural equilibrium and sway. A deficit is often the result of deprivation or dysfunction along the Somatosensory-Motor pathways and in the CNS representation. It includes:

- Trouble in the **acquisition** of the afferent information (Foot and sensorimotor afferent transmitters),
- Trouble in the **integration** of the forces and messages (Structure)
- Trouble in **transmitting** afferent response (Spinal cord)
- Trouble in the **processing** of the information (CNS),
- Trouble in **activating** an efferent response. (Motor)

In the research report, *Bart Bingenen* [6] explains that the first three seconds are the most important to complete this process on a quiet single-leg stance.

For most active and healthy adults, maintaining **the equilibrium** in a quiet single-leg stance is natural and requires no specific attention. Therefore, a physiological **postural sway** exists in adults' static quiet single-leg stance. *Neboja's* research [11] shows that highly-trained athletes have less postural sway than less-trained athletes. Additionally, the postural sway is increased on children, seniors and elderlies, affecting and limiting their abilities to maintain the quiet single-leg stance and making them more at risk of falling. *Reynard's* [22]research also shows that in a quiet single-leg stance, the postural sway is higher in women than men, and obese people tend to have wider postural sway. **As a result, age, sex and fitness are determinants for quiet single-leg stance performance**.

1. Role of the Ankle-Foot Complex in a Quiet Single-Leg Stance

A Quiet Single-Leg Stance is an effortless upright standing position on one leg with an unsupported contralateral foot. In a single-leg stance, the foot is the only interface between the body and the ground surface.

In a Quiet Single-Leg Stance with a unique interface on the ground, the foot-ankle complex plays an essential role in capturing sensory information. The pressure on the foot is transmitted to the somatosensory-motor system in the brain for equilibrium and postural sway control. In this case, the foot act as a **sensory transmitter** [20]. In response to sensory information, the ankle-foot complex integrity must allow high adaptability and stability to maintain postural balance.

The afferent sensory information comes from the pressure on the foot bone-joint structure and the soft tissue such as the skin, ligaments and muscle receptors. The main mechanoreceptors collecting cutaneous pressure are Pacinian, Ruffini, Meissmer corpuscules and Merkel-s disks [20].

The ankle-foot complex is a highly articulated system comprising 26 bones, 33 joints stabilised by multidirectional ligaments and fascia, and 29 intrinsic and extrinsic muscles. Many diseases and ageing processes may also affect nerves and the vascular system. The deficit of the foot sensory motor transmitter system can compromise the efficiency of stability, such as for the following conditions, including sub-cutaneous nerves damage in Chemotherapy, Diabetes Mellitus or Neurologic disease [21], muscles spasm or repetitive foot injuries affecting muscle spindles that are receptors sensitive to stretch or joint sprain, arthritis reducing joint mobility and mechanoreceptors activity. In addition, musculoskeletal pain, laxity or rigidity may affect the **foot sensory information capture and the foot reaction response** compromising balance.

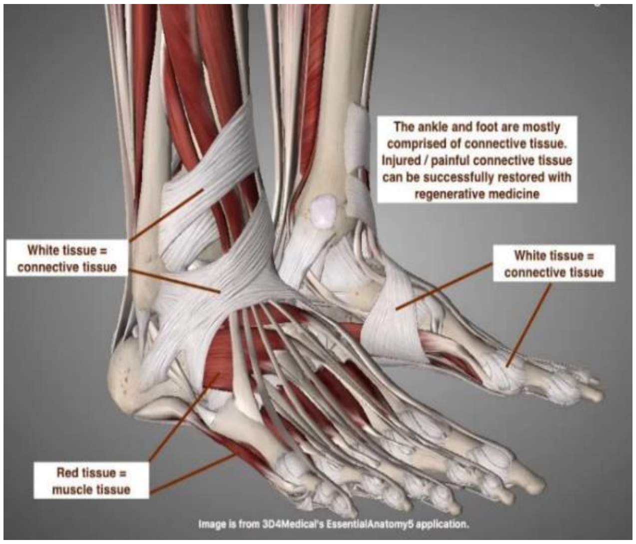


Figure 4: Ankle foot joints ligament complex

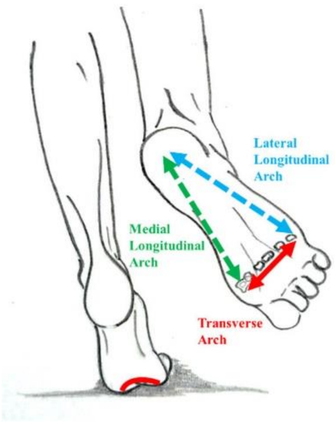


Figure 5 Foot arches

Moreover, the foot structure comprises 3 arches: The medial longitudinal arch, the lateral longitudinal arch and the transverse arch. Each arch allows **foot flexibility and functional coordination** of the stabiliser muscles. When there is a deficit in arch flexibility, the **ground reaction forces** are not well-distributed to the foot and may compromise the postural balance.

