Universidad CEU Cardenal Herrera

Departamento de Fisioterapia

Proprioception as a preventive method in lower limb sport injuries: from theory to practice.

TESIS DOCTORAL

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A los míos…….

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CERTIFICA:

Que el trabajo titulado **“Propioception as a preventive method in lower limb sport injuries”,** realizado bajo mi dirección en el Departamento de Fisioterapia de la Universidad CEU-Cardenal Herrera de Valencia por D. Alberto Sánchez Sierra, reúne todos los requisitos legales y académicos necesarios para que el interesado pueda optar al título de Doctor por dicha Universidad.

Valencia, 24 de enero de 2017

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Dra. Sara Vila Maldonado

Contents

Table Index

Graph Index

Abbreviations Index

ACL: Anterior cruciate ligament

CG: Control group.

CNS: Central nervous system

COG: Center of gravity

EG: Experimental group.

FE: Force error

JPS Joint position sense

LPI: Lateral preference inventory

MVC: Maximum voluntary contraction

MTH: Metatarsian head

PF: Peak force

PT: Physical therapist

PVV: Proprioception vestibular view

QMU: Queen Margaret University

ROM: Range of movement

RMS: Root mean squared

SEBT: Star excursion balance test

SH: Side hope test

SIMTP: short intense multidisciplinary training programme

SSF: side steps and forward

SR: Stochastic resonance

TRAL: Rebalance therapy of the locomotive system

WBV: Whole body vibration

Figures

Appendix

CHAPTER 1. EVOLUTION OF THE TERMINOLOGY

1.1 EVOLUTION OF THE TERMINOLOGY

In 1557 J. C. Scaliger already described a sense of movement. In 1833 Sir Charles Bell spoke for the first time about a sixth sense or muscular sense (Mascaró 1999). But Sir Scott Sherrington, Nobel Prize in medicine in 1932, is who first described in 1906 the proprioception system (Asiron 1991). The term of proprioception can be attributed then to C. Sherrington and he can be considered the father of proprioception.

The anatomical observations and ideas that Ramón y Cajal summarized in his monumental "Histologie du système de l'homme et nerveux des vertebrates" (Ramón y Cajal, 1909, 1911, 1995) served as a great inspiration to a young British physiologist, Charles Scott Sherrington, to explore the mammalian central nervous system in a completely different way. As a result, in 1906 Sherrington published "the integrative action of the nervous system" (Sherrington 1906), which summarized his nearly two decades of extensive research and thoughts. It is not an overstatement to say that Sherrington´s book changed the subsequent course of neurophysiology (Burke 2007).

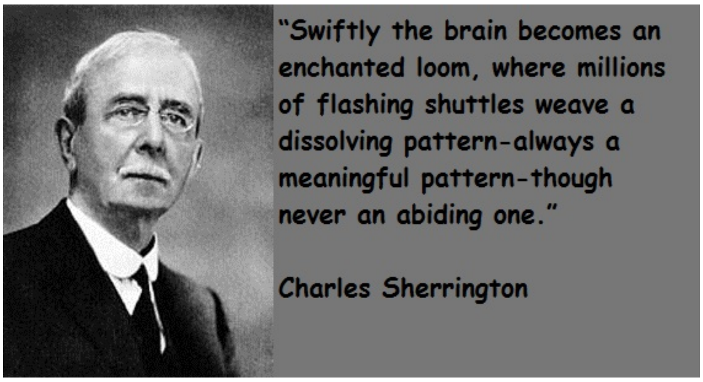


Figure 1: Sir Charles Sherrington.

Sherrington described proprioception as the afferent information arising from proprioceptors located in propioceptive fields (Sherrington 1906). In some of his writings Sherrington states that proprioception is used in the regulation of posture (postural equilibrium), segmental posture (joint stability) and where some conscious sensations (muscle sense) starts (Matthews 1982).

Although he included the vestibular system as part of the proprioception responsible for head, Sherrington clearly delineated the functions of the labyrinth within respect of the receptors in the peripheral. Sherrington described four sub modalities of proprioception: posture, passive movement, active movement and resistance to movement.

Also in 1900 Erwin Payr proposed the hypothesis of the existence of a protective reflex from ligament and muscle (Erwing 1900). Later Palmer Partridge continued with this hypothesis (Partridge 1924, Palmer 1938), but it wasn´t until 1958 when physiological tests started; Stener in 1959, Skoglund in 1960 (Ekholm et al. 1960) and later in 1987 Salomnon worked with cats to test the muscle reflex activity using EMG working in ischiofemoral musculature, checking the activity in these muscles when the anterior cruciate ligament was tensed (Mascaró 2007).

