BalanceTutor™

Protocol & Clinical Guidelines

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BalanceTutor a dynamic and static postural control trainer

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1 Introduction

A postural perturbation is a sudden change in conditions that displaces the body posture away from equilibrium. Reactive postural control response is an automatic "like reflex" response which is initiated by unexpected postural perturbation in order to maintain balance and can be improved through practice.

Traditional physical rehabilitation based mainly on proactive training (self-initiated actions). Clinical research has shown that in addition to proactive training, reactive training must be targeted.
Traditional tools and methods simply cannot target reactive response training due to major safety issues and a lack of sophisticated treatment customization.

The system's unique technology for the first time allows training reactive postural control response while standing or walking at different gait phases. Together with proactive training, the system allows for optimal rehabilitation outcome and recovery.

2 Neuromuscular Function

Neuromuscular function relates to the ability of the body to efficiently recruit a muscle or group of muscles in order to perform a specific task and works on two main categories:

Interlimb coordination - Interlimb coordination primarily involves movements requiring sequential and simultaneous use of both sides of the body with a high degree of rhythmicity.

Intralimb coordination - Interlimb coordination is commonly divided into two categories: bimanual coordination and coordination of hands/feet.

For instance, coordination between adequate muscle activities of plantar flexors of one leg together with adequate magnitude of the ground reaction force provided by contralateral limb during heel strike is critical for normal gait ability and Balance.

In addition to Interlimb coordination (between limbs) proper Intralimb coordination (within limb) is also needed for normal gait ability and Balance. For instance, Spatio-temporal parameters or muscle synergies of several joints of the limb such as ankle, knee and hip joints is critical for Intralimb coordination during standing or walking. The Intralimb coordination can be impaired due to inadequate Spatio-temporal parameters leading to compensatory strategies adopted by post stroke patients.

Example I - Stepping forward requires coordination of weight bearing on one limb and Center of Mass transferring by another limb in initial swing phase in interlimb coordination.

Example II - Stepping forward requires coordination of Hip and knee flexion of the limb in initial swing phase.

3 Neuromuscular Dysfunction

Neuromuscular function can be impaired as a result of varied body system dysfunction as follows;

3.1 Neurological problems

Neurological disease and injuries such as Stroke, Head injuries, Spinal cord injury, Cerebral Palsy and Parkinson's disease can affect gait and balance ability. The features of Neurological problems vary according to medical condition, type of rehabilitation received, and other individual differences.

The gait of neurological patients is mainly characterized by reduced speed, stride length, and cadence, decreased angular excursions at leg joints, increased energetic cost, and asymmetry in kinematic and kinetic variables

These kinematic and kinetic deficits caused by neurological problems must be specifically targeted and properly rehabilitated for achieving optimal physical rehabilitation.

Normal balance ability and gait control requires adequate proactive and reactive postural control responses. Proactive response refers to ability of the body to maintain balance before some perturbation to the balance of the body such as a voluntary step whereas reactive postural response refers to ability of the body to maintain the balance of the body after unexpected perturbation like a compensatory step following a slip or trip.

Effective rehabilitation program must include both proactive and reactive postural control response evaluation and treatment.

Unfortunately, traditional rehabilitation is mostly based on proactive balance control response and not reactive responses. This limited rehabilitation program of traditional therapy mainly arises from safety issues and lack of treatment customization.

BalanceTutor system enables to target both proactive and reactive response to achieve optimal rehabilitation using professional protocols as demonstrated in this guide.

3.2 Orthopedic problems

Orthopedics disease and injuries such as Joint surgery, Amputation, Prosthetic, Muscle weakness, Ligament sprain and Muscle/ tendon strain can affect gait and balance ability. The features of orthopedic problems vary according to medical condition, type of rehabilitation received, and other individual differences.

3.3 Vestibular problems

The vestibular system is the sensory system that provides the leading contribution about the sense of balance and spatial orientation for the purpose of coordinating movement with balance. As movements consist of rotations and translations, the vestibular system comprises two components: the semicircular canal system, which indicates rotational movements; and the otoliths, which indicate linear accelerations. The vestibular system sends signals primarily to the neural structures that control eye movements, and to the muscles to t keep a body upright. The projections to the former provide the anatomical basis of the vestibulo-ocular reflex, which is required for clear vision; and the projections to the muscles that control posture are necessary to keep an animal upright.

The brain uses information from the vestibular system in the head and from proprioception throughout the body to understand the body's dynamics and kinematics (including its position and acceleration) from moment to moment.

Vestibular function together with proper function of proprioceptive sensors located in soft tissues such as muscles, tendon and ligament can be damaged due to varied of diseases or injuries and even by aging.

3.4 Sport injuries

Sports injuries are commonly caused by overuse, direct impact, or the application of force that is greater than the body part can structurally withstand. Some of the more common sports injuries include ankle sprain, Knee injuries, Hamstring and Groin strain.

Following a musculoskeletal damage due to sport injuries the proper function of proprioceptive sensors located in soft tissue can be affected leading to deficit of postural control and balance ability.

Proper balance ability requires adequate proactive and reactive postural control responses. Proactive response refers to ability of the body to prepare before an anticipates perturbation like hitting a ball whereas reactive response refers to ability of the body to regain balance after an unexpected perturbation like a compensatory step following a slip or trip.

In regards to motor learning, it is well known that by specific task practicing the reactive automatic response can be learned and improved. Therefore, exposing the athlete to an unexpected perturbation in safe environment is needed to train properly neuromuscular system for optimal postural control and balance ability achievement.

A dedicated proprioceptive rehabilitation program based on both proactive and reactive balance training is needed to regain optimal postural control and balance ability after the injury and reduce significantly recurrent sport injuries.

4 BalanceTutor System

The BalanceTutor by MediTouch is a Perturbation Treadmill that is an innovative system for postural control and balance training. The device consists of a treadmill mounted on a moving force plate platform. The platform moves in medial/ lateral and forward/ backward direction to simulate a slip and a trip in both the standing and walking phase.

An innovative approach using wireless sensors integrated in the BalanceTutor allows for the provision of numerous kinds of controlled expected and unexpected perturbation. These different kinds of perturbation can be generated in relation to the specific phase of the gait namely in stance or swing phase. In addition to controlled expected and unexpected perturbation in the standing and gait, the device also allows for Center of Pressure control practice.

5 Safety

In general, any kind of training on the system requires special attention to the ability and medical condition of the patient. However, the following list highlights particular indications that require specific care in use according to relevant therapy protocols and doctor recommendation and also list of contraindications that the system must not be used.

5.1 Use under special attention

The following list highlights particular indications that require specific attention in use according to relevant therapy protocols, and must be with the approval of a qualified physician/ doctor recommendation:

- Joint instability following surgery or trauma
- Soft tissue damage such as Muscle or ligaments tear
- ACL/PCL restoration of Knee
- Droop foot
- Limb prosthesis
- Joint replacement like Hip, knee and Ankle
- Epilepsy

5.2 Forbidden use – Contraindications

Any kind of medical problems including cardiovascular, mental or physical impairment leading to an inability to use the system are contraindicated for the device. The following contraindications must be taken into account before using of the BalanceTutor:

! Patients who are not able to stand or walk without walk aid devices or external assistance.
! Body weight greater than 135 kg
! Severely fixed contractures
! Bone instability (non-consolidated fractures, unstable spinal column, severe osteoporosis)
! Open skin lesions in the area of the lower limbs and torso
! Unstable circulation
! Cardiac (blood) contraindications
! Uncooperative or (self) aggressive behavior, such as transitory psychotic syndrome
! Severe cognitive deficits
! Patients with (long-term) infusions

! Mechanical ventilation
! Severe vascular disorders of the lower limbs
! In general, patients who have been ordered to remain in bed or immobile

The above list does not claim to be exhaustive. The decision as to whether a patient is suitable for treatment always comes under the remit of the physician in charge, who has sole medical responsibility for the treatment. As part of this, he must evaluate in particular, in each individual case, possible risks and side-effects of the treatment against the benefit gained from it. In addition, the patient's individual situation plays just as important a role as the basic risk assessment for specific patient groups.

Being a scientific discipline, medicine is subject to constant change in response to new knowledge and progress. It is therefore the task of the physician in charge to continually keep his knowledge up to date by reading the latest scientific literature and to acquire new knowledge during the course of treatment.

6 Protocols & Applications

When an unexpected perturbation occurs, Center of Mass (COM) passively moves toward the perturbation's direction. The body needs to react immediately (70-120 ms) to restrain this unplanned COM passive movement. This reactive postural response is intended to stabilize the COM over the Base of Support by returning it back to the initial position or to create new safe BOS for COM using a compensatory step. In these two cases the body tries to move actively to the opposite direction of the applied perturbation.

There are several guidelines in this document that are intended, based on the concept above, to explain how to formulate the appropriate perturbation according to the rehabilitation aims as follows. Furthermore, perturbation can also be triggered at any phase of the gait cycle based on kinetics or kinematics parameters. Based on these guidelines the therapist can customize the treatment as demonstrated in the following protocols:

6.1 Neurological Rehabilitation

Numerous neurological diseases and injuries such as Stroke, Parkinson, Head injuries, Cerebral Palsy, Multiple Sclerosis and Spinal Cord Injuries can be treated by BalanceTutor as detailed in the following paragraphs.

6.1.1 Stroke

Falls are the number one medical complication after acute stroke [1–2]. Furthermore, the high fall risk for individuals with stroke is not only present in the acute phase, but it remains a considerable health concern throughout the poststroke life span. Because the incidence and prevalence of stroke increase as a result of ageing of the population [3] and the prevalence also increases as a result of continued improvement of post-stroke life expectancy [4], the societal impact of falls in stroke is rapidly growing. The impact is primarily related to the physical and psychosocial consequences of falls, which can be devastating. For instance, post stroke individuals are much more likely to sustain a hip fracture due to a fall and more often lose independent mobility and suffer from a higher mortality rate after a hip fracture [5–6]. These findings make falls and their prevention an important issue for every person involved in stroke care (neurologists, physiatrists, physiotherapists, nurses, and also caregivers at home) and all of the post stroke stages.

Both prospective and retrospective studies have consistently reported high fall rates in individuals with stroke. For comparison, in the general population of elderly people, ~30 percent fall at least once a year and ~15 percent fall twice or more [7–9], yielding an incidence rate of ~0.65 falls each person-year [10]. In the limited time that individuals with stroke are admitted in an acute care setting, 3.8 to 22.0 percent of the patients fall at least once [1–2,11], which makes falling the most frequent medical complication during hospitalization after stroke (~40% of all complications). The variability in these fall rates can be attributed at least partly to differences in length of stay. Expressed as fall incidence rates, they vary considerably less between studies, yielding 2.2 to 4.9 falls per person a year [1–2, 11]. Compared with other pathologies, such as congestive heart failure and community-acquired pneumonia, the risk for hospital falls is more than doubled in acute stroke [1]. The incidence rates are remarkably high given the degree of surveillance and the proportion of patients bedridden with, consequently, little exposure to risky situations.

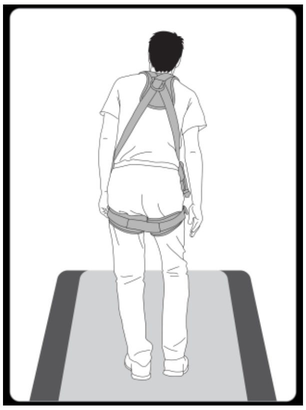
The reported rates of people falling during inpatient rehabilitation range from 10.5 to 47.0 percent [12–24], with 5 to 27 percent of patients falling twice or more [14–16, 18–19]. Patients are most likely to fall during the first 3 weeks of rehabilitation [20–21]. The proportion of fallers as well as fall incidence rates (1.3–6.5 falls each person year) [14–16,18–21] varies considerably between studies, but particularly the incidence rates are, without exception, much higher than in the general population of elderly people.