Additionally, the structure of the ankle-rear foot comprises a long anteroposterior axis crossing a short mediolateral axis. In a Quiet Single-Leg Stance, ankle-foot muscle co-activation aims to maintain the body's gravity centre on the grounded foot. As a result, the centre of pressure velocity fluctuates over the foot in a mediolateral and anteroposterior direction. *Eduard Kurs* also shows [23] that to maintain the centre of pressure, the anteroposterior sway frequency increase in children and older adults compare to young adults. However, in adult, the postural stability control [24]on the mediolateral axis of the ankle-foot is very active and reactive and promote an early ankle-foot muscle co-activation

Finally, the adaptability, flexibility and stability of these joints, muscles, foot arches system and ankle axis are the key factors for managing foot-ankle forces absorption, adapting reaction forces, and adjusting foot pressure on the ground

2. The Role of the Hip-Pelvic Complex in a Quiet Single-Leg Stance

The hip-pelvic complex is a solid and large structure allowing the distribution of the body load and the alignment of the gravity line on the ground-based support to maintain the body's equilibrium

The hip-pelvic complex is the **first activation strategy in transferring the load to initiate the single-leg stance or restore the double-leg stance.**

In a **Quiet Single-Leg Stance**, the hip-pelvic complex has two different functions:

- **A low-energy dynamic function** occurs when the body shifts the weight from a double-leg stance to a one-leg stance or restores the double-leg stance after a one-leg stance.
- **A low-energy static function** occurs when the pelvic frame is maintained horizontally while the centre of gravity is on one foot.

In a Quiet Single-Leg Stance, shifting the gravity line involve a minimal range of motion on the hips and sacroiliac joints. In addition, it involves a low level of **inner and outer pelvic muscle** co-activation to move to one leg and maintain that position. **Therefore, it would be a significant stability factor** in more complex single-leg stances, such as active or reactive ones.

In reaction to the ground pressure, the hip-pelvic complex receives back the ground forces transmitted by the foot-leg structure and then centralises the forces received on the spine and the trunk structure.

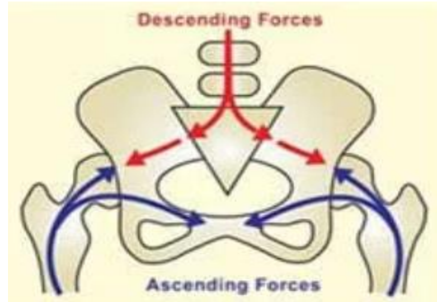


Figure 6: Pelvic force distribution

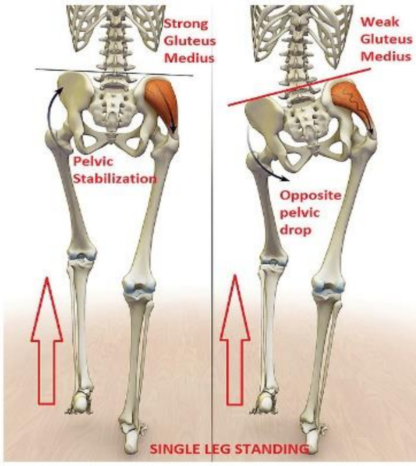


Figure 7 Quiet leg stance : left picture strong gluteus muscle , Right side gluteus muscle weakness

The **gluteus medius** muscle plays a significant role in initiating pelvic alignment and activating kinetic chains. Then the **gluteus group** muscles work in coordination with all **pelvic stabilisers**. For example, *Kim Alison* [25]shows that individuals affected by gluteal tendinopathy used different strategies to maintain the single-leg stance. Other synergic muscles are the deep core, inner pelvic, and lumbo-abdominal muscles.

In a Quiet Single-leg Stance, the equilibrium and the postural sway are affected in adults with acquired weakness, children and adults with age-induced. In this case, the hip stabiliser's weakness shows a pelvic drop on the contralateral side and loss of balance.

3. The Quiet Single-Leg Stance Screening Test

The Quiet Single-Leg Stance screening is a simple test overviewing the proper functioning of the overall postural balance system, including the CNS and PNS, by screening the equilibrium, the postural sway and a low amplitude motor function. The test does not require any equipment and takes 30 seconds to complete.
Doctors and therapists widely use this screening test on seniors and older adults. In addition, preventive medicine specialists implement this test on workers to assess their ability to perform specific job tasks requiring balance or for driving tests. Finally, therapists frequently use this test to assess weight-bearing pain, leg alignment, proprioception and balance on different surfaces.

Test

Starting position: The patient is barefoot, stands upright on both legs, arms relaxed, feet aligned hip-width apart, eyes open and looking ahead.

Instruction: Please stand on one leg, whichever side, and stay quiet (effortless) until otherwise instructed. Do not touch your legs together. *Note: let the patient choose the side. It indicates the most confident leg*

No trial before the test.

The patient shifts the body weight to one leg and lifts the contralateral leg off the ground.

Time: Maintain the quiet single-leg stance for 10 seconds, restore the double-leg stance, and then change the side to test the other leg.

Do: only 1 time on each side

Figure 8: Quiet single leg stance

Physiotherapist observation: Postural sway range, equilibrium, pelvic drop and foot muscles activation

Stop the test: at 10 seconds of completion or when the patient loses control before the end of 10 seconds.