1.2 TERMINOLOGY

The term proprioception has suffered changes since 1906 when Sherrington described this new sense or ability of the human body to inform the brain about the joint position in each moment (Asiron 1991). Since then, investigators have been working and researching in this human capacity, investigating its complexity and adding new components to become part of a system now called the sensorimotor system (Riemann & Lephart 2002). Other authors, such as Owen Anderson, call this system proprioceptive vestibular view (PVV) (Anderson 2002) or sensory-motor-perceptual system (Neiger1999).

Proprioception is often used to describe many physiological processes of the sensorimotor system including joint position, kinesthesia, balance, reflex muscle activation and is even linked to the description of locomotion. Furthermore, proprioception has been inappropriately used in the laboratory as a measure of many of the variables in the sensorimotor system (Lephart & Fu 2000). It is therefore appropriate to review, understand and use the correct terminology and concepts that support the need to work in a more specific way.

1.2.1 PROPRIOCEPTION.

Proprioception (from the Greek “proprius” - belonging to himself) has been defined as the awareness of the position and orientation of a body segment (Malliou et al. 2004), or specialized variation of touch that involves ability to identify the position of the joints (joint position sense) and the ability to identify movement (kinesthesia).

Proprioception is described as afferences arriving from peripheral areas of the body that contribute to postural control, joint stability and some conscious feelings. This term should not be confused with those activities that involve more complex neuromuscular control and are embedded within the motor control or sensorimotor system (Riemann & Lephart 2002).

Proprioception is important for balance, control movement of the limb and joint stability (Roberts 2003). The contribution of the vision to balance, proprioception and vestibular system in different groups of different ages has been studied and it has been found that regardless of age, all groups depend more on proprioception than on vision to maintain balance (Xu et al. 2004).

1.2.2 SENSORIMOTOR SYSTEM

The sensorimotor system is described as the mechanisms involved in the acquisition of sensory stimuli and its conversion into neuronal signal transmission and afferent pathways to the central nervous system. It includes the integration of the information and motor responses resulting in muscle activation for locomotion and execution of functional tasks and joint stabilization. Maintaining functional joint stability through complementary relationships between static and dynamic constraints is the role of the sensorimotor system (Lephart & Fu 2000).

It can be considered a sub-component of the motor control and it is extremely complex. This term was coined in 1997 by the Foundation of Sports Medicine Education and Research to describe the influence in functional joint stability and the maintenance of homeostasis, motor and sensory inputs integration and its central integration and processing involved.

The sensorimotor performance (often referred to in contemporary literature as proprioception) is defined by Gleeson et al. 2001 as the ability to graduate volitional forces and joint positions precisely and accurately.

The integration of afferent receptors from peripheral information (proprioception) and the central processing and efferent information (sensorimotor system) contributes significantly to effective muscle activation and joint precision (Lephart & Fu 2000).

1.2.3 BALANCE

Balance corresponds to a complex motor response involving the integration of diverse sensory information, preparation and execution of movement patterns that aims to maintain a stable and correct posture (Maki et al. 1990).

This postural control depends on the input that collects information, the integration center that receives and prepares and disseminates the information and the effector system that allows appropriate responses to maintain the posture. Any change in any of these points can manifest an alteration on balance (Petrella et al. 1997).

Balance can be defined as the ability to maintain or make adjustments in order to keep the body's center of gravity over the basis of support (Kean et al. 2006). This adjustment occur through movements of the ankles, knees, and hips and may be disturbed when the center of gravity and the basis of support is disrupted or when corrective movements are not executed in a smooth and coordinated fashion. Furthermore, an individual with an unstable center of gravity may not direct all their propulsive forces in the optimal direction to increasing the proportion of prime muscles allocation thus not allowing them to maximize their contribution to the propulsion of the body when jumping or running (Bernier & Perrin1998).

Two types of balance are known:

1. ***Static Balance***: It is used to maintain static posture in space, keeping the center of gravity within the base of support either standing or sitting (Maki et al. 1990, Yim-Chiplis & Talbot 2000, Winter 1995).