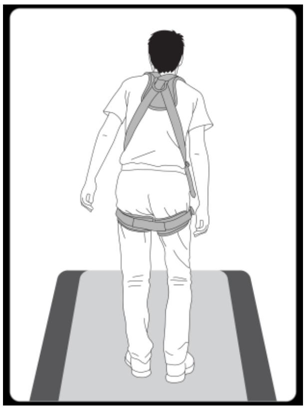
In community dwelling of stroke survivors, fall incidents are very common as well. The proportion of fallers increase as times goes by: 23-34, 40-73 and 43-70 percent for 3-4 month [12, 25], 6-month [17, 26–33], and 1-year follow-up [22, 34–36], respectively. Fallers in the stroke population are also more likely to become repeat fallers in comparison to elderly people in the general population. Most studies report proportions of repeat fallers in stroke populations between 21-57 percent for a 6-12 month period [17, 22, 27–28, 30–36]. Most studies have identified balance and gait deficits as important fall risk factors [17, 19, 27, 29, 31, 33, and 35].

Furthermore, research has suggested that individuals with stroke are more likely to fall when walking as it requires substantial cognitive control (i.e., was less automated), because fallers are more often unable to walk and talk at the same time or slow down when performing a concurrent mental task [28,35,44].

BalanceTutor system allows for several unique reactive response training in both standing and walking using controlled perturbation in simple task or multitask performance as follows:

6.1.1.1 Weight bearing on paretic limb – Medial / Lateral

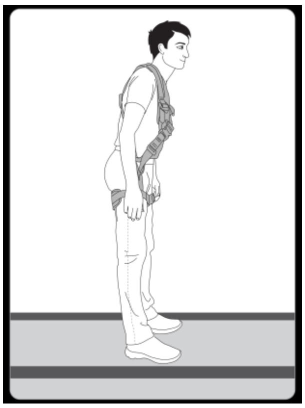


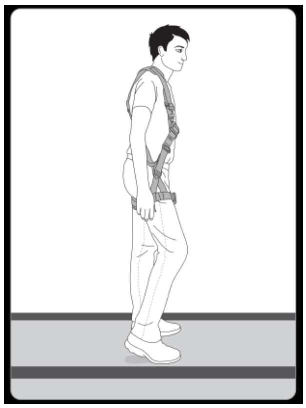


Before perturbation	After perturbation

Patient position:	Standing comfortably with minimal external support
Platform's direction:	moves from healthy to paretic side
Comments:	partial weight bearing - low intensity and full weight bearing - high intensity

6.1.1.2 Weight bearing on paretic limb- Anterior/ Posterior

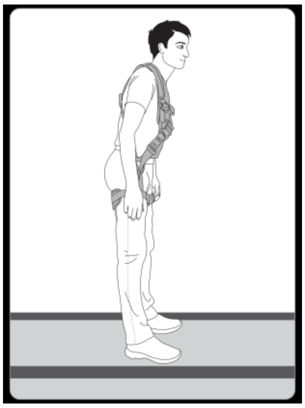
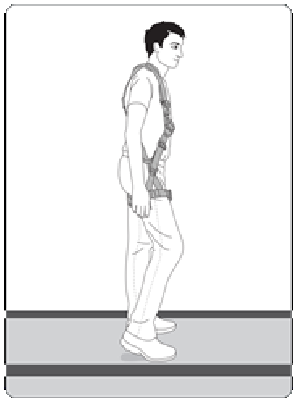




Before perturbation	After perturbation

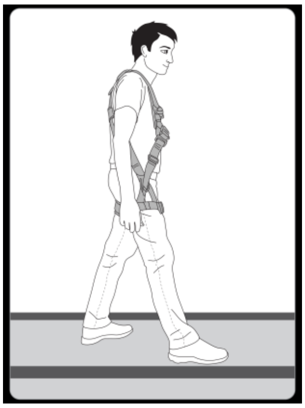
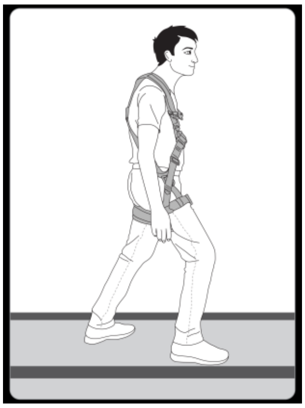
Patient position:	Comfortable forward stance of paretic limb with minimal external support
Platform's direction:	Anterior to posterior
Comments:	partial weight bearing - low intensity and full weight bearing - high intensity

6.1.1.3 Equilibrium training

	
Before perturbation	After perturbation

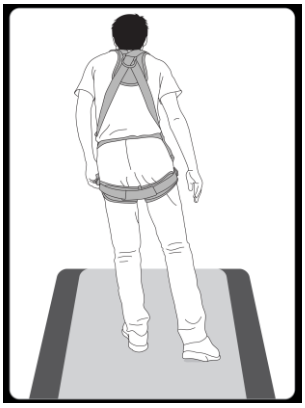
Patient position:	Decreased base of support while standing with minimal external support
Platform's direction:	Anterior to posterior
Comments:	partial weight bearing - low intensity and full weight bearing - high intensity

6.1.1.4 Knee snapping training

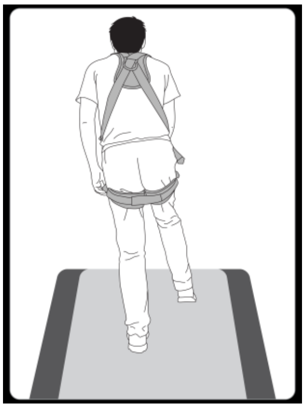
	
Before perturbation	After perturbation

Patient position:	Standing at forward stance with weight bearing on slightly flexed paretic leg
Platform's direction:	posterior to Anterior
Comments:	partial weight bearing - low intensity and full weight bearing - high intensity

6.1.1.5 Compensatory step of paretic leg training



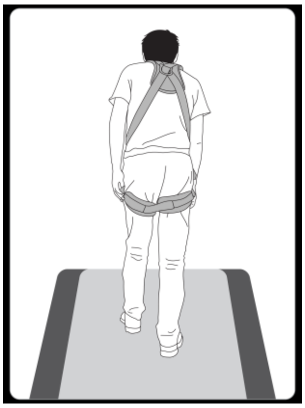
Before perturbation



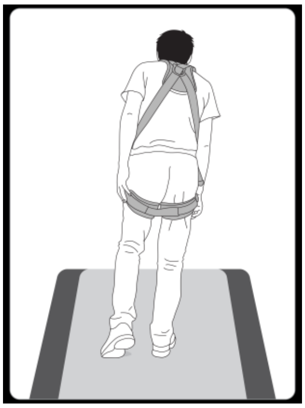
After perturbation

Patient position:	Comfortable walking speed with minimal external support
Platform's direction:	Perturbation at swing phase of paretic leg
Comments:	For early stage of rehabilitation - Medial/ Lateral from healthy to paretic side and for advanced stage of rehabilitation - Medial/ Lateral from paretic to healthy side

6.1.1.6 Stabilization of paretic leg



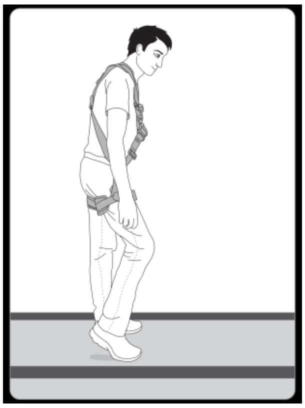
Before perturbation



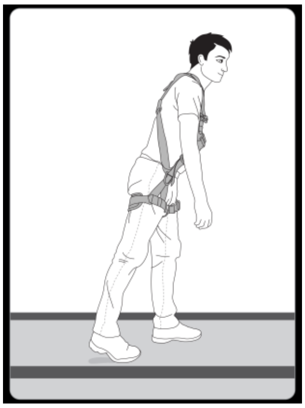
After perturbation

Patient position:	Comfortable walking speed with minimal external support
Platform's direction:	Medial/ Lateral Perturbation at stance phase of paretic leg
Comments:	For early stage of rehabilitation – Medial / Lateral from healthy to paretic side and for advanced stage of rehabilitation – Medial / Lateral from paretic to healthy side

6.1.1.7 Hip extensor muscle strengthening



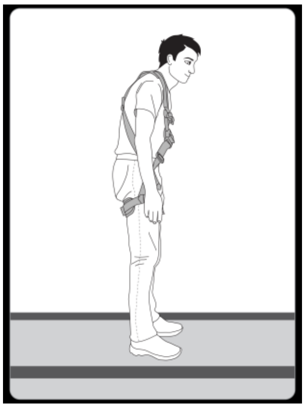
Before perturbation



After perturbation

Patient position:	Standing comfortably with minimal external support
Platform's direction:	posterior to Anterior
Comments:	This treatment can also be used while walking

6.1.1.8 Drop foot training

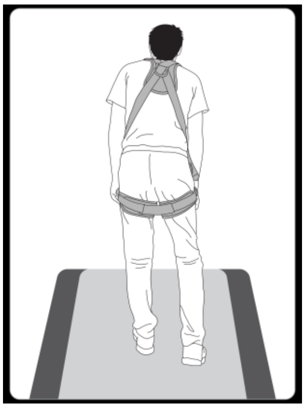


Before perturbation

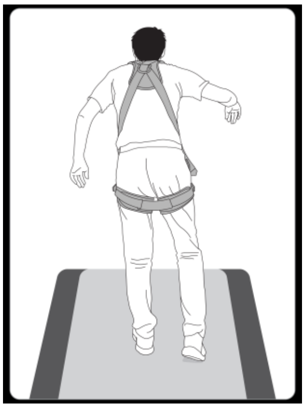
After perturbation

Patient position:	Standing comfortably with minimal external support
Platform's direction:	posterior to Anterior
Comments:	Fast and high level muscle contraction of ankle extensors

6.1.1.9 Unique upper paretic limb muscle activation



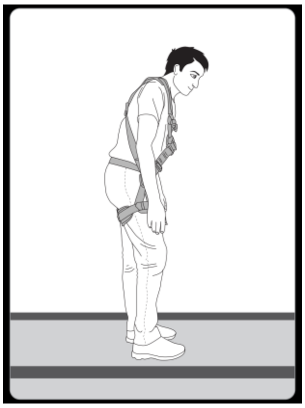
Before perturbation



After perturbation

Patient position:	Standing comfortably with minimal external support
Platform's direction:	Medial / Lateral from healthy to paretic side
Comments:	This technique 'forces' the patient to initiate an active movement of upper limb

6.1.1.10 Neuromuscular coordination



Before perturbation

After perturbation

Patient position:	Comfortable walking speed with minimal external support
Platform's direction:	Medial / Lateral Perturbation at stance and swing phase of paretic leg
Comments:	For early stage of rehabilitation – Medial / Lateral from healthy to paretic side and for advanced stage of rehabilitation – Medial / Lateral from paretic to healthy side

6.1.2 Multiple Sclerosis

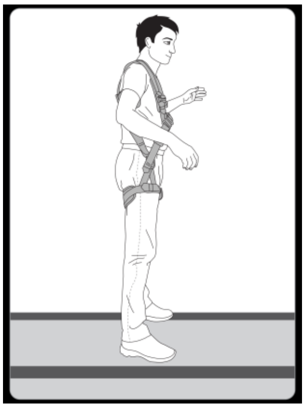
Multiple sclerosis (MS) is a chronic progressive disease and the most common neurologic disease of young adults.