Interpretation:

- Teens and adults must be able to complete 10 seconds of single-leg stance on each leg.
- Teens and adults failing the Quiet Single-Leg Stance Test must receive recommendations for a self-management programme,
- Teens and adults failing this test and having other positive tests such as spine deviation, joint restriction, or pain must receive a postural assessment by a physiotherapist for further postural training or rehabilitation.
- Seniors failing the Quiet Single Leg Stance test must be suggested the four-stages balance test, Time-Up-and-Go test or Tinetti test by a physiotherapist to assess their balance and gait, then receive a rehabilitation programme.

B. The Active Single-Leg Stance

Based on the developmental acquisition process of the postural balance system, the next step, after being able to maintain the postural balance in a quiet single-leg stance, is to maintain the equilibrium on one leg while the other leg performs a movement. The **Active Single-Leg Stance** test is a non-validated test to screen **equilibrium efficiency and locking mechanisms symmetry of the pelvic complex**. This test is similar to the Stork Test [26]**,** a validated test with low reliability to assess sacroiliac dysfunctions in a one-leg stance.

Dynamic daily activities, work and sports frequently require combining a single-leg stance with an active contralateral hip-knee flexion. It includes daily activities such as stepping over, climbing stairs or dynamic activities such as running or climbing. Compared with the Quiet Single-Leg stance Stance, in the Active Single-Leg Stance, the ankle-foot complex still reacts as a **sensory transmitter** but manages **higher force variability** in the sagittal and frontal planes.

The contralateral hip-knee flexion at 90 degrees **generates an internal perturbation** requiring a high level of pelvic stabilisation forces from the stance side to maintain the gravity line alignment onto the foot base. As a result, to maintain the postural equilibrium in that position, there is an intensive engagement of the **lumbopelvic articular complex and the co-synergic lateral pelvic muscle chains**.

Figure 9: Active Single-Leg Stance Test

1. The LumboPelvic Articular Complex

In the Active Single-Leg Stance, the **lumbopelvic articular complex integrity** is crucial in maintaining the equilibrium while lifting the contro-lateral hip at 90 degrees. This hip flexion mechanism at 90 degrees creates a more substantial perturbation on the pelvic [22] than on a quiet stance. Therefore, any joint restriction in the lumbopelvic complex may compromise the postural balance. As a result, in a one-leg stance, the contralateral hip flexion at 90 degrees must activate a **hip articular stabilisation strategy**

The lumbopelvic complex comprises two iliac bones, the sacrum, the two femoral heads, and the lumbar vertebrae.

The sacroiliac joints connecting the iliac bones to the sacrum are two complex joints with a minimal range of motion playing a fundamental role when shifting the body weight to one leg. Although the two sacroiliac joints are gliding-type joints with only a few millimetres of mobility (2 to 4 millimetres), they provide mobility control from their shape and the ligamentous elasticity system.

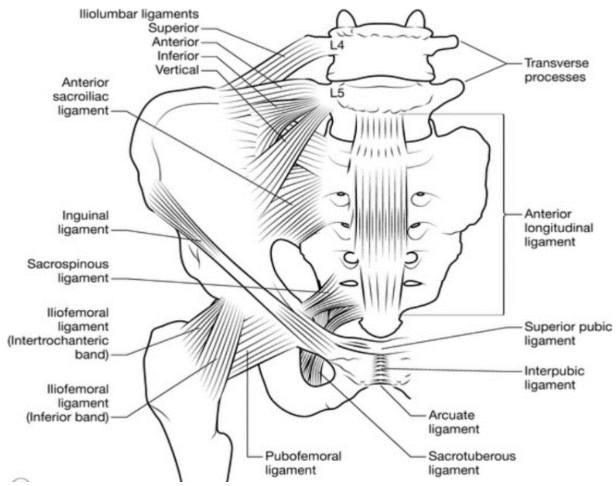


Figure 10: Sacroilac ligaments complex

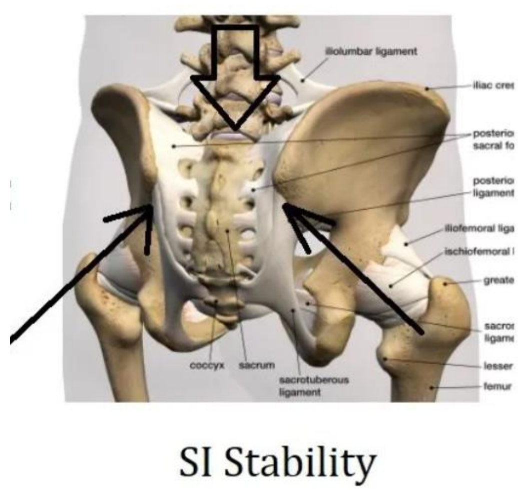
Figure 11: sacroiliac joint shape of the sacrum. V= vertical, H= horizontal

The primary role of the sacroiliac joints within the pelvis is to provide:

- **Ascendant shock absorption** by maintaining the sacrum aligned with the pelvis for further spine alignment

- Or **descendant load distribution** to the foot.

In addition, the sacroiliac joints work directly with the pubic symphysis to set up a **locking mechanism** helping to increase the foot load [12] for walking and having activities in one leg stance.



In a one-leg stance, when the contralateral hip flexes at 90 degrees, the iliac of the flexed side rotates posteriorly at the sacroiliac joint. This action is a **self-pelvic-locking mechanism allowing initiation of the co-synergic muscle activation** to stabilise the pelvis at one leg lifting.