2. ***Dynamic Balance***: Involves movement either with displacement or performance of activities in space trying to keep the center of gravity within the base of support. The dynamic balance involves maintaining proper posture, both when the center of gravity and the base of support are moving as when the center of gravity is moved out of the base of support. For a proper balance, inputs from the vestibular system, visual system and proprioceptive system are required (Yim-Chiplis & Talbot 2000, Winter 1995, Maki et al. 1990).

Balance depends on three factors (Gonzalez & Keglevic 2004, Shumway-Cook & Woollacott 2007):

1. The base of support.
2. The distance of the line of gravity to the edge of the base of support, being more unstable the closer to the edge of the base of support.
3. The height of center of gravity which lead to greater instability.

1.2.4 JOINT STABILITY

It can be defined as the capacity of staying in one position even in the presence of forces that normally would change that state or condition. It can also be described as the property of returning to an initial position after being disturbed. It is the ability of the joint to remain or return as soon as possible to the correct alignment through the balance of forces (Riemann & Lephart 2002).

The process of maintaining joint stability is achieved through a complementary relationship between static components such as ligaments, joint capsule, cartilage, bone geometry and friction (static or passive component) and the feedforward and feedback to the muscles that cross joints without forgetting the biomechanical and physical characteristics of each joint including the range of movement, muscle strength and endurance (dynamic component).

1.3 SENSORIMOTOR SYSTEM FUNCTION

The information is carried at various levels throughout the sensorimotor system. Formed by the central axis and two associated areas. The central axis corresponds to the spinal cord, brain stem and cerebral cortex, whereas the associated areas correspond to the cerebellum and basal ganglia. The central areas of the shaft are organized hierarchically and in parallel. Hierarchical organization allows the lower motor areas to control automatically the details of common motor activities, while high levels areas can dedicate its resources to control motor activities, which require more precision and skills, and regulate the afferent information. The parallel organization allows to the sensorimotor system to control centers and send descending motor commands that act directly on the motor neurons.

The activation of motor neurons can occur in direct response to a peripheral sensory input (reflex) or by descending commands initiated in the brainstem and cerebral cortex. Regardless of the source that initiates the stimulus, the activation of skeletal muscle produces a convergence of the signal on the motor neurons located in the ventral horn of the spinal cord. This concept is what Sherrington called “final common field”.

There are two types of motor neurons that leave the ventral horn of the spinal cord:

1. Alpha motor neurons that control the extrafusal (skeletal) muscle fibers,
2. Gamma motor neurons controlling the intrafusal fibers (spindle muscle) (Riemann & Lephart 2002).

There is a dynamic equilibrium due to both somatic and vegetative nervous systems that give a quick response; the endocrine system responds slower through metabolic pathways.

1.4 FEEDBACK and FEEDFORWARD

Feedback mechanisms incorporate sensory information that modulate and adjust the movement. The somatosensory feedback is a critical component of the balance and postural control (Mergner & Rosemeier 1998, Collins et al. 2003). It occurs in response to a sensory input (vestibular, visual and somatosensory) generated against an external perturbation (Shumway-Cook & Woollacott 2007). Its main function is to restore the adequate position after a stimulus. This system is also called "closed loop" because external stimuli enter the nervous system and directly influence the answer. The main inconvenience can be found when quick responses are required: as the transmission is slow, unsuitable motor responses will be generated for rapid movement (Shumway-Cook & Woollacott 2007).

Not only proprioceptors are important, but also mechanoreceptors will play an important role when sending feedback information, as it has been demonstrated by the importance of the plantar pressure receptors to the pressure that feet suffer. Pressure changes are related to changes in the center of gravity and thus it helps to maintain the standing position (Hijmans et al. 2008, Kavounoudias et al. 2001).

The feedforward mechanism involves postural preparations of movement control, memory constructions, motor scheme and motor development. Feedforward uses the proprioceptive information to prepare anticipated loads or activities that may be performed. It creates an anticipatory response based on previous experiences under known conditions. This background information is coupled with real-time proprioceptive impulses to generate preprogrammed motor commands that will achieve the desired results (Childs & James 2003, Buz et al. 2004). Although the feedback mechanism has been considered the principal one in the neuromuscular control, the anticipatory mechanism that plans movement programmes and activates muscles based on previous experiences, also plays an important role in maintaining joint stability.