Existing research indicates that people with MS fall frequently [54–56], likely more than the general population [57–59], and more than the elderly, a group in which fall risk [60–16] and its effects are well studied and characterized [62–68]. A cross-sectional study in Italy found that 54 percent (27/50) of their small sample of subjects reported falling at least once and 32 percent (16/50) reported falling twice or more within the previous 2 months [54]. Similarly, another larger cross-sectional study of falls among people with MS aged 45 to 90 years in the United States (n = 1,089) found that 52 percent of subjects reported falling at least once in the previous 6 months [55]. Most recently, the first prospective study of falls among people with MS found that 63 percent of the subjects (48/76) recorded at least one fall and 58 percent (44/76) recorded two or more falls over a 3-month period [56]. Peterson et al. found that, of 354 people with MS aged 55 to 94 years in the United States, more than 50 percent reported receiving medical care for a fall-related injury at least once and 12 percent reported receiving medical care for a fall-related injury in the 6 months before the interview [69]. This potential for fall-related injuries likely contributes to loss of independence (mobility and activities of daily living) as well as reduced length [70] and quality of life [55] for people with MS.

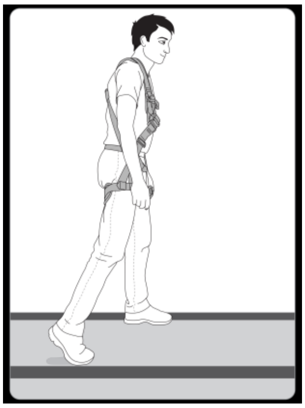
Falls in people with MS have been found to be associated with being male [55–56], impaired balance [54–56], reduced ability to walk [54–56, 72], and use of a cane [54] or other walking aid [56]. In addition, studies have identified disturbed proprioception [56, 72], spasticity [55,72], and more severe MS (higher Expanded Disability Status Scale scores) [56] as risk factors for falls. People with MS also report that divided attention, reduced muscular endurance, fatigue, and heat sensitivity can cause them to fall [72]. Establishing whether individuals with MS have more injurious falls than other groups and identifying high-risk groups with MS is essential to developing effective and meaningful interventions.

BalanceTutor system allows for several unique postural control ability assessments as well as reactive response training in both standing and walking using controlled perturbation in simple task or multitask performance as follows:

6.1.2.1 Gait Ataxia training



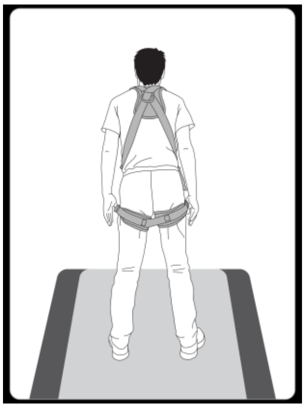
Before perturbation



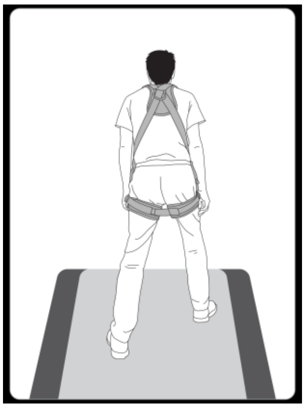
After perturbation

Patient position:	Comfortable walking speed with minimal external support
Platform's direction:	Anterior to posterior
Comments:	Increasing walking speed according to patient ability

6.1.2.2 Dysmetria



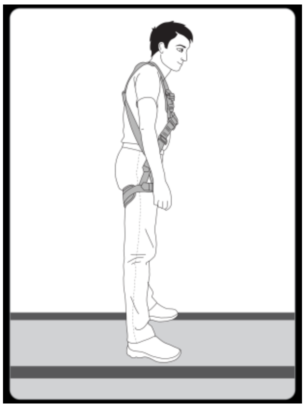
Before perturbation

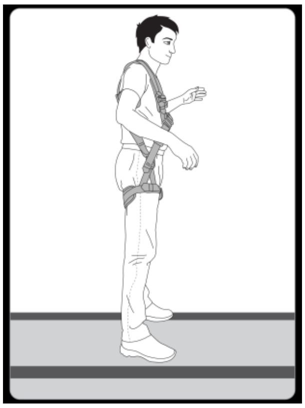


After perturbation

Patient position:	Standing comfortably with minimal external support
Platform's direction:	Medial / Lateral and Anterior/Posterior in four directions
Comments:	Challenging and forcing the patient to react by initiating a compensatory step while walking

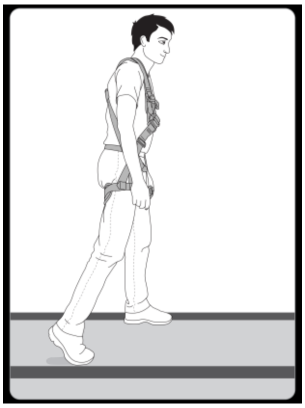
6.1.2.3 Hypertonia


Before perturbation


After perturbation

Patient position:	Standing comfortably with minimal external support
Platform's direction:	Medial/ Lateral and Anterior/Posterior in four directions
Clinical effects:	Mild perturbation in order to a cause ankle and hip balance strategy and improvement of Automatic Postural Adjustment and controlled posture

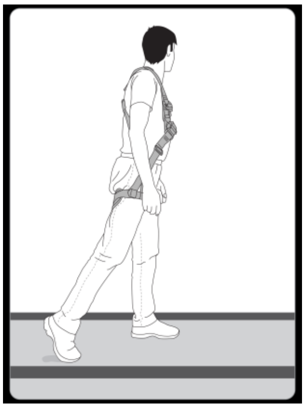
6.1.2.4 Proprioceptive Rehabilitation


Before perturbation

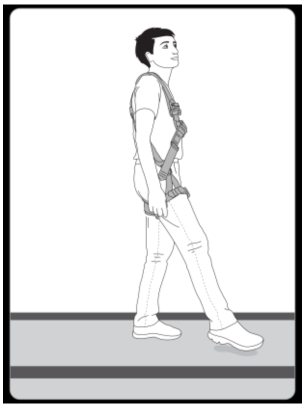

After perturbation

Patient position:	Comfortable walking speed with minimal external support
Platform's direction:	Random utilizing four directions
Comments:	This treatment is suitable while standing and walking with customized mild perturbation

6.1.2.5 Vestibular Ataxia



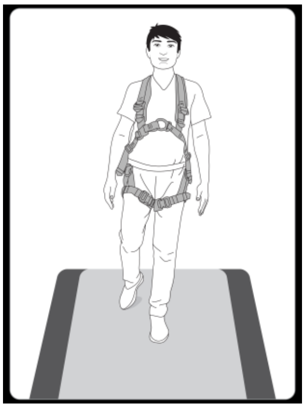
Before perturbation



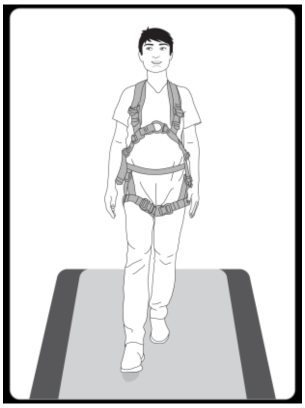
After perturbation

Patient position:	Comfortable walking speed with minimal external support
Platform's direction:	Random utilizing four directions
Comments:	This treatment is suitable while standing and walking with customized mild perturbation with rotation of the head during the treatment

6.1.2.6 Eye Movement Abnormalities



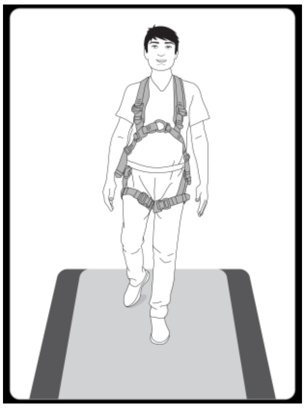
Before perturbation



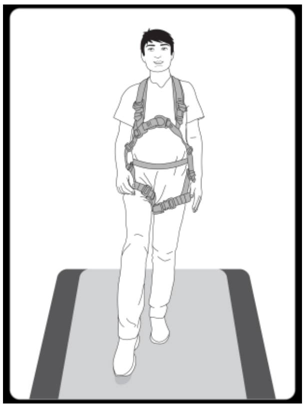
After perturbation

Patient position:	Comfortable walking speed with minimal external support
Platform's direction:	Random utilizing four directions
Comments:	This treatment is suitable while standing and walking with customized mild perturbation with gaze fixation at different targets during the treatment

6.1.2.7 Neuromuscular coordination



Before perturbation



After perturbation

Patient position:	Comfortable walking speed with minimal external support
Platform's direction:	Random utilizing four directions
Clinical effects:	Multi-joint coordination and Coordinated Muscle group activation

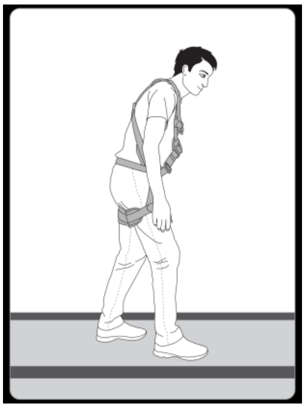
6.1.3 Parkinson's disease

Parkinson's disease (PD) is a chronic and degenerative neurological disorder that leads to performance changes that affect an individual's ability to stay active PD results in severe disability in approximately 1 percent of people over the age of 60 [73–74], including veterans. The Department of Veterans Affairs treats an estimated 40,000 veterans with PD each year [75]. Akinesia, which typically occurs about 10 years after onset [76–77], is one of the most debilitating symptoms of PD. Studies report prevalence of akinesia ranging from 32 [76] to 60 percent [78] among people with PD. Akinesia is noted most prominently in the gait pattern of the person with PD. Akinetic gait is seen as a series of shuffling steps with reduced step length [79–80] and sometimes includes moments when movement ceases completely. These moments are referred to as "frozen gait," which is generally described as feeling as if the feet are glued to the floor [67, 78, and 80]. Freezing is most common in initiating gait, turning, and walking through doorways or narrow spaces [74,76–78,81–82]. In addition to physical location, freezing is influenced by the person's emotions, appearing more frequently in times of distress [81] or when the person is attempting complex tasks, such as doing two things at once [82]. Freezing gait also increases the risk for falls [73– 74, 77, 81]. Gray and Hildebrand examined 118 people with PD and found that freezing is closely linked to reports of falling. Of patients with occasional or frequent episodes of freezing, 80 percent experienced falls". Greater depression and lesser quality of life [83] are also found among those who have a history of falls, gait disturbances, and akinesia and rigidity [84], especially if they subsequently experience further decline in physical mobility, emotional reactions, pain, and social isolation [85]. People with akinesia due to PD often continue to experience gait impairment even with current medical treatments [90,86]. As a result, nonpharmacological approaches are needed for akinesia, including the use of external sensory cues to help the person initiate or maintain movement. People with PD use a wide variety of techniques to overcome akinesia, including being pushed, marching to a cadence, rocking the body, walking over objects, and walking to music, but over time these strategies lose effectiveness [87].