The two hip joints are ball-and-socket motion joints with a wide range of motion combining axial hip movements with rotations. The iliofemoral ligament, called the Y ligament, is one of the strongest ligaments of the body. Its role is to help to stabilise the hip head into the socket and control the hip constraint.

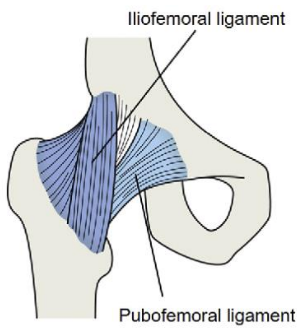


Figure 13: hip front view- ligamant iliofemoral

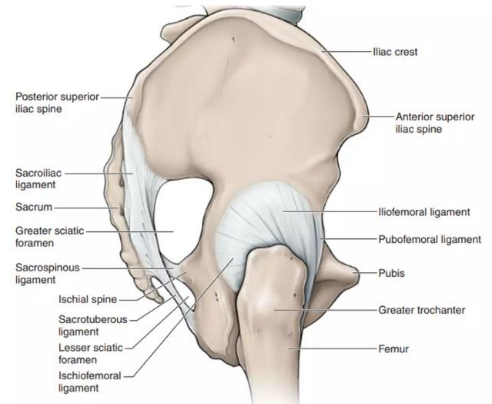


Figure 12: Hip lateral view ligaments

Most adults have a comfortable hip range of motion for physical and daily activities. However, minor and silent femur head misalignment may affect hip integrity and terminal motion on the related axis. At that time, the misplacement of the femur head in the acetabulum compromises the transmission forces chain foot-hip-pelvic-spine and leads to silent pelvic misalignment, rotation or tilt, spine deviations and balance disorders. Not detecting signs may gradually increase joint/pelvis or spine pain, muscle fatigue, cartilage damage, risks of falling, and reduced ability to stay active.

Additionally, osteoarthritis and posterior capsule stiffness often affect hip joints during ageing. It restricts the hip range of motion and consequently affects the ability to flex the contralateral hip when standing on one leg. Hip stiffness and reduced mobility increase the challenge of maintaining equilibrium and directly increase the risk of falling.

In The Active Single-Leg Stance, the weight transfer is mainly lateral and requires a low range of mobility from the stance side. However, the range of motion of the contralateral hip-knee flexion at 90 degrees must be unrestricted to activate the ligamentous and the co-synergic muscular pelvic stabilisation system to maintain the gravity line on the stance leg and hold the balance.

2. The lumbopelvic muscle synergies

In an Active Single-Leg Stance, the transfer from the double-leg stance to the single-leg stance engages lateral muscles and core motor synergies. It **includes a dynamic and a static phase**. Both phases use pelvic force variability and stability muscles to move smoothly to one side, raise one hip-knee at 90 degrees and maintain equilibrium.

The dynamic or active phase requires sensorimotor anticipation with the preparation for weight-bearing shifting and the preparation of increasing the load on the ground-contact surface through a well-coordinated and well-adjusted muscle synergy.

The study of *Bart Dingenen* [7] shows that when transitioning from one position to another position, there is a contralateral push-off movement, anticipating the load to the contralateral side. In this phase, the postural balance requires a more controlled force variability to achieve stability.

The static or steady phase requires muscular co-activation synergies to maintain the postural balance with an unconstant level of force variability to maintain stability. These muscular chains are also called myofascial slings

During the 2 phases of an Active-Single-Leg-Stance, the muscle slings activation is continuous to achieve equilibrium. The lumbopelvic and lower-limb muscle synergies contribute to achieving a functional single-leg stance and initiating activities in close kinetic chains. In addition, the gluteus medius-minimus, pyriformis, and iliotibial band activations from the contralateral push-off foot movement stimulate the Lumbo-Pelvic lateral muscle synergy.

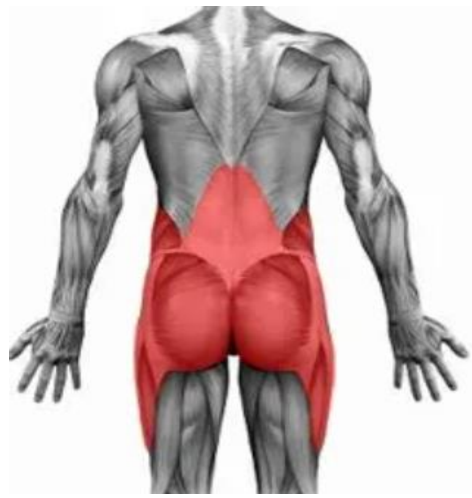


Figure 14: outer pelvic muscles

In the Active Single-Leg Stance test, the hip flexion position at 90 degrees activates the contralateral hip flexors, including the psoas muscle and the quadratus femoris, followed by the stabilisation from the inner and outer pelvic girdle muscles