The feedforward model must be built through learning, with multiple attempts (Wolpert et al. 1995, Lanphier 1998). This model is manifested through anticipatory postural adjustments (Horak & Nashner 1986, Shumway-Cook & Woollacott 2007, Lomar & Lakie 2002) responsible for modifying the muscle postural activity before undertaking any action; within these postural adjustments we can find those that precede the movement and those that accompany the movement, each one using a set of different muscle groups in order to generate forces opposite to the mechanical effect of the possible positional perturbation (Krishnmoorthy & Latash 2005).

Unfortunately, trying to rate one of the two actions is not as simple as the definitions suggest. In some circumstances there is a combination of both such as in postural control. The feedback model contributes to provide internal information to the feedforward model, which is why the latter is called "open loop" (Lanphier 1998). The feedforward term is recommended to be described as actions that occur on the identification of the beginning and the effects of imminent action or stimulus. In contrast, the feedback should be used to describe actions that occur in response to sensory detection or direct effects by the arrival of an event or stimulus to the system (Riemann & Lephart 2002).

1.5 NEUROMUSCULAR RESPONSES

The neuromuscular responses are closely related to motor control. Lephart and Fu (2000) interpret them as an unconscious efferent response to an afferent signal that aims to achieve the dynamic stability of the joint. Williams et al. (2006) suggest that this neuromuscular control helps to produce a controlled activity through a coordinated muscle movement, resulting from a complex interaction between the nervous system and the musculoskeletal system. To achieve this neuromuscular control, intramuscular and intermuscular coordination should work in a coordinate manner.

1.5.1 INTRAMUSCULAR COORDINATION

Intramuscular coordination will influence the strength of a single muscle. Training will help to increase the recruitment of motor units and increased their pulse frequency. Synchronization of different motor units will produce a maximal voluntary contraction (Cometti 2007).

1.5.2 INTERMUSCULAR COORDINATION

Intermuscular coordination is controlled by the agonist and antagonist co-activation and reciprocal activation of agonists and antagonists.

Co-activation is the high-intensity activity of agonist muscles simultaneously with a low intensity activity of antagonist muscles of the same joint. Co-activation is mainly used in new and/or ballistic tasks when execution speed increases and when it is needed to maintain joint stability constant for a position. This co-activation causes a reduction of the load that may suffer ligamentous and joint structures (Lloyd 2001).

On the contrary the existence of an unwanted co-activation will cause a decrease of run speed, increased energy expenditure and, in parallel, a decrease in performance.

The reciprocal activation is given by the reciprocal inhibition, which consist of the inhibition of a muscle contraction to facilitate its antagonist (Guyton 2011). It is used in many automatic polyarticular movements such as standing up or walking (Lloyd 2001).

When a new movement is learned, the task is performed first with high levels of co-activation and as the learning process evolves there is a progression to the reciprocal activation (Lloyd 2001). These strategies are modifiable with training (Hubster et al. 2010).

1.6 MOTOR LEARNING

Motor learning is defined as the process of acquiring different motor skills or motor habits involving simple to complex skills (Aguado 2001, Besson et al. 2005, Carrillo 2005, Torrents 2005).

It is the process of finding a solution to an activity. It emerges from the interaction of the individual with the activity, the context and the environment, in which the individual has the ability to self-organize the learning process. For this purpose the individual has the following tools:

- Trial-error: On motor learning feedback is necessary but to learn an activity trial-error is mandatory. Practice and repetition feedforward is developed which involves postural preparations for controlled movement (Montgomery & Connolly 1997).

- Ability to organize.
- Development of feedforward.

Once this information is obtained, the central control allows sensory and motor systems to prepare against an anticipatory stimulus or environmental challenge. Preparatory aspects in the response help decrease the time it takes to the central nervous system to develop an appropriate response. However, it should be noted that the central controller can generate erroneous responses when stimulus or external condition changes unexpectedly (Horak et al. 1988). Alertness is essential for the central nervous system to prepare, receive and process sensory and perceptual information, Also to prepare for the activity, take decisions and execute the action. The learning process can be measured by the degree of long-term retention of learned skill and the possibility of being able to learn from other life situations or activities (Macias 2009).

Applying these concepts to sports, it can be say that the neuromuscular dynamic components (proprioceptive) of the lower limb movement should include anticipation (feedforward) and feedback for motor control during turns (feints and cuts). Preparatory activity can stabilize joints before unexpected disturbances (Mascaró 2007). All the above should be taken into account when implementing injury prevention investigations.

1.7 FATIGUE AND PAIN

The importance of fatigue and pain in sports injuries must be taken into account when creating a preventive programme.