BalanceTutor system allows for several unique postural control ability assessments as well as reactive response training in both standing and walking using controlled perturbation in simple task or multitask performance as follows:

6.1.3.1 Abnormal gait characteristics - Step forward initiation

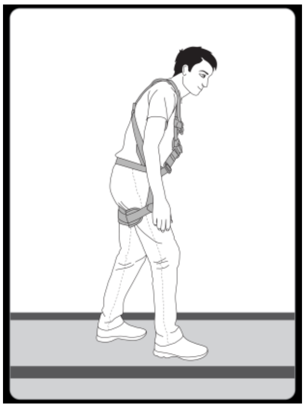
Before perturbation



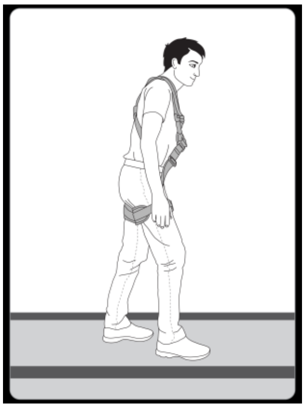
After perturbation

Patient position:	Standing comfortably with minimal external support
Platform’s direction:	Anterior to posterior
Clinical effects:	Forward step initiation as part of gait training

6.1.3.2 Abnormal gait characteristics - stopping after starting



Before perturbation

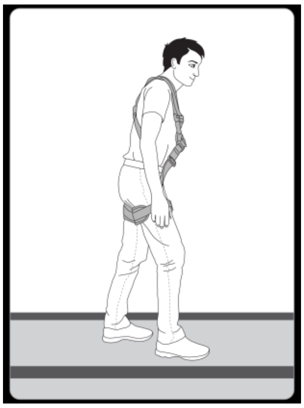


After perturbation

Patient position:	Comfortable walking speed with minimal external support
Platform's direction:	Anterior to posterior
Comments:	This treatment is also recommended to be practiced while standing

6.1.3.3 Abnormal gait characteristics - shuffling steps

Before perturbation

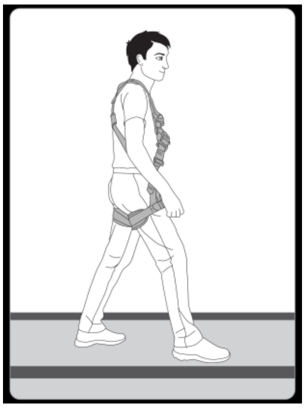


After perturbation

Patient position:	Comfortable walking speed with minimal external support
Platform's direction:	Anterior to posterior
Comments:	Prolonged period of time at accelerated speed to Improve of stride length

6.1.3.4 Abnormal gait characteristics - Freezing of Gait

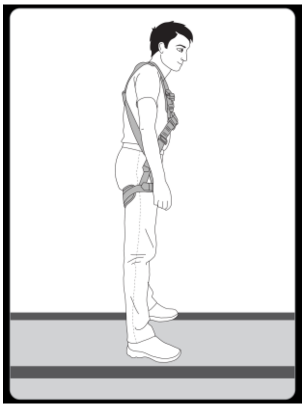
Before perturbation



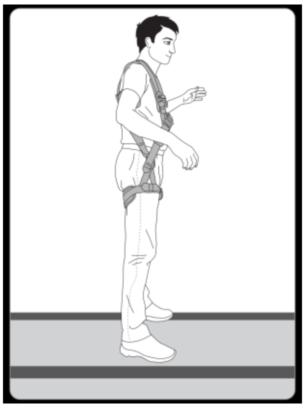
After perturbation

Patient position:	Comfortable walking speed with minimal external support
Platform's direction:	Anterior to posterior
Comments:	Minimal period of time at highly accelerated perturbation in various walking speed

6.1.3.5 Falls Prevention - Equilibrium



Before perturbation

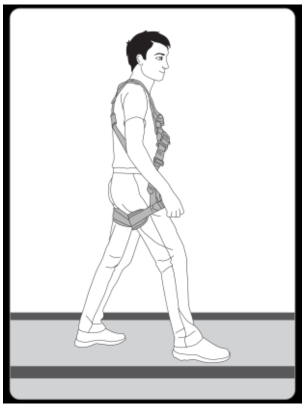


After perturbation

Patient position:	Standing comfortably with minimal external support
Platform's direction:	Medial/ Lateral
Comments:	Mild perturbation in order to a cause ankle and hip balance strategy while standing or walking

6.1.3.6 Falls prevention - Balance

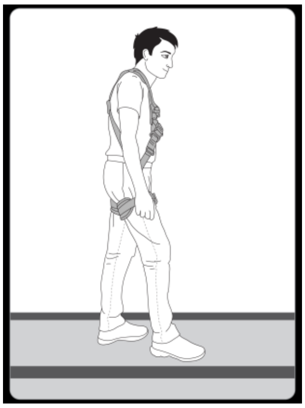
Before perturbation



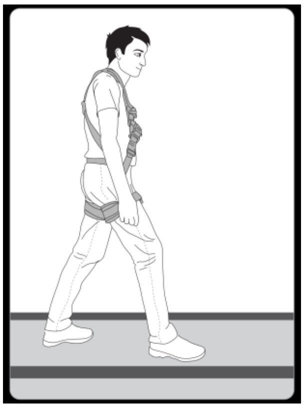
After perturbation

Patient position:	Comfortable walking speed with minimal external support
Platform's direction:	Medial/ Lateral
Comments:	Customized challenge forcing the initiation of a compensatory step while standing or walking

6.1.3.7 Increase walking speed



Before perturbation

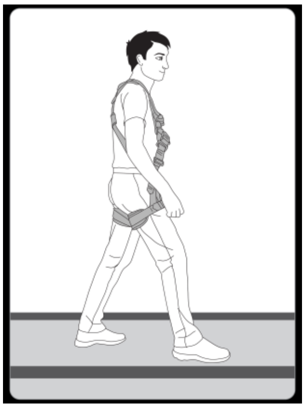


After perturbation

Patient position:	Comfortable walking speed with minimal external support
Platform's direction:	Anterior to posterior
Comments:	Increasing walking speed- Challenging the patient to reach max ability

6.1.3.8 Abnormal gait characteristics - Neuromuscular coordination

Before perturbation



After perturbation

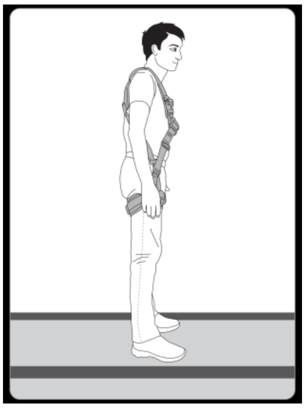
Patient position:	Comfortable walking speed with minimal external support
Platform's direction:	Random utilizing four directions
Comments:	Coordination of joint movements and muscle activation

6.2 Falls Prevention

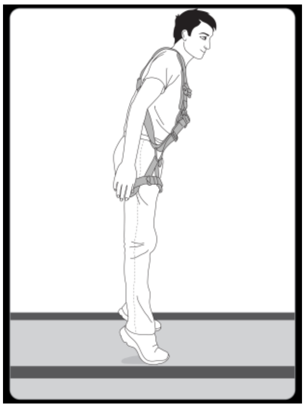
Falls are a major problem among elderly population; they are the leading cause of injury above the age of 65 [88]. Of those who fall in the U.S., 20 to 30 % suffer moderate to severe injuries that reduce mobility and independence, and increase the risk of death [89]. The financial impact in 2000, adjusted for inflation, was $30 billion and is expected to reach $67.7 billion by 2020 [88]. Walking is the major activity in which large proportion of falls in older adults occurs [90]. Sixty percent of outdoor falls among older adults resulted from slips or trips [91]. Even among older adults capable of independent walking, there could be a substantial decline in balance performance, which does not become evident until a slip or a trip happens [92]. In fact, the inability to step rapidly in response to unexpected loss of balance ultimately determines whether a fall occurs [93, 94]. Thus, a better way to improve balance, improve stepping and reduce risk of falls may be to direct preventive efforts towards older adults who have not yet fallen. Until recently, these balance recovery responses were considered hardwired postural reflexes that could not be influenced by training. However, [95–97] it was showed that older adults were able to adapt in a reactive manner after participation in a perturbation exercises that challenged the mechanisms responsible for dynamic stability (i.e., increase in base of support and counter-rotating segments around the center of mass). A number of studies have begun to examine the effect of perturbation training on balance of older adults. Shimada et al. [98] found improvement in mobility and a trend to fall reduction after split treadmill training. This training method is a very unnatural condition, given that most people walk with the same velocity in each leg. Other studies have other issues. Pai et al. [99] showed a rapid decrease in loss of balance in response to multiple presentations of a slip perturbation after rising from sit to stand. Mansfield et al [100] found that older adults with a history of falls or instability reduced the frequency of multi-step reactions and foot collisions after perturbation training while standing or walking in place. The training methods perturb the balance of their participants from sit to stand or during standing or walking in place, which may not be as relevant in a natural setting as might be a perturbation while walking. Melzer and Oddsson [101] found improvement in voluntary stepping, and balance control, in an exercises program that incorporate mild external balance perturbation exercises applied by the instructors; and Halvarsson et al. [102] found that old fallers that suffered from fear of falling, decreased their fear of falling, and voluntary stepping times during dual-task performance and increased velocity of walking post perturbation training.. However, in these program the perturbations of posture were expected, and not random. Recently it was showed that unidirectional translational treadmill training (i.e., a laboratory induced trip) reduced falls [103, 104]. Bhatt et al. [105] found that inducing unannounced right-leg slips, participants significantly reduced fall and balance loss incidence. Pai, et al. [106] found that a single session of repeated-slip exposure reduced older adults' annual risk of falls from 34 to 15 % ($p < 0.05$) especially among those who had history of falls. The above protocol provided an anterior perturbation, causing a backwards "slip" initiated always by on the right foot. Participants might have learned and expected the right-leg slips perturbations. In a recent meta-analysis [107] that include 8 perturbation-based balance training studies (n = 404) participants reported fewer falls than those in the control groups. Motivated by the above perturbations training studies and trying to accommodate for some of the issues mentioned above (i.e., perturbation training while standing or walking in place; highly predictable repeated-right leg slip exposure; a very unnatural walking on split treadmill), we aimed to explore whether unexpected multidirectional perturbation training while walking on a treadmill [108] can reduce risks of falls in independent older adults. A perturbation exercise while walking provides a more realistic balance training that is sufficiently task-specific so that responses on this training regime will be more likely to be transferred to other measures of balance control and voluntary stepping measures. Exposure to a gait training program that includes unexpected perturbations exercises during walking will significantly improve voluntary stepping times as well as balance control in older adults, two factors that are associated with falls and injuries related with falls [109–114]. Perturbation exercises that will challenge both balance control during walking as well as trigger a quick stepping responses to avoid fall during walking. This postural response following an external perturbation receives a higher priority than a voluntary action thus can be incorporated into centrally programmed voluntary movements [115]. This concept should be of importance for balance training and it further supports the notion that postural perturbations should be incorporated into balance training programs.