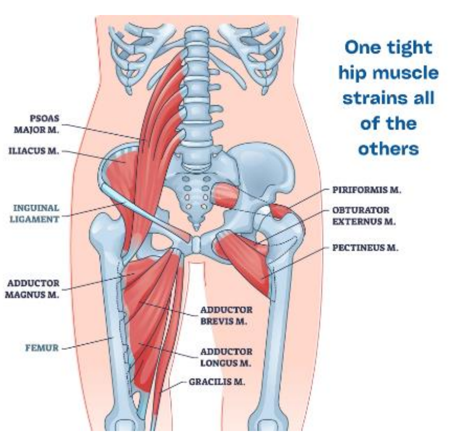


Figure 15: Hip flexors synergies

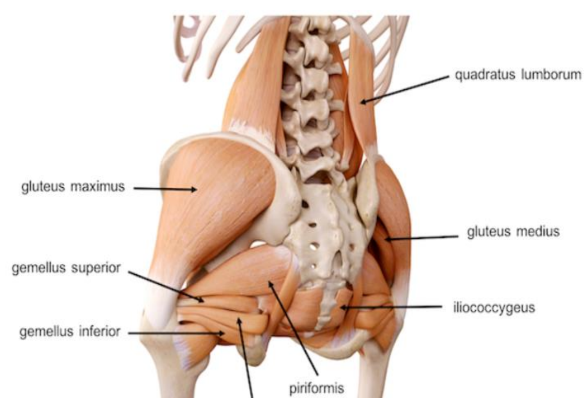


Figure 16: Inner outer pelvic co-synergic muscles

The myofascial slings coordinate the muscle’s synergies

The **anterior myofascial sling** helps to activate the lateral trunk-hip muscle chain, quadratus lumbar and gluteus on the leg stance side, then obliques and deep pelvic core to contralateral anterior muscles, adductors and hip flexors

Figure 17: Anterior Myofascial Sling-Myers

Figure 18: Posterior Myofascial Sling-Myers

The **posterior myofascial sling** helps to activate the gluteus maximus to the contralateral latissimus dorsi, crossing the sacroiliac joint

The **Intrinsic deep core pelvic sling** helps to activate the pelvic floor with deep pelvic and deep core muscles.

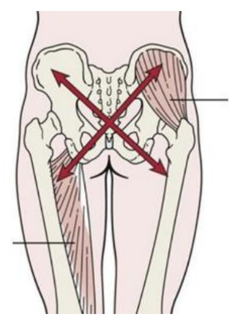


Figure 19: Pelvic crossed lateral sling

3. The Active Single-Leg Stance Screening Test

The **Active Single-Leg Stance test screening test** is towards individuals who can successfully achieve the Quiet Single-Leg Stance. The Active Single-Leg Stance screening tests the ability to engage active motion with the contralateral leg while standing steady on one leg to maintain equilibrium and control the postural sway. It takes 30 seconds to complete, and no specific equipment is required.

This test screen:

- Postural balance disorders
- Standing patterns and muscle chains deficit
- Postural functional disorders
- Muscles weakness
- Hip restriction
- Lumbopelvic and sacroiliac dysfunction
- Musculoskeletal compensatory mechanisms
- Musculoskeletal overuse mechanisms
- Risks of re-injuries
- Risks of pelvic or low back pain
- Ability to participate safely and effectively in an active lifestyle, recreational or sportive activities

Starting position: The patient is barefoot, stands upright on both legs, arms relaxed, feet aligned hip-width apart, eyes open and looking ahead.
Instruction: Please lift one knee at 90 degrees hip flexion and hold the standing position for 10 seconds.
No trial before the test
The patient raises the knee at 90 degrees and holds the position without support.
Time: Hold for 10 seconds, restore double leg stance, then change the leg.
Do: only 1 time on each side
Physiotherapist observation: Pelvic rotation or drop, stance foot muscle activation, postural sway range, equilibrium and lower or upper muscles activation
Stop the test at 10 seconds of completion or when the patient loses control before the end of 10 seconds,

Interpretation:

- Adults must be able to complete 10 seconds of single-leg stance on each leg.
- Adults failing the Active Single-Leg Stance Test or having asymmetry in their performance must receive a complete joint and muscle assessment by a therapist, including:
    - Hip joints and pelvic evaluation
    - Spine evaluation
    - Ankle-foot evaluation
- Adults failing the Active Single-Leg Stance Test and having other positive tests must receive a complete musculoskeletal and neurological assessment.

C. Reactive Single-Heel-Raise

Finally, following the Quiet and the Active Single-Leg Stance test, the last screening stage tests the ability to **control thrice single-heel raises** and perform the test **equally on both sides.** Again, it assumes that the individual pass successfully the quiet stance and can activate the pelvic-complex locking mechanisms tested in the Active-Single-Leg Stance.

This screening does not aim to test the ankle range of motion or the maximal plantar flexion strength [28]**,** as many single-heel raise tests do.

Instead, the Reactive Single-Heel-Raise test, a non-validated tool, screens the ability to actively engage successive reactive forces on the stance foot by shrinking and restoring the ground base. For each side, it helps to screen the ability to react to an external perturbation, restore the body alignment and equilibrium on one foot and compare the muscle activation symmetry.

From a single-leg motionless stance, the Reactive-Single-Heel-Raise stage screens the ability to initiate a highly skilled dynamic movement moving the centre of gravity from the foot surface to the forefoot and restoring the balance to the initial position three consecutive times. This movement repetition engages **high equilibrium skills,** involving a well-adjusted activation of all balance systems, including vestibular, visual, and somatosensory-motor systems, combined with the musculoskeletal biomechanical integrity.