1.7.1 FATIGUE

It has been suggested two ways of peripheral fatigue and weakness that will produce progressive failure of voluntary neural impulse. First, the failure of the metabolism contractile process derived from the metabolic inhibition and the failure of binomial excitation-contraction. Second, the central fatigue due to lack of motivation, concentration or an error in sending the stimulus (Harkins et al. 2005).

Fatigue increases the threshold of muscle spindles thereby disrupts afferent feedback and consequently alters the warning of the joint. During this period the postural stability is compromised and can make an athlete more susceptible to injury (Harkins et al. 2005).

Nardone et al. (1997) stated that exercise induced fatigue has a detrimental effect on postural stability, thus increasing the possibility of injury.

It has been shown that most injuries occur at the end of athletic competitions and training sessions due to muscle fatigue, this affects posture control forcing the subject into a higher balance control effort (Padua et al. 2006, Mello et al. 2007). Intense fatigue also diminishes the ability to generate the desired strength and stability to provide shock absorption, thus increasing the chances of sprains and stress fractures. Severe fatigue of the peroneus longus is the main cause of ankle lack of stability (Geferi 2002). Fatigue also worsened the results of subjects with chronic ankle instability when the joint stability test, Star Excursion Balance Test, SEBT, was applied, creating kinematic changes in the knee and the hip (Gribble 2004). It has been shown that joint instability may contribute to reduced muscle force production (Anderson & Behm 2004, Kornecki et al. 2001) and to increased fatigue. (Hoffman et al, 1997, Mattsson & Brostrom 1990).

1.7.2 PAIN

Injury, in sport argot, is considered so when the athlete has to be removed from the game or training session or prevented from participating in the next match, training or both. This concept excludes all subacute and chronic injuries which allow the athletes further training or even compete but may decrease the athlete's performance (McLain & Reynolds 1989).

Nonetheless pain can affect both types of injuries. Following the new theory of the influence of pain by Hodgesand Tucker (2011), it will be very important to ensure that pain is not present when working with the subject as it can cause:

- Disruption of the body scheme due to the withdrawal reflex.

- Decreased muscle strength and increased agonist- antagonist co-activation to decrease the range of motion (Paul et al. 2011).
- Increased number of recruited fibers to reduce fibers total performance (Paul et al. 2011).

CHAPTER 2: RISKS ASSOCIATED TO RISK FACTORS

2.1 SPORTS PRACTICE

Some epidemiological studies have shown that sports and recreation injuries constitute a major public health burden in many developed countries (Belechri et al. 2001, Conn et al. 2003). Yet, practicing sports is saving money to governments, as statistics from United States, Austria and Switzerland showed that sedentary people generate 30 to 50% more output than active people (Schneider et al. 2006).

Sports injuries in Germany represent the second most common accident after, household accidents and along with work accidents. Articular and ligamentous injuriesare most frequent injuries with a men-women ratio of 3:1. Injuries are commonly produced before the age of 30. Data registered in Germany are consistent with those found in Canada, United States, Australia and New Zealand. Usually injuries affect two to three times more to lower limbs than upper limbs, and this seems to be a constant between societies and cultures (Schneider et al. 2006).

A study in adolescents sport injuries of the United States showed a 2:1 boy-girl ratio. The most frequent injuries occurred in soccer followed by handball injuries during sports and school activities. The lower extremity was involved in 68.71% of cases; Knee problems were the most frequent follow up closely by ankle injuries, 29.79% and 24.02% respectively. Sprains injuries constituted a 35.34% and ligament injuries a 18.76% (Habelt et al. 2011).

Sprain ankle is the most common injury in sports (Nitz et al. 1985, Holme et al. 1999, Hertel 2002, Fong et al. 2007), and once the injury is produced there is a 4.7 times more possibilities to suffer another sprain (McKay et al. 2001) which can lead to chronic ankle instability (McKay et al. 2001). This occurs in the 10 to 30% of cases of ankle sprain (Peters et al. 1991, Ryan 1994). Within ankle sprains, sprains of the lateral ankle ligament occurs more often (MacAuley 1999, Mangwani et al. 2001,Hockenbury & Sammarco 2001, Hertel et al. 2001, Willems et al. 2002) and this is the mainly concern to young physically active persons (Eils & Rosenbaum 2001). It has also been reported that the knee accounts for 23% to 41% of all athletic injuries (Kujala et al. 1986). There is strong evidence in the literature showing that after an injury or inadequate rehabilitation athletes increase the risk of ankle or knee injury (Murphy et al. 2003).