BalanceTutor system allows for several unique postural control ability assessments as well as reactive response training in both standing and walking using controlled perturbation in simple task or multitask performance as follows:

6.2.1 Forward automatic postural response



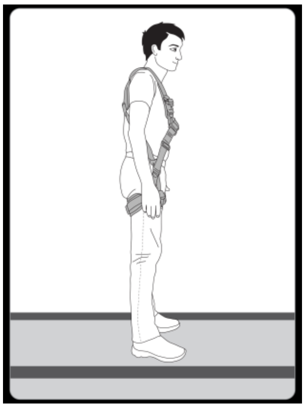
Before perturbation



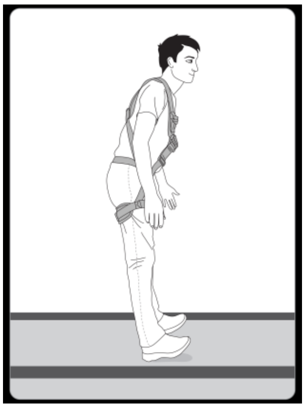
After perturbation

Patient position:	Standing comfortably
Platform's direction:	Anterior to Posterior
Clinical effects:	Fast and highly intensive activation of lower limb flexors muscles

6.2.2 Backward automatic postural response



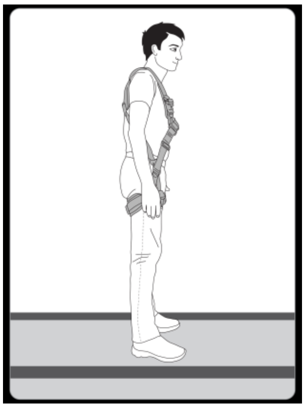
Before perturbation



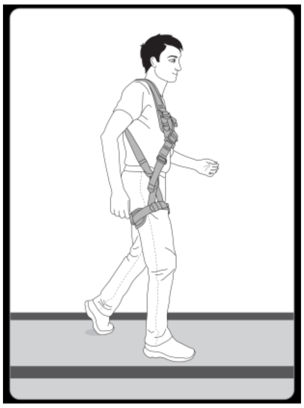
After perturbation

Patient position:	Standing comfortably
Platform's direction:	Posterior to Anterior
Clinical effects:	Fast and highly intensive activation of Lower limb extensors muscles

6.2.3 Left side automatic postural response



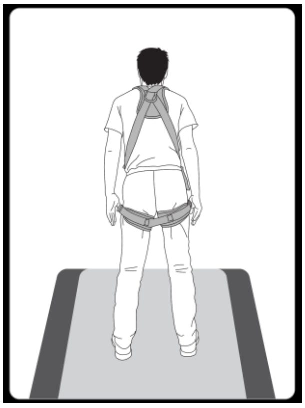
Before perturbation

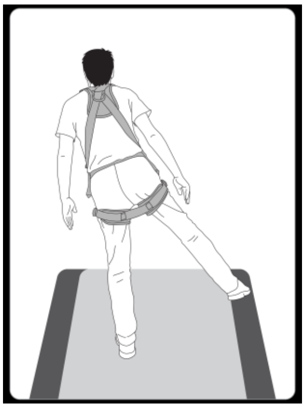


After perturbation

Patient position:	Standing comfortably
Platform's direction:	Medial to Lateral
Clinical effects:	Fast and highly intensive activation of Left limb

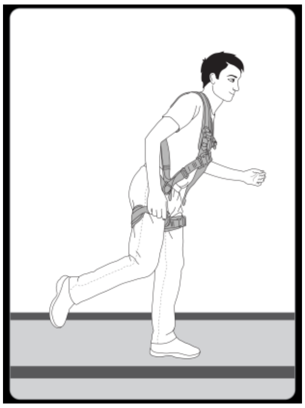
6.2.4 Right side automatic postural response

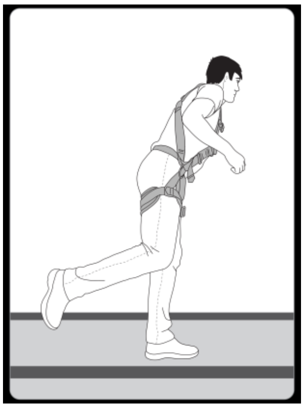

Before perturbation


After perturbation

Patient position:	Standing comfortably
Platform's direction:	Lateral to Medial
Clinical effects:	Fast and highly intensive activation of Right limb

6.2.5 Dynamic balance training


Before perturbation


After perturbation

Patient position:	Walking or running
Platform's direction:	Random Multi-Direction perturbation
Clinical effects:	Faster compensatory step Improvement of Recovery time

6.3 Orthopedic and Sport Rehabilitation

Rehabilitation continues to evolve with the increased emphasis on patient management and proprioceptive training. Proprioception can be defined as a specialized variation of the sensory modality of touch that encompasses the sensation of joint movement (kinesthesia) and joint position (joint position sense). Numerous investigators have observed that afferent feedback to the brain and spinal pathways is mediated by skin, articular, and muscle mechanoreceptors. Examining the effects of ligamentous injury, surgical intervention, and proprioceptive mediated activities in the rehabilitation program provides an understanding of the complexity of this system responsible for motor control. It appears that this neuromuscular feedback mechanism becomes interrupted with injury and abnormalities, and approaches restoration after surgical intervention and rehabilitation. Rehabilitation programs should be designed to include a proprioceptive component that addresses the following three levels of motor control: spinal reflexes, cognitive programming, and brainstem activity. Such a program is highly recommended to promote dynamic joint and functional stability. Thus far, current knowledge regarding the basic science and clinical application of proprioception has led the profession of sports medicine one step closer to its ultimate goal of restoring function. The proper management of athletic-related injuries and orthopedic lesions can be complex in the sports medicine settings. One of the most challenging aspects to the clinician is the understanding the role of proprioceptively mediated neuromuscular control after joint injury and its restoration through rehabilitation. Proprioception contributes to the motor programming for neuromuscular control required for precision movements and also contributes to muscle reflex, providing dynamic joint stability. The coupling effect of ligamentous trauma resulting in mechanical instability and proprioceptive deficits contributes to functional instability, which could ultimately lead to further micro trauma and occurrence of re-injury. Improvement of functional and sport-specific activities after musculoskeletal trauma and rehabilitation can be enhanced significantly if proprioception is addressed and introduced early in the treatment program. In addition to the mechanical restraint provided by articular structures, it has been observed that ligaments provide neurologic feedback that directly mediates reflex muscular stabilization around the joint. The inclusion of proprioception in the rehabilitation program should be based on the preceding findings and not on anecdotal evidence without an understanding of the neuromuscular mechanism. This understanding, coupled with a base of knowledge regarding the current research on proprioception, is necessary for sports medicine practitioners to optimize treatment programs for athletes. Numerous researchers have provided definitions regarding the terminology of joint sensation, or proprioception and kinesthesia [118,141].

Most contemporary authorities define proprioception as a specialized variation of the sensory modality of touch that encompasses the sensation of joint movement (kinesthesia) and joint position (joint position sense). The sensory receptors for proprioception that are found in the skin, muscles, and joints as well as in ligaments and tendons all provide input to the central nervous system (CNS) regarding tissue deformation [130]. Visual and vestibular centers also contribute afferent information to the CNS regarding body position and balance [148]. Trauma to tissues, that contain mechanoreceptors, may result in partial differentiation, which can lead to proprioceptive deficits. Susceptibility to re-injury, therefore, becomes a realistic possibility because of this decrease in proprioceptive feedback. However, studies have shown at least partial restoration of kinesthesia and joint position sense in surgically reconstructed shoulders and knees after rehabilitation [139,140]. Regaining neuromuscular control after injury or surgery is a necessary prerequisite for athletes wishing to return to competition. The neural input that is provided by the peripheral mechanoreceptors as well as the visual and vestibular receptors are all integrated by the CNS to generate a motor response. These responses generally fall under three levels of motor control: spinal reflexes, cognitive programming, and brainstem activity. In a situation where a joint is placed under mechanical loading, reflex muscular stabilization is stimulated through the spinal reflexes[132]. Cognitive programming that involves the highest level of CNS function (motor cortex, basal ganglia, and the cerebellum refers to voluntary movements that are repeated and stored as central commands. This awareness of body position and movement allows various skills to be performed without continuous reference to consciousness [148]. As defined earlier, proprioceptive feedback plays a major role in the conscious and unconscious awareness of a joint or limb in motion. The concept of proprioception is based on the fact that neural feedback to the CNS is mediated by cutaneous, muscle and joint mechanoreceptors. When examining the neural composition of joints, Hilton's law states that joints are innervated by articular branches of the nerves supplying the muscles that cross the joint[134]. In addition to proprioceptive mechanoreceptors, articular structures also include nociceptive free nerve endings. Activation of joint mechanoreceptors are triggered by the deformation and loading of the soft tissues that compose the joint. This neural stimulation travels to the CNS for integration via cortical and reflex pathways. These mechanoreceptors demonstrate adaptive properties depending on a particular stimulus [130]. Quick-adapting joint mechanoreceptors, such as the Pacinian corpuscles, decrease their discharge rate to extinction within milliseconds of the onset of a continuous stimulus. The Ruffini ending, Ruffini corpuscles, and the Golgi tendon-like organs that are referred to as the slow adapting mechanoreceptors, continue their discharge in response to a continuous stimulus [130]. The properties of the quick-adapting mechanoreceptors lead to the notion that they mediate the sensation of joint motion because they are very sensitive to changes in position. Muscular mechanoreceptors and Ruffini ending joint receptors are slow adapting mechanoreceptors and are thought to mediate the sensation of joint position and changes in position because they are maximally stimulated at specific joint angles. One form of the slow-adapting receptors is the complex, fusiform muscle spindle receptors found within skeletal muscle. The muscle spindle receptor functions to measure muscle tension over a large range of extrafusal muscle length. It has been suggested that muscle and joint mechanoreceptors are complementary to each other in providing afferent input in regard to limb position [130].

This relationship between muscle and joint mechanoreceptors has been supported by the identification of the neural components necessary for the sensation of motion (rapidly adapting receptors, e.g., Pacinian corpuscles), joint position and acceleration (slow-adapting receptors, e.g., Ruffini endings and Ruffini corpuscles), and pain (free nerve endings) within ligamentous, cartilaginous, and muscular structures of the joints.

The spindle receptors found within the muscle are composed of a small bundle of modified muscle fibers called intrafusal fibers, to which the endings of several sensory nerves are attached. The extrafusal fibers that form the bulk of the muscle are responsible for generating force and are innervated by the alpha-motor neurons whereas the intrafusal fibers are innervated by the gamma-motor neurons. In the case of muscle contraction, alpha-gamma co-activation is believed to be the mechanism through which muscle length and tension are monitored. Activation of gamma-motor neurons allows the readjustment of spindle sensitivity in the case where extrafusal fibers are shortened. This allows the spindles to be functional at all times during a contraction. When a muscle is loaded beyond an anticipated level, intrafusal fiber shortening occurs to a greater degree than extrafusal shortening. Stretching of the spindles in the central region causes a burst of excitatory postsynaptic potentials from spindle afferents. These signals summate with the alpha-motor neurons from descending pathways, thereby increasing force production [142].

With respect to changes in muscle and tendon tension, the Golgi tendon organs function as a protective mechanism. The Golgi tendon organs are located within the tendons of the muscle and are recruited when muscle contraction pulls on the tendon, which straightens the collagen bundles and distorts the receptor endings of the afferent neurons[142].

This distortion increases the discharge rate of action potentials of these receptors that travel and synapse on spinal interneurons that project to motor neurons. Increased activity of the Golgi tendon organ afferents result in the inhibition of the motor neurons innervating the muscles that were stretched while exciting the motor nerves of the antagonistic muscles.

Studies have demonstrated the detrimental effect on reflex joint stabilization as a result of joint injury [145,146]. The contribution of musculotendinous receptors over joint receptors to the proprioceptive reflex remains a controversial issue in the literature.

Clinical application of proprioception research findings must be achieved at various levels of care for the management of orthopedic lesions. A thorough understanding of proprioception assessment techniques will aid the clinician and orthopedic surgeon to apply what is currently known concerning the no traumatized joint to muscular, ligamentous, and cartilaginous injury. Establishing the effects of musculoskeletal trauma on joint position sensibility and neuromuscular control assists the need for critical decision-making regarding the appropriateness of various forms of treatment. From this point, it is known that surgical intervention plays an important role in the restoration of mechanical joint stability but its effects on proprioception pathways require further clarification. Finally, rehabilitation activities incorporating principles that stimulate the different levels of motor control to facilitate the return to function should be examined not only for its theoretical basis but also for its practical applicability.