Figure 20: Reactive Single-Leg stance Test- Heel raise

This test also screens the muscle fatigue and symmetrical performance of the reactive chains, especially the deep longitudinal muscle slings, which includes the foot plantar muscles performance, leg extensors chain strength and proprioception.

This heel-raise skill helps the body ensure an equal ability to react to **external perturbations** with both sides of the body and re-adjust the centre of gravity and the equilibrium on each side. This skill is frequently used during gait acceleration, walking on uneven ground surfaces, changing directions or any propulsive activities such as running or jumping.

1. The Ankle-Foot Plantar Performance

The ankle-foot plantar performance requires flexibility, strength and proprioception but also an excellent sensitivity to adjust pressures and restore the balance between each raise.

Plantar flexor strength appears to be an essential element in initiating the heel-raise motion [29]. Muscle fatiguability or control weakness may interfere with repeated motions and the ability to restore the starting position.

Additionally, the symmetry of the plantar flexor strength appears essential in the general postural balance during functional and sportive activities allowing movements from both sides of the body. Heel raise strength balance between the two sides of the body helps to address and optimises the ability to react to external perturbation equally and prevent the risks of falling.

2. The posterior longitudinal chain

During the heel raise and return to single-leg stance, the centre of gravity COG moves just a few centimetres from the rear foot to the forefoot

So, the plantar flexor muscles initiate the deep longitudinal posterior chain, adjusting the body axis alignment onto the foot and then to the forefoot. This motion does not involve much strength. However, it requires a **very well-adjusted anteroposterior balance system with minimal motion**.

Figure 21: Deep longitudinal myofascial chain (Myers)

3. Reactive Single-Heel Raise Screening Test

The **Reactive Single-Heel-Raise test is the third and last stage of the Single-Leg Stance screening tests**. This test requires skills proficiencies to maintain the single-leg postural balance while moving on that minimal base. It also helps to compare balance and plantar flexor strength discrepancies on the dominant and non-dominant leg. It takes 30 seconds to complete, and no specific equipment is required.

Starting position: The patient is barefoot, stands upright on both legs, arms relaxed, feet aligned hip-width apart, eyes open and looking ahead. The therapist places hands near the shoulders level without any contact with the patient

Instruction: Please stand quietly on one leg, then, when instructed, raise your heel 3 consecutive times. Do not raise at the maximum range. Do not hold the heel up.

No trial before the test

The patient stands on one leg for 3 seconds to set the balance, raises the heel thrice, and then restores balance on both feet.

Time: Hold a quiet stance for three seconds at the beginning of the test. Then perform heel raises.

Do: Start with the preferred leg. Raise the heel thrice. Redo on the other leg

Physiotherapist observation:

- Ability to move the heel off the ground,
- Ability to restore the balance between heel raises
- Ability to repeat heel raise motion
- Ability to adapt gravity centre alignment from foot to forefoot
- Ability to control the pelvic alignment
- The symmetry of both sides

Stop the test: After the completion of the test or when the patient loses control

Caution: After the 1rst raise failure, the physiotherapist can offer shoulders lateral support to compare both plantar flexors muscle chains.

Interpretation

- Adults must be able to complete three heel raises and restore balance on both sides
- Adults able to perform the Reactive Single-Heel-Raise test on both sides but show **asymmetrical performance** must receive a self-management training programme, then the performance is reassessed and monitored
- Adults failing the test **on one side** must receive foot, musculoskeletal, and postural assessment and training recommendations.
- Adults failing the test **on both sides** must receive a physical assessment from a therapist and a rehabilitation programme.

DISCUSSION AND CONCLUSION

This thesis investigated the interest of a Three-Stages-Single-Leg test in adults to screen their postural balance disorders. This series of the three tests proposed are low-cost, equipment-free, easy-to-do, not time-consuming and can be easily implemented by individuals or in the medical practice. Furthermore, it shows that the postural balance systems integrity of the CNS, PNS and mastering postural balance experiences are fundamental factors for optimising equilibrium and controlling postural sway in adults.

It also shows that the single-leg balance and equilibrium skill is the last fundamental and primary somatosensory motor skill acquired during childhood and the first skill declining during early adulthood from around 32 years old. However, further studies may help to consider if this early decline is a consequence of the ageing process, a failure in the development acquisition process or a lack of mastering experiences during teenhood.

The three stages of this test, including the Quiet-Single-leg Stance, Active-Single-Leg Stance and Reactive-Single-Heel-Raise, are established based on the child's motor and balance acquisition process. It means, for whichever position, to acquire the ability to maintain a quiet position, to be voluntarily active and to react to perturbation in that position. However, studying the validity and the reliability of the three-stages-single-leg test in the adult population and analysing data may help to investigate the implementation criteria and choose the specific targetted population. For example, at the beginning of each sports year, screen all athletes and compare results with their injury background or injuries of the year. As women are more affected than men, screening with this series of 3 tests of all women during their postnatal rehabilitation and comparing with pelvic-low back pain reported may be interesting.