As above stated, an injury increases the possibilities of further wounds which constitutes a major concern. Parkkari et al. emphasize the importance of physical therapists (PTs). These professionals are an important link on the chain of prevention and to gather information. PTs are in continued contact with the athlete which allows them to identify early the risk factors for overload injuries and sports accidents. To plan a prevention programme for sports injuries PTs must recognize the types of injury and identify as many risk factors as possible (Parkkari et al. 2001). To achieve this, clinical experience is not enough, as Van Mechelen et al 1992 explains, it is necessary to develop cohort studies that allow professionals to determine the effectiveness and efficiency of the proposed programmes.

2.1 INJURY RISK FACTORS

Van Tiggelen et al 2008 expanded on the previous Van Mechelen´s four steps model to prevent sports injuries (Vanmechelen et al. 1992, Trop 2002). He states two main paths to prevent sport injuries.

- Identify sports injury risk factors.
- Search techniques for an effective prevention.

Van Tiggelen adds to the above a seven stage impact study and corresponding assessment.

Table 1. Seven stage in Preventive Programme (Van Tiggelen et al 2008).

1	Establish the magnitude of the problem
2	Establish the risk factors and injury mechanisms
3	Introduce preventive mesures
4	To establish the effectiveness of the programme
5	To establish the efficiency of the preventive measures
6	Assessment of the risk-benefit ratio of the preventive programme
7	Assessment of the effectiveness of the prevention programme

Many injuries are due to unavoidable accidents, but there are many other factors that can be prevented (Parkkari et al. 2001). Table 2 summarizes risk factors according to previous literature

Table 2. Three classifications about injury risk factors found in the literature.

Bahr and Holmes 2003	Modifiable Factors
	Non modifiable Factors
Fuster and Elizalde 1995	Factors related to the environment
	Factors related to the activity
	Factors related to the person
Hunt Valley meeting 2005	Environmental Factors
	Anatomical Factors
	Hormonal Factors
	Biomechanical and neuromuscular Factors

Hunt Valley classification is focused on the knee joint, The Anatomical Risk Factors intensifies its relevance when movement occurs (Silvers et al. 2007). Anterior cruciate ligament (ACL) injuries are 4 to 6 times more frequent in women (Jae Ho Yoo et al.

2010). It has been shown that levels of estrogen and progesterone appear to exert an important influence on ligament injuries (hormonal risk factors) and many aspects must be taken into account when talking about Neuromuscular risk factors, such as decreased ability to produce force, inadequate muscle stiffness, slow muscle activation times, altered muscle recruitment, pre-activation of the quadriceps, decreased kinesthetic awareness, muscle fatigue, ligament dominance, quadriceps dominance and dominance of the lower limb (Olsen et al. 2004, Griffin et al. 2006).

Risk factors are divided into two main groups: **intrinsic factors** related to the athlete himself and **extrinsic factors** or environmental factors (Williams 1971, Taimela et al. 1990, Lysens et al. 1991, van Mechelen 1992, Bahr & Holme 2003).

Sports injuries are the result of a multifactorial model as explained by in the First World Congress on Sport Injury Prevention undertaken in Oslo, Norway, in 2005. Meeuwisse believes that it must be a final link, an event associated with the beginning of the injury and the presence of these risk factors that could produce an injury to the athlete (Meewisse 1994). Meeuwise states that these internal risk factors interact, but rarely produce injuries by themselves, and he argues that external factors depend on the performance of athletes, and classifies them as factors that allow the expression of the injury to occur.

Table 3. Literature review summary-Risk Factors.