The assessment of neuromuscular control includes the measurement of cortical, spinal reflex, and brainstem pathways. The evaluation of this complex neuromuscular system as different components allows a more detailed explanation of afferent control mechanisms. As defined previously, kinesthesia and joint position sense are components of proprioception. Functionally, kinesthesia is assessed by measuring threshold to detection of passive motion while joint position sense is assessed by measuring reproduction of passive positioning and reproduction of active positioning. When tested at a slow angular velocity (0.5 to 2 deg/sec), threshold to detection of passive motion as well as the reproduction of passive positioning is thought to selectively stimulate Ruffini or Golgi-type mechanoreceptors. Because the test is performed passively, it is believed to maximally stimulate joint receptors, thereby relying on the cortical pathway in the neuromuscular control system. After ligament lesions, passive joint sensibility testing is often chosen to assess afferent activity because muscle activity is negated. Stimulation of both joint and muscle receptors is done by the reproduction of active positioning, which provides a more functional assessment of the afferent pathways. The evaluation of reflex capabilities is often assessed by measuring the latency of muscular activation to involuntary perturbation via Electromyography interpretation. The ability to quantify the sequencing of muscle firing can provide a valuable tool for the assessment of asynchronous neuromuscular activation patterns that may predispose an articulation to overuse trauma.

Functional assessment of the combined peripheral, vestibular, and visual contributions to neuromuscular control is best accomplished through the use of balance and postural sway measurements for the lower extremity. The availability of stabilometric methods and instrumentation can provide a relatively accurate index for these measures.

To reiterate this understanding of the proprioception mechanism, the clinician must apply the available knowledge to try to delineate the effects of orthopedic injury, surgical reconstruction, and rehabilitation on the various afferent pathways. Specifically, clinical research aimed at determining the effects of injury, surgery, and rehabilitation on joint position sensibility, neuromuscular control as well as balance and postural sway can provide a solid foundation for the development of a testing model for the knee, ankle, and shoulder that attempt to address these issues.

Numerous studies have been performed that examined the role of proprioception in the knee joint. It has been found that damage to articular structures, such as the ACL and meniscus, in addition to osteoarthritic changes disrupts articular structures containing mechanoreceptors. The disruption in the cortical pathway, therefore, results in an alteration in joint position sense and kinesthesia. Barrack et al. ~ and Skinner et al[143].observed decreased kinesthesia with increasing age and ACL disruption. Joint position sensibility decrements have also been documented as a result of osteoarthritic changes in the knee[117].

Deficits in the neuromuscular reflex pathway may have a detrimental effect on this motor control system's role as a protective mechanism in acute knee injury. The initiation of the reflex arc stimulated by mechanoreceptors and muscle spindle receptors occurs at a faster rate than signals induced by nociceptors (70 to 100 m/sec versus 1 m/sec) [130]. This suggests that proprioception may play a more significant role than pain impulses in preventing injury in the acute setting. However, the incidence of reinjury and the cause of chronic injuries may be attributed, to a greater extent, to proprioceptive deficits. These deficits may be induced by partial deafferentation as a result of initial knee injury and may also contribute to chronic joint disease through a decrease in joint afferents. This phenomenon has been observed by Beard et a1 [120].in subjects with arthroscopically confirmed ACL deficiency. A significant deficit in reflex activation of the hamstring muscles after a 100 N anterior shear force in a single legged closed kinetic chain position was identified, as compared with the contralateral uninjured limb.5 Furthermore, Solomonow et al [145].found that a direct stress applied to the ACL resulted in reflex hamstring activity, thereby contributing to the maintenance of joint integrity.

Although Barrack et al [116].demonstrated a proprioceptive deficit after ACL disruption, it appears that kinesthetic awareness may be partially restored after ACL reconstruction. Kinesthesia has been reported to be restored after surgery as detected by the threshold to the detection of passive motion in the midrange of motion (45°).~ However, a longer threshold to the detection of passive motion was observed in the ACL reconstructed knee compared with the contralateral uninvolved knee when tested at 15° of flexion. Lephart et a1[139]. found similar results in patients after either arthroscopically assisted patellar-tendon autograft or allograft ACL reconstruction. This evidence suggests that kinesthesia may have returned in the midrange of motion after ACL reconstruction and appears to be more sensitive in the near-terminal range of motion. The importance of incorporating a proprioceptive element in any comprehensive rehabilitation program is justified based on the results of these studies. Proprioceptive deficits may predispose an athlete to reinjury through decrements in the neuromuscular pathways resulting in the inhibition of complete rehabilitation.

Chronic ankle instability as a result of partial deafferentation of articular mechanoreceptors with joint injury was first postulated by Freeman et al.1o They observed that a decrease in the ability to maintain a one-legged stance occurred in the sprained ankle versus the contralateral uninjured ankle. The effect of unilateral ankle sprains on cortical pathway measures of proprioception have been investigated by Garn and Newton, [127] who measured the ability of a subject to properly sense a passive movement or no movement state in the sagittal plane. Deficits in the ability to actively replicate passive ankle and foot positioning in this plane was reported by Glencross and Thornton [128] while testing the sprained ankle versus the contralateral uninjured ankle. Gross [131] recently reported that an increased probability of reinjury occurs as a result of a decrease in sensory input from joint receptors, leading to abnormal body positioning and diminished postural reflex responses. It was also found by Konradsen and Ravn [136] that chronic ankle instability resulted in a prolonged peroneal reaction time in response to a sudden inversion stress when compared with agematched controls. Partial deafferentation resulting in diminished reflex joint stabilization may contribute to these findings.

The development of high technologic systems to assess the effects of musculoskeletal injury on balance has occurred in an attempt to quantify both static and dynamic components of proprioception. [133] The method of evaluation is based on the notion that damage to joint proprioceptors after injury to the lateral ligamentous complex of the ankle diminishes afferent feedback from the injured joint, thereby resulting in increases in postural sway[125].
To date, however, documented evidence exists concerning the alterations in postural sway after ankle injury using subjective evaluation (i.e., Romberg test). No increases in postural sway were observed by Tropp and Odenrick [147] when comparing a group of soccer players with previous ankle sprains to a control group of uninjured soccer players. Furthermore, no differences in postural sway were found between the involved and uninvolved ankles in a group of soccer players with a history of unilateral, recurrent ankle sprains. [147].

However, significant increases in postural sway were observed by Cornwall and Murrell[123] when comparing patients with acute ankle sprains with uninjured controls as long as 2 years after their injuries.

The effects of surgical reconstruction for functional ankle instability on proprioception pathways as measured through joint position sensibility or balance and postural sway assessments have not yet been thoroughly investigated. Empirical evidence exists suggesting that proprioceptive training techniques after acute and chronic ankle injuries are highly effective. In addition, ankle wrapping and bracing have also been suggested to have a proprioceptive benefit. However, this notion remains untested and, therefore, unproven.

The objectives of proprioceptive rehabilitation are to retrain altered afferent pathways to enhance the sensation of joint movement. Proprioceptively mediated neuromuscular control of joints takes into account three distinct levels of motor activation within the CNS. Reflexes at the spinal level mediate movement patterns that are received from higher levels of the nervous system. This action provides for reflex joint stabilization during conditions of abnormal stress about the articulation and has significant implications for rehabilitation.2° The use of exercises that facilitate dynamic joint stabilization may result in the improvement of this neuromuscular mechanism. The second level of motor control, located within the brainstem, receives input from joint mechanoreceptors, vestibular centers, and visual input from the eyes to maintain posture and balance of the body. Reactive neuromuscular activities that allow this pathway to process input from the aforementioned forms of afferent stimuli can be used to enhance brainstem function.

The highest level of CNS function (motor cortex, basal ganglia, and cerebellum) provides cognitive awareness of body position and movement in which motor commands are initiated for voluntary movements. Use of the cortical pathway allows movements that are repeated and stored as central commands to be performed without continuous reference to consciousness. Kinesthetic and proprioception training are such types of activity that can enhance this function.

Incorporating the three levels of motor control into activities to address proprioceptive deficiencies should be initiated early during the rehabilitation process [138]. Encouraging maximum afferent discharge to the respective CNS level must be the goal in stimulating joint and muscle receptors. [148]. To stimulate reflex joint stabilization, which emanates from the spinal cord, activities should focus on sudden alterations in joint positioning that necessitate reflex neuromuscular control. Enhancing motor function at the brainstem level can be achieved by performing balance and postural activities, both with and without visual input. Maximally stimulating the conversion of conscious to unconscious motor programming can be achieved by performing joint positioning activities, especially at joint end ranges. [148]. Simple tasks such as balance training and joint repositioning should begin early in the rehabilitation program and should become increasingly more difficult as the patient progresses. Regaining joint sense awareness to initiate muscular reflex stabilization to prevent reinjure should be the primary objective once the final stage of rehabilitation is reached. Some contemporary authors believe that adaptations that occur during rehabilitation are related to (mediated by) feed-forward processing and are less a function of enhanced afferent pathways [137]. This theory suggests that fast movements are controlled by advance information known about the task, while concurrent proprioceptive feedback is relatively less important. Feedback is used primarily at the cortical level to determine the success or failure of that movement and to a lesser extent at the subcortical level for directing the movement. With repetition, the cerebral cortex can determine the most effective motor pattern for a given task, based on the proprioceptive information of previous attempts [137]. Biofeedback training appears to use the feed-forward learning process. However, there is still controversy regarding the contribution of afferent feedback in feed-forward processing. In order to achieve optimum rehabilitation the trainer has to accurately target and customize the practice to joint stability. Joint stability relies of neuromuscular coordination which in turn is dependent on proper proprioception function. This therefore singles out rehabilitation of the proprioception system as an important target during rehabilitation.

Exercises that focus on proprioceptive rehabilitation will improve postural control and balance ability. There are two main methods that target will result in an improvement in the target the In order to improve proprioception function balance practice and postural control training customized to the level of joint stabilization needs to be implemented.

Traditional balance practice works through anticipatory exercises. response ability so as to afford neuromuscular reeducation in all rehabilitation stages, covering both the inner and outer limits of ability from injury to return to play. In addition the practice has to be specific enough so that increments in difficulty levels do not lead to further injury.

Traditional rehabilitation relies on the use of proactive postural control practice. This means joint stabilization is performed as a result of a proactive movement in the body's center of mass. The trainer's ability to customize the practice is limited by both the limits and the specificity of the practice.

Perturbation is the introduction of an unexpected event that actively moves the body's centre of mass. Perturbation elicits a reactive or anticipatory postural control reflex like movement. Reactive response training enforces the use of selective co-contraction patterns which keeps the joint within its physiological range of motion and avoids injury.

In order to better understand how anticipatory postural control practice more effectively targets proprioception a brief recap in the role of type I and type II mechanoreceptors is needed.

Type I mechanoreceptors have a low threshold and slow adaptation and are involved in proactive postural control. Type II mechanoreceptors have a low threshold and rapid adaptation and are more involved in responding to rapid unexpected joint destabilization elicited by perturbation and reactive postural control.

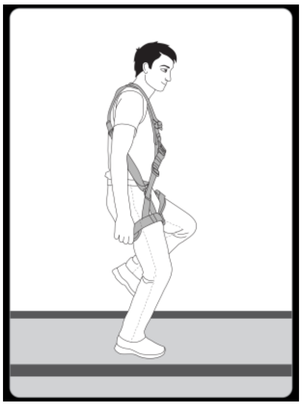
In order to avoid recurrent injury caused by a sudden perturbation to postural control it is important to train for this eventuality by practicing movements that safely require the input from type I and type II mechanoreceptors are necessary to avoid injury train for co-contraction It is also important Reactive response training by eliciting reactive response to perturbation both type I and Type II mechanoreceptors are forced to work and the proprioception system is optimized.