Studies show that adult postural balance disorders are often silent or neglected, letting them unaddressed during adulthood. So, raising awareness among the adult population, at work, in sports or the medical practice, with a systematic adult screening from 31 to about 60’s, seems helpful for the early detection of transitional or recurrent balance disorders. Timely awareness and intervention in developing physical abilities, skills and balance strategies during adulthood may help to progress to the seniors and the elderly stage by maintaining an active lifestyle and reducing the risks of falls, bone fractures, injuries and premature death. Additionally, this postural balance screening in the active adult population may help detect asymmetrical mobility, function or ergonomics to reduce spine and pelvic pain and injuries, the most common musculoskeletal disorders. Moreover, postural balance screening may help adults maintain an active lifestyle by increasing their abilities and confidence to participate safely in recreational or sportive activities and reducing the risks of non-contact injuries. Although, by regularly screening their postural balance abilities, athletes may optimise their athletic performance and the time away from competition because of injuries.

Finally, this study is towards adulthood; however, we may also consider opening this screening on teens and young adults, the most sportive and physically active population, to optimise their balance experiences, reduce their risks of sports-physical activity injuries and optimise their ergonomics.

REFERENCES

[1] " Center for Disease Prevention and Control," CDC, 2022. [Online]. Available: https://www.cdc.gov/injury/features/older-adult-falls/index.html#:~:text=About%2036%20million%20falls%20are,departments%20for%20a%20fall%20injury.

[2] L. R. T. 1. G. M. E. E. G. P. 2. Anthea M White 1, "Fall Risk Factors in Mid-Age Women: The Australian Longitudinal Study on Women's Health," observational study, Jan 2018. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/29254554/.

[3] Jennifer Howcroft, Edward D. Lemaire, Jonathan Kofman, William E. McIlroy, "Elderly fall risk prediction using static posturography," PLOS One Journal, February 21, 2017. [Online]. Available: https://journals.plos.org/plosone/article/authors?id=10.1371/journal.pone.0172398.

[4] Flavien Quijoux, Aliénor Vienne-Jumeau, François Bertin-Hugault, Philippe Zawieja, Marie Lefèvre, Pierre-Paul Vidal and Damien Ricard, "Center of pressure displacement characteristics differentiate fall risk in older people: A systematic review with meta-analysis," Ageing Research Reviews, 2020. [Online]. Available: https://www.clinicalkey.com/#!/content/playContent/1-s2.0-S156816372030252X?returnurl=https:%2F%2Flinkinghub.elsevier.com%2Fretrieve%2Fpii%2FS156816372030252X%3Fshowall%3Dtrue&referrer=https:%2F%2Fpubmed.ncbi.nlm.nih.gov%2F.

[5] Wytske MA Meekes, Joke C Korevaar, Chantal J Leemrijse, and Ien AM van de Goor, "Practical and validated tool to assess falls risk in the primary care setting: a systematic review," BMJ Open, 2021. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8483054/.

[6] Bart Dingenen, PT, PhD1, Bart Malfait, PT, PhD1, Stefaan Nijs, MD, PhD2, Koen H.E. Peers, MD, PhD3, Styn Vereecken, PT, MSc3, Sabine M.P. Verschueren, PT, PhD1, Luc Janssens, Eng1,4, Filip F. Staes, PT, PhD1, "Postural Stability During Single-Leg Stance: A Preliminary Evaluation of Noncontact Lower Extremity Injury Risk," Journal of Orthopaedic and Sports Physical Therapy, July 31, 2016. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/27374015/.

[7] Jaap H. van Dieën, corresponding author Marloes van Leeuwen, and Gert S. Faber, "Learning to balance on one leg: motor strategy and sensory weighting," JNP Journal of Neurophysiology, No 2015. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4737414/.

[8] B A Foudriat 1, R P Di Fabio, J H Anderson, “Sensory organisation of balance responses in children 3-6 years of age: a normative study with diagnostic implications,” Int J Pediatr Otorhinolaryngol, Oct 1993. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/8270364/.

[9] Shu Morioka 1, Takahiko Fukumoto, Makoto Hiyamizu, Atsushi Matsuo, Hideaki Takebayashi, Kenzo Miyamoto, “Changes in the equilibrium of standing on one leg at various life stages,” Current Gerontology and Geriatrics Research, 2012. [Online]. Available: https://www.hindawi.com/journals/cggr/2012/516283/.

[10] S. L. S. &. A. D. Goodworth, “Postural Control in Children and Youth with Cerebral Palsy,” Springer link, 2019. [Online]. Available: https://link.springer.com/referenceworkentry/10.1007/978-3-319-50592-3_161-1#Fig2.

[11] Patrick J Sparto 1, Mark S Redfern, Jeff G Jasko, Margaretha L Casselbrant, Ellen M Mandel, Joseph M Furman, “The influence of dynamic visual cues for postural control in children aged 7-12 years,” National Library of Medicine, January 2006. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/16151780/.

[12] Leonardo George Victorio Victor, “Postural control during one-leg stance in active,” University of Panama- Bresil, [Online]. Available: https://www.scielo.br/j/motriz/a/m5TzbKspKXFwVVBk8qrZH6D/?format=pdf&lang=en.

[13] Bryan L. Riemann, PhD, ATC, FNATA1 and Randy Schmitz, PhD, ATC2, “THE RELATIONSHIP BETWEEN VARIOUS MODES OF SINGLE LEG POSTURAL CONTROL ASSESSMENT,” Int J Sports Phys Ther., June 2012. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3362983/.