LOWER LIMB GENERAL INJURY RISK FACTORS
Control deficits in center of gravity position (Matsusaka et al. 2001)
Increased stress suffered by ligaments, muscles and joints (Beynnon 2003)
Movement awareness (Bernier and Perrin 1998)
Previous injuries or bad rehabilitations (Beynnon 2003)
Alterations on the proprioception system (Engstrom BK and Renstrom PA. 1998).
Strength alteration (Engstrom BK and Renstrom PA. 1998)
Lumbopelvic instability (Sherry and best 2004)
Bad warm up or incorrect preparation (Dvorak et al. 2000; Verrall et al. 2005).
Footprint alterations (*Bahr R 2007)*.
INTRINSIC SPECIFIC ANKLE INJURY RISK FACTORS
Mechanical and functional insufficiencies. (Madras & Barr 2003; Kaminski and Hartsell 2003; Beynnon. 2003)
Artroligaments Restrictions (Madras & Barr 2003; Kaminski & Hartsell 2003; Beynnon. 2003)
Degenerative changes in the periarticular structures (Madras & Barr 2003; Kaminski & Hartsell 2003; Beynnon. 2003)
Diminished postural control. (Madras & Barr 2003; Kaminski & Hartsell 2003; Beynnon. 2003)
Strength alterations. (Madras & Barr 2003; Kaminski & Hartsell 2003; Beynnon. 2003)
Neuromuscular control (Madras & Barr 2003; Kaminski & Hartsell 2003; Beynnon. 2003)
Proprioception decreased (Hertel J.2000; De Noronha et al 2006).
Ability to detect joint movement (Bernier & Perrin 1998)
Footprint alterations (*Bahr R 2007)*.
INTRINSIC SPECIFIC KNEE INJURY RISK FACTORS
ROM (Range of Movement) alterations (Beynnon 2003).
Strength alteration (Beynnon 2003).
Knee proprioception alteration (Powell et al. 2000).
Muscle contraction latency (Beard et al 1993).
Lack of dynamic neuromuscular knee control (Hewett et al 2005).
Bad biomechanical and neuromuscular control in lower limb (Benjaminse et al 2010).
Prolonged exposure to eccentric contractions throughout sporting activities (Eston et al. 2003)
MUSCLE SPECIFIC INJURY RISK FACTORS
Sensorimotor system alterations (Saxton et al 1995; Proske & Morgan 2001).
Alterations in the sensitivity of peripheral mechanoreceptors (Kuitunen et al 2004).
Changes of muscle spindles changes and reflex sensitivity (Kuitunen et al 2004).
Impaired central processing methods whereby the perception of sense of effort is altered (Proske et al 2004b; Gregory et al 2004).
Rapid change from eccentric contraction concentric contraction phase (Hoskins & Pollard 2005).
Previous injuries (Brockett et al. 2001)
Bad recovery (Askling et al. 2003).
Strength alterations (Beynnon 2003).

2.2.1 LOWER LIMB GENERAL INJURY RISK FACTORS

One of the most common risk factors is control deficit on the center of gravity's (COG) position because an increased variation in postural stability is associated with a neuromuscular disorder (Matsusaka et al. 2001), intersegmental increased joint strength and its corresponding increased tension suffered by ligaments, joint and muscle structures (Beynnon 2003).

The ability to detect joint movement and being able to make postural adjustments in response to these perceived movements, is also crucial in injury prevention (Bernier & Perrin 1998) and therefore recommendable to take this factor into account when building a preventive programme.

Previous injuries and an inadequate rehabilitation not only compromise the static and dynamic lower limb joint stabilizers, it may be also associated with differentiations of the joint, and thus, to an increased risk of injury (Beynnon 2003). Such differentiations can lead to a proprioceptive and motor deficit (Sekir et al 2006).

Alterations in the proprioceptive system, a decrease in strength or muscle imbalance, a persistent ligamentous laxity, a decrease in muscle flexibility, loss of ROM and persistence of scar tissue that produces discomfort, are also risk factors to consider (Engstrom, Renstrom 1998) as proprioception contributes to motor programme, movements precision, muscle reflex and joint stability.

Some authors emphasize the importance of assessing and work lumbo-pelvic stability and had shown that core training decreased the number of injuries in the lower limb (Sherry & Best 2004). It also has been notices on the literature that a bad or poor warm up execution or physical preparation of athletes may lead to injuries (Dvorak et al. 2000, Verrall et al. 2005).

One of the most important variables that need to be controlled in runners is their foot contact (Kelly et al. 2010). There are several common injuries in athletes, whether amateur or professional, related to plantar pressures that occur during the race (Bahr 2007). This sports activity generates impacts (ground reaction forces) during the stance phase that multiplies the athlete's weight 2 to 5 times in each stride (Hreljac 2004) and may cause injuries to the lower limb (Thijs et al. 2008).