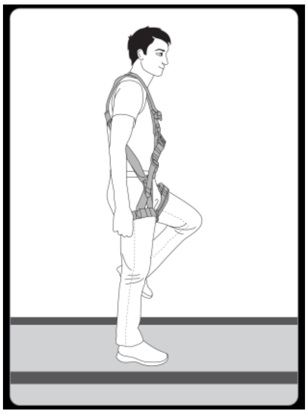
Proprioceptive system relies on wide spectrum and high resolution sensation using different types of specific Mechanoreceptors dealing with both expected and also following an ankle sprain, part of this specific mechanoreceptors mainly oriented rapid unexpected perturbation detectors at the earliest stage of the sprain event are damaged leading to recurrent ankle sprain.

At high ability level the use of reactive training will initiate the of type II mechanoreceptors which are necessary for reactive postural control. A higher level of reactive postural control ability and more efficient use of type II mechanoreceptors will decrease the risk of recurrent injury.

BalanceTutor system allows for several unique postural control ability assessments as well as proprioceptive rehabilitation using reactive response training in both standing and walking using controlled perturbation in simple task or multitask performance as follows:

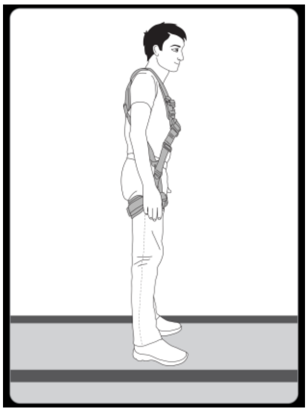
6.3.1.1 ACL Rehabilitation

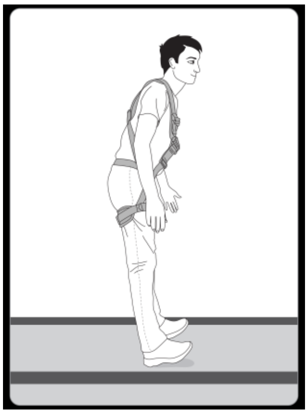

Before perturbation


After perturbation

Patient position:	Standing on injured leg with knee slightly bent
Platform's direction:	Anterior/ posterior
Clinical effects:	Fast and Highly Intensive activation of Knee muscles Use of ACL Proprioceptive and Kinesthesis abilities at maximum capacity Accurate and Fast Quadriceps and Hamstrings Coordination

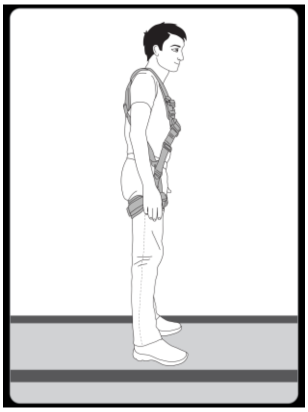
6.3.1.2 Ankle extension Rehabilitation

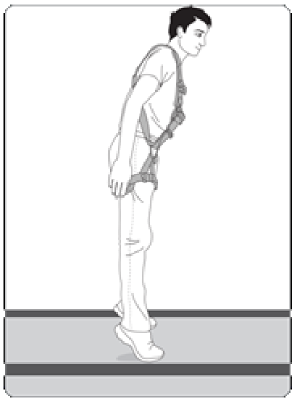

Before perturbation


After perturbation

Patient position:	Standing comfortably
Platform's direction:	Posterior to Anterior
Clinical effects:	Fast and highly intensive activation of ankle extensors muscles Unique technique for rearfoot weight bearing High level coordination of ankle agonist and antagonist muscle activation

6.3.1.3 Ankle flexion rehabilitation

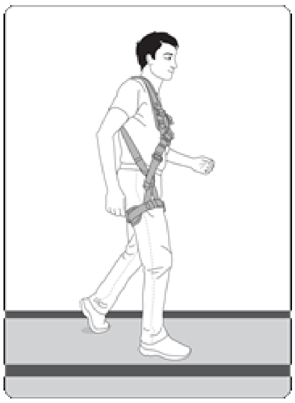

Before perturbation


After perturbation

Patient position:	Standing comfortably
Platform's direction:	Anterior to Posterior
Clinical effects:	Fast and highly intensive activation of Gastrocnemius and Soleus muscles Unique technique for Forefoot weight bearing High level coordination of ankle agonist and antagonist muscle activation Unique facilitation of gait initiation

6.3.1.4 Ankle instability rehabilitation

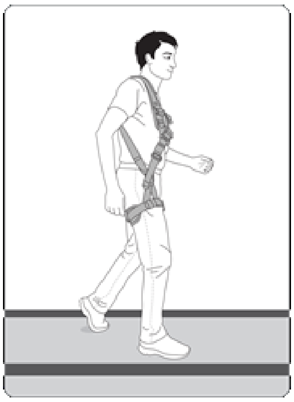

Before perturbation


After perturbation

Patient position:	Standing on injured leg with knee slightly bent
Platform's direction:	Multi-Direction Unexpected Perturbation
Clinical effects:	High Level ankle neuromuscular coordination Static and Dynamic ankle joint stabilization High resolution of Proprioceptive and Kinesthesis activation

6.3.1.5 Knee stabilization

Before perturbation

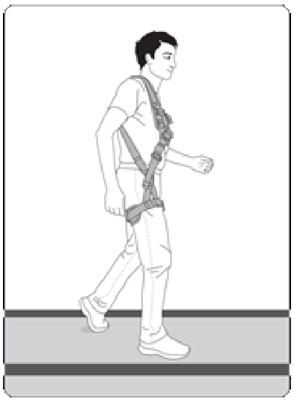


After perturbation

Patient position:	Standing on injured leg with knee slightly bent
Platform's direction:	Multi-Direction Unexpected Perturbation
Clinical effects:	High Level ankle neuromuscular coordination Static and Dynamic ankle joint stabilization High resolution of Proprioceptive and Kinesthesis activation

6.3.1.6 Neuromuscular Coordination Training

Before perturbation



After perturbation

Patient position:	Walking at customized speed
Platform's direction:	Multi-Direction Unexpected Perturbation
Clinical effects:	Fast Co-contraction of Agonist and Antagonist muscles of the limb in stance phase. Fast Co-ordination of Agonist and Antagonist muscles of the limb in swing phase

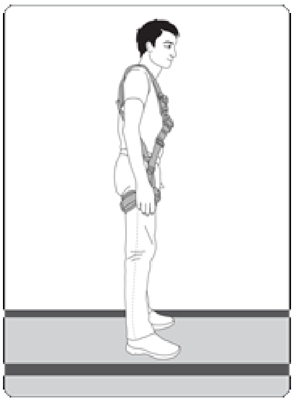
6.3.1.7 Groin strain rehabilitation

Before perturbation

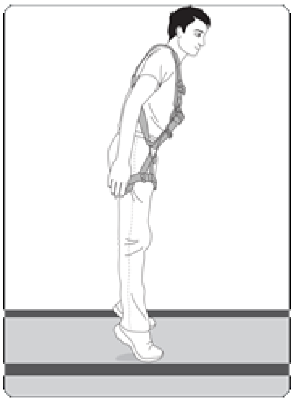
After perturbation

Patient position:	Standing while both feet are together
Platform's direction:	Anterior to Posterior Perturbation while walking sideways
Clinical effects:	Controlled contraction and stretching of the hip adductors

6.3.1.8 Hip flexion rehabilitation



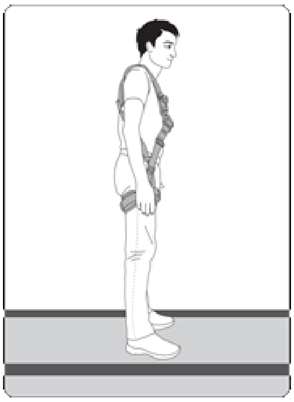
Before perturbation



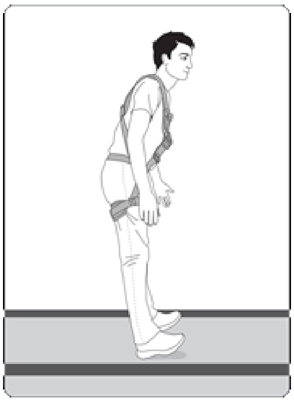
After perturbation

Patient position:	Standing comfortably
Platform's direction:	Anterior to Posterior perturbation standing or walking
Clinical effects:	Unique technique for stretching of Iliopsoas in stance phase Fast contraction of Iliopsoas through automatic response at swing phase

6.3.1.9 Hip extension rehabilitation



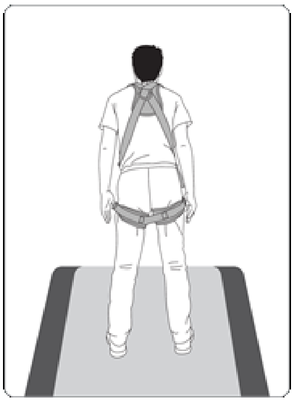
Before perturbation



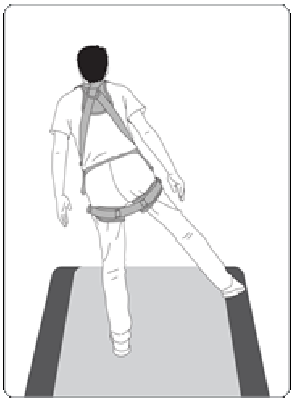
After perturbation

Patient position:	Standing comfortably
Platform's direction:	Posterior to Anterior Perturbation while standing and walking
Clinical effects:	Fast contraction of Gluteus maximus

6.3.1.10 Hip abduction rehabilitation



Before perturbation

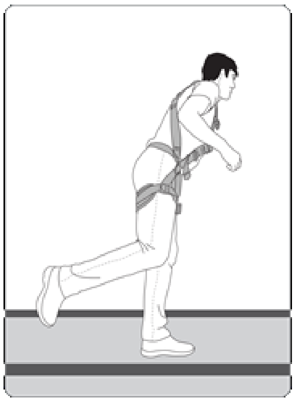


After perturbation

Patient position:	Comfortable walking speed with minimal external support
Platform's direction:	Medial/ Lateral Perturbation while standing or walking
Clinical effects:	Fast contraction of Gluteus mediums toward opposite direction of applied perturbation

6.3.1.11 Pure Reactive Response Training

Before perturbation

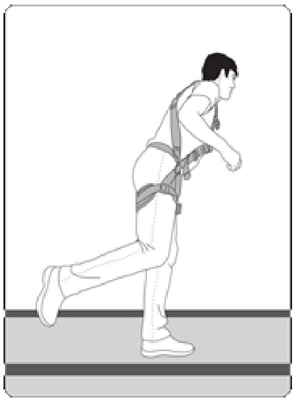


After perturbation

Patient position:	Walking or running
Platform's direction:	Random Multi-Direction perturbation
Clinical effects:	Improvement of Automatic Postural adjustment Faster compensatory step Improvement of Recovery time

6.3.1.12 Multi task training

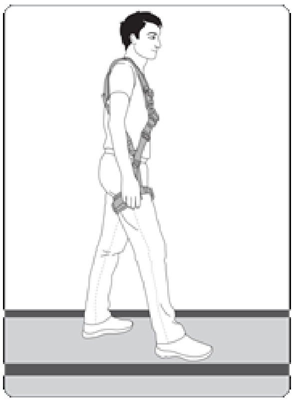
Before perturbation



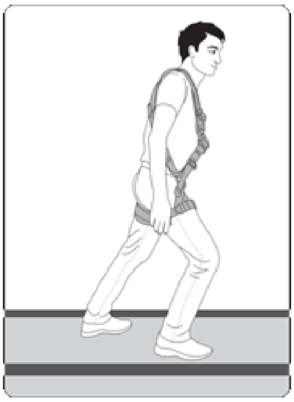
After perturbation

Patient position:	Standing, walking or running at customized speed
Platform's direction:	Multi-Direction perturbation
Clinical effects:	Neuromuscular coordination Fast Static and Dynamic multi-joints stabilization Optimal balance training