[14] Anthea M. White MSc, Leigh R. Tooth PhD and G.M.E.E. (Geeske) Peeters PhD, “Fall Risk Factors in Mid-Age Women: The Australian Longitudinal Study on Women’s Health,” American Journal of Preventive Medicine, 01 2018. [Online]. Available: https://www.clinicalkey.com/#!/content/playContent/1-s2.0-S0749379717305925?returnurl=https:%2F%2Flinkinghub.elsevier.com%2Fretrieve%2Fpii%2FS0749379717305925%3Fshowall%3Dtrue&referrer=https:%2F%2Fpubmed.ncbi.nlm.nih.gov%2F.

[15] Yi-Liang Kuo, 1 Kuo-Yuan Huang, 2 Pei-Tzu Chiang, 3 Pei-Yun Lee, 3 and Yi-Ju Tsai 3 ,*, “Steadiness of Spinal Regions during Single-Leg Standing in Older Adults with and without Chronic Low Back Pain,” PLOS ONE, May 29 2015. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4449109/.

[16] Isabelle Poulain 1, Guillaume Giraudet, “Age-related changes of visual contribution in posture control,” gait posture, January 2008. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/17442574/.

[17] Muyinat Y. Osoba, BA, 3 Ashwini K. Rao, OTR, EDd, 1 Sunil K. Agrawal, PhD, 4 and Anil K. Lalwani, MDcorresponding author 1 , 2 , 4, “Balance and gait in the elderly: A contemporary review,” Feb 2019. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6383322/.

[18] Adrianna Borowicz, PhD,1 Ewa Zasadzka, PhD,1,* Agnieszka Gaczkowska, MPT,1 Olga Gawłowska, MPT,1 and Mariola Pawlaczyk1, “Assessing gait and balance impairment in elderly residents of nursing homes,” J Phys Ther Sci. , Sept 2016. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5080158/.

[19] P. DA Winter PhD, “Human balance and posture control during standing and walking,” Gait & Posture, December 1995. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/0966636296828499.

[20] NebojšaTrajković, Žiga Kozinc, Darjan Smajla, 4 & Nejc Šarabon, “Relationship between ankle strength and range of motion and postural stability during single-leg quiet stance in trained athletes,” Scientific report, Jun 3 2021 . [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/34083684/.

[21] Fabienne Reynard, David Christe, Philippe Terrier,, “Postural control in healthy adults: Determinants of trunk sway assessed with a chest-worn accelerometer in 12 quiet standing tasks,” PLoS One., 2019. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6344019/.

[22] F. J. F. V. 1, “The sensory role of the sole of the foot: Review and update on clinical perspectives,” Neurophysiol Clin, February 2020. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/32007381/.

[23] Eduard Kurz 1 2, Oliver Faude 3, Ralf Roth 3, Lukas Zahner 3, Lars Donath 3 4, “Ankle muscle activity modulation during single-leg stance differs between children, young adults and senior,” Eur J Appl Physiol, February 2018. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/29188450/.

[24] A. P. 1. 2. 3, “Modulation of Lower-Limb Muscle Activity in Maintaining Unipedal Balance According to Surface Stability, Sway Direction, and Leg Dominance,” Sports (Basel), October 2022. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/36287768/.

[25] Kim Allison 1, Kim L Bennell 2, Alison Grimaldi 3, Bill Vicenzino 4, Tim V Wrigley 5, Paul W Hodges 6, “Single leg stance control in individuals with symptomatic gluteal tendinopathy,” gait posture, Septembre 2016. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/27395451/.

[26] physiopedia, “stork test,” Physiopedia, [Online]. Available: https://www.physio-pedia.com/Stork_test.

[27] Rebeka Boaventura Guimarães, PT, MSc, 1 Cesario Rui Callou Filho, PT, MsC, 2 Alex Rey Norberto, MsC, 3 Renata Salatini, PT, PhD, 4 , * Juliana Zangirolami-Raimundo, MsC, 3 , 4 and Rodrigo Daminello Raimundo, PT, PhD 4, “Relationship of the mobility of the sacroiliac joint with foot plant pressure,” Journal of Physical Therapy Science, 2021. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8219602/.

[28] Lauren K. Sara ,Savannah B. Gutsch,Sandra K. Hunter, “The single-leg heel raise does not predict,” Plos one, August 2021. [Online]. Available: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0253276.

[29] Rami Hashish 1, Sachithra D Samarawickrame 2, Man-Ying Wang 2, Sean S-Y Yu 2, George J Salem 2, “The Association between Unilateral Heel-Rise Performance with Static and Dynamic Balance in Community Dwelling Older Adults,” Geriatr Nurs, January 2015. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/25457285/.

[30] “elderly,” *annals,* no. https://doi.org/10.1371/journal.pone.0172398 PMID: 28222191, 2017.

[31] P. E. Maarit Piirtola 1, “Force platform measurements as predictors of falls among older people—a review,” *Gerontology,* pp. 52(1):1-16. , 2006.

[32] J. S. D. M. Asir John Samuel*, “A Critical Review on the Normal Postural Control,” Physiotherapy and Occupational Therapy Journal, June 2015. [Online]. Available: https://www.researchgate.net/publication/304234831_A_Critical_Review_on_the_Normal_Postural_Control.