6.3.1.13 Weight bearing



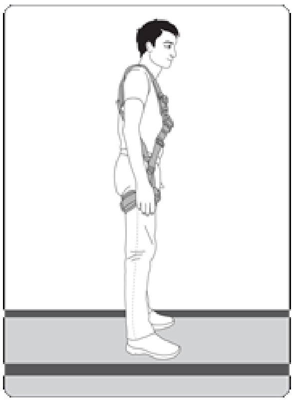
Before perturbation



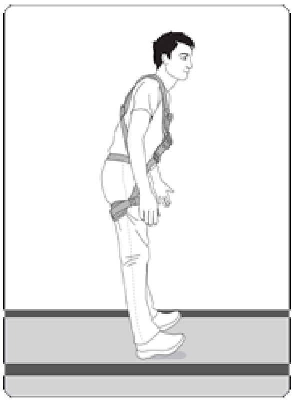
After perturbation

Patient position:	Based on instructions of the game
Platform's direction:	None, Shifting of Center of Pressure (COP)
Clinical effects:	COP feedback training

6.3.1.14 Low back muscle strengthening



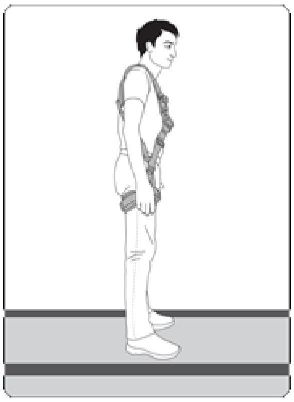
Before perturbation



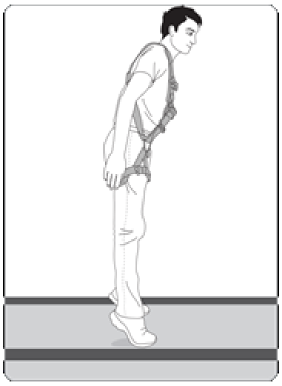
After perturbation

Patient position:	Standing comfortably
Platform's direction:	Posterior to Anterior
Clinical effects:	Fast and highly intensive activation of ankle extensors muscles Unique technique for Rear foot weight bearing High level coordination of ankle agonist and antagonist muscle activation

6.3.1.15 Abdominal muscle strengthening



Before perturbation



After perturbation

Patient position:	Standing comfortably
Platform's direction:	Anterior to Posterior
Clinical effects:	Fast and highly intensive activation of Gastrocnemius and Soleus muscles Unique technique for Forefoot weight bearing High level coordination of ankle agonist and antagonist muscle activation Unique facilitation of gait initiation

6.4 Recommended Protocol

A person's gait pattern can be affected by numerous kinds of neuromuscular or musculoskeletal disease or injury and severity of the signs and symptoms. The following recommended protocol provides guidelines on how to build the treatment according to gait problems such as reduced single support in one side of the body, reduced step length, reduced gait speed or wide step width. The protocol presented below shows several tables. Each table details a treatment schedule for a particular movement deficit identified either through gait observation or computerized gait analysis using the BalanceTutor system. Each table breaks down the treatment into sessions with a suggested protocol for the indicated gait. The protocol divided into three different treatment levels. The total time for each treatment is 30 minutes that is divided up into three session numbers. Each session may have increasing difficulty level according to different rehabilitation goals and patient ability. Instructions are given for both patient gait or standing position during the session and the instructions that the patient is given on weight bearing during stance. Guidelines presented within the program settings for speed and perturbation baseline settings in addition to perturbation direction and interval. The program setting also indicates which BalanceTutor trigger treatment option should be used. The intensity strategy indicates the values of the perturbation (intensity 0-30) according to required balance strategy following unexpected perturbation and the patient's ability.

REDUCED RIGHT SINGLE SUPPORT

Session Parameters				Patient Position		Program Settings				Intensity Strategy
Treatment Levels	Treatment Time	Session Number	Duration	Gait / Standing Mode	Weight Bearing	Walking speed	Trigger Treatment	Perturbation Direction	Perturbation Intervals	
Level I	30 min	I	10 min	Feet apart standing	Lt < Rt	Standing	Time Trigger	Rt to Lt	11 sec	Fixed support
		II		Normal walking	As symmetrical as possible	Initial speed	COP + Lt Swing	Decceleration		Low value
		III		Normal walking	As symmetrical as possible	Initial speed + 20%	COP + Lt Swing	Decceleration		Low value
Level II	30 min	I	10 min	Feet apart standing	Lt < Rt	Standing	Time Trigger	Rt to Lt	8 sec	Fixed support
		II		Normal walking	As symmetrical as possible	Initial speed	COP + Lt Swing	Decceleration		Moderate value
		III		Normal walking	As symmetrical as possible	Initial speed + 30%	COP + Lt Swing	Decceleration		Moderate value
Level III	30 min	I	10 min	Tandem standing	Lt leg forward	Standing	Time Trigger	Posterior to Anterior	5 sec	Changed in support
		II		Tandem walking	As symmetrical as possible	Initial speed	Time Trigger	Rt to Lt & Lt to Rt (random)		High value
		III		Normal walking	As symmetrical as possible	Initial speed + 40%	COP + Lt Swing	Rt to Lt & Lt to Rt (random)		High value

REDUCED LEFT SINGLE SUPPORT

Session Parameters				Patient Position		Program Settings				Intensity Strategy
Treatment	Treatment	Session	Duration	Gait / Standing Mode	Weight Bearing	Walking speed	Trigger Treatment	Perturbation Direction	Perturbation	
Level I	30 min	I	10 min	Feet apart standing	Lt > Rt	Standing	Time Trigger	Lt to Rt	11 sec	Fixed support
		II		Normal walking	As symmetrical as possible	Initial speed	COP + Rt Swing	Decceleration		Low value
		III		Normal walking	As symmetrical as possible	Initial speed + 20%	COP + Rt Swing	Decceleration		Low value
Level II	30 min	I	10 min	Feet apart standing	Lt > Rt	Standing	Time Trigger	Lt to Rt	8 sec	Fixed support
		II		Normal walking	As symmetrical as possible	Initial speed	COP + Rt Swing	Decceleration		Moderate value
		III		Normal walking	As symmetrical as possible	Initial speed + 30%	COP + Rt Swing	Decceleration		Moderate value
Level III	30 min	I	10 min	Tandem standing	Rt leg forward	Standing	Time Trigger	Posterior to Anterior	5 sec	Changed in support
		II		Tandem walking	As symmetrical as possible	Initial speed	Time Trigger	Rt to Lt & Lt to Rt (random)		High value
		III		Normal walking	As symmetrical as possible	Initial speed + 40%	COP + Rt Swing	Rt to Lt & Lt to Rt (random)		High value

REDUCED RIGHT STEP LENGTH

Session Parameters				Patient Position		Program Settings				Intensity Strategy
Treatment	Treatment	Session	Duration	Gait / Standing Mode	Weight Bearing	Walking speed	Trigger Treatment	Perturbation Direction	Perturbation	
		I		Feet apart standing	Lt > Rt	Standing	Time Trigger	Anterior to Posterior		Compensatory step
Level I	30 min	II	10 min	Normal walking	As symmetrical as possible	Initial speed	COP + Rt Swing	Aecceleration	11 sec	Low value
		III		Normal walking	As symmetrical as possible	Initial speed + 20%	COP + Rt Swing	Aecceleration		Low value
		I		Feet together standing	Lt > Rt	Standing	Time Trigger	Anterior to Posterior		Compensatory step
Level II	30 min	II	10 min	Normal walking	As symmetrical as possible	Initial speed	COP + Rt Swing	Aecceleration	8 sec	Moderate value
		III		Normal walking	As symmetrical as possible	Initial speed + 30%	COP + Rt Swing	Aecceleration		Moderate value
		I		Semi-Tandem standing	Lt > Rt	Standing	Time Trigger	Anterior to Posterior		Compensatory step
Level III	30 min	II	10 min	Normal walking	As symmetrical as possible	Initial speed + 30%	COP + Rt Swing	Aecceleration	5 sec	High value
		III		Normal walking	As symmetrical as possible	Initial speed + 40%	COP + Rt Swing	Aecceleration		High value

REDUCED LEFT STEP LENGTH

Session Parameters				Patient Position		Program Settings				Intensity Strategy
Treatment	Treatment	Session	Duration	Gait / Standing Mode	Weight Bearing	Walking speed	Trigger Treatment	Perturbation Direction	Perturbation	
		I		Feet apart standing	Lt < Rt	Standing	Time Trigger	Anterior to Posterior		Hip startegy
Level I	30 min	II	10 min	Normal walking	As symmetrical as possible	Initial speed	COP + Lt Swing	Aecceleration	11 sec	Low value
		III		Normal walking	As symmetrical as possible	Initial speed + 20%	COP + Lt Swing	Aecceleration		Low value
		I		Feet together standing	Lt < Rt	Standing	Time Trigger	Anterior to Posterior		Compensatory step
Level II	30 min	II	10 min	Normal walking	As symmetrical as possible	Initial speed	COP + Lt Swing	Aecceleration	8 sec	Moderate value
		III		Normal walking	As symmetrical as possible	Initial speed + 30%	COP + Lt Swing	Aecceleration		Moderate value
		I		Semi-Tandem standing	Rt leg forward	Standing	Time Trigger	Anterior to Posterior		Compensatory step
Level III	30 min	II	10 min	Normal walking	As symmetrical as possible	Initial speed + 30%	COP + Lt Swing	Aecceleration	5 sec	High value
		III		Normal walking	As symmetrical as possible	Initial speed + 40%	COP + Lt Swing	Aecceleration		High value

REDUCED GAIT SPEED

Session Parameters				Patient Position		Program Settings				Intensity Strategy
Treatment Levels	Treatment Time	Session Number	Duration	Gait / Standing Mode	Weight Bearing	Walking speed	Trigger Treatment	Perturbation Direction	Perturbation Intervals	
Level I	30 min	I II III	10 min	Normal walking	As symmetrical as possible	Initial speed Initial speed + 10% Initial speed + 20%	Time Trigger	Aecceleration	11 sec	Low value
Level II	30 min	I II III	10 min	Normal walking	As symmetrical as possible	Initial speed + 30% Initial speed + 40% Initial speed + 50%	Time Trigger	Aecceleration	8 sec	Moderate value
Level III	30 min	I II III	10 min	Normal walking	As symmetrical as possible	Initial speed + 60% Initial speed + 70% Initial speed + 80%	Time Trigger	Aecceleration	5 sec	High value

WIDE STEP WIDTH

Session Parameters				Patient Position		Program Settings				Intensity Strategy
Treatment Levels	Treatment Time	Session Number	Duration	Gait / Standing Mode	Weight Bearing	Walking speed	Trigger Treatment	Perturbation Direction	Perturbation Intervals	
Level I	30 min	I II III	10 min	Feet apart standing Normal walking Normal walking	As symmetrical as possible	Standing Initial speed Initial speed + 20%	Time Trigger	Rt to Lt & Lt to Rt (random)	11 sec	Fixed support Low value Low value
Level II	30 min	I II III	10 min	Feet apart standing Normal walking Normal walking	As symmetrical as possible	Standing Initial speed Initial speed + 30%	Time Trigger	Rt to Lt & Lt to Rt (random)	8 sec	Hip startegy Moderate value Moderate value
Level III	30 min	I II III	10 min	Tandem standing Tandem walking Normal walking	As symmetrical as possible	Standing Initial speed Initial speed + 40%	Time Trigger	Rt to Lt & Lt to Rt (random)	5 sec	Compensatory step High value High value

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8 Version History

Date	Change description	Written by	Ver.
05 Oct 2016	Initial revision	Dr. Avraham Cohen	161005
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