2.2.2 INTRINSIC SPECIFIC ANKLE INJURY RISK FACTORS.

Factors involved in ankle injuries described in the literature framed within neuromuscular intrinsic factors are:

- Mechanical and functional insufficiencies.
- Arthro-ligaments restrictions and impaired ROM, specially a reduced dorsiflexion (De Noronha et al. 2006).
- Ligamentous hypermobility.
- Degenerative changes in the periarticular structures.
- Neuromuscular control.
- Changes in strength: The evertor muscles are called to play an important role in preventing ligamentous injuries, the strength of these muscles should provide support to the lateral ligaments (Willems et al. 2002).
- The alteration in the muscle reflex response and decreased muscle strength in supinator and pronator muscles (Freeman et al. 1965, Tropp et al. 1984, Hertel 2000, Meana et al. 2000) are also risk factors for an ankle injury.

Likewise, the individual's ability to detect the position of the foot before the heel strikes the ground at the beginning of the stance phase is crucial. Ankle instability leads to a decreased ability to maintain posture and decreased sense of joint position (Bernier & Perrin 1998). Ankle risk factors include those that induce a decrease in proprioceptive ability, poor postural control and alteration of the biomechanics of the ankle (Hertel 2000, De Noronha et al. 2006).

Witchalls et al. (2012) reviews 13 articles that showed the following aspects could influence ankle injuries:

- Balance.
- Lower postural stability.

- Lower inversion ankle proprioception and greater plantar flexion concentric strength at high speeds.
- Less eversion muscles eccentric force at low speeds.

Plantar food also has an influence on the ankle joint during the race in the stance phase. The initial foot contact in the activity is marked by the position of the ankle (Turmo 2000). Normally the stance phase begins with a heel strike, finding the forefoot in slight abduction, this contact is made with the center of gravity behind the supporting leg, and as it moves forward, the foot takes a normal pronation movement to suit the terrain. This phase ends when the athlete supports the midfoot, the corresponding leg is bent in its three joints (ankle, knee and hip) and the foot is in full contact with the ground (Kerrigan et al. 2009). The overall movement of foot pronation is maintained until the end of this phase, at this point begins to supinate for greater momentum. Furthermore, it is shown that foot pronation position depends on the speed of the race (Shanthikumar et al. 2010) and its increase is the result of fatigue (Fromme 1997). Pronation is due, mostly, to the initial position of the calcaneus, which is not vertical, and the body weight projection medially relative to the fulcrum of the calcaneus. The exaggerated movements of supination or pronation of the rear foot are those that may predispose athletes to suffer running injuries.

Also, prolonged exercise induces a translation of the lateral loads to the medial heel area, which is closely related to the change in foot posture towards pronation and muscle fatigue that occurs after exercise of moderate length (Escamilla et al. 2010).

2.2.3 INTRINSIC SPECIFIC KNEE INJURY RISK FACTORS.

In addition to the general risk factors for lower limb injuries described above, the literature also describes other specific factors which taken into account could reduce knee injuries (Benjaminse et al. 2010).

The latency (time between application of the stimulus to the muscle response) in hamstrings´ contraction is higher in people with deficiencies in the anterior cruciate ligament in the knee than in their contralateral leg or uninjured subjects leg. Functional knee instability is related to the latency in the contraction of the hamstrings. It can be concluded then that latency in muscle contraction is a proprioceptive measure that can be used to provide data for the management of patients with chronic ACL deficiency (Beard et al. 1993).

The lack of dynamic neuromuscular control of the knee (active component) is also described as a risk factor (Hewett et al. 2005). Neuromuscular recruitment pattern compromises the active structures submitting the passive structures of the joint to a larger load decreasing the joint stability and increasing the risk of a knee injury (Mascaró 2007). The feeling of failure phenomenon is relevant to determinate the knee instability parameters (Mascaró 2007).

Prolonged exposure to eccentric contractions, which usually occur in many sports due to acceleration and braking tasks, jumps and spins, can also lead to a knee injury (Eston et al. 2003).

2.2.4 INTRINSIC MUSCLE INJURY RISK FACTORS

Alterations on the sensorimotor system which alters the ability to scale the volitional force and joint position precisely and accurately may also be a risk factor that can cause a muscle injury or a malfunction affecting the joint stability (Gleeson 2001).

It has been found that alterations on the sensorimotor performance after experimentally induced muscle damage may be due to various mechanisms:

- Alterations in the sensitivity of peripheral mechanoreceptors (Kuitunen et al. 2004).
- Changes in the signal of muscle spindles and reflex sensitivity (Saxton et al. 1995, Proske and Morgan 2001).
- Altered central processing methods by which the perception of the sense of effort is altered (Proske et al. 2004, Gregory et al. 2004).

The following risk factors are also described:

- Eccentric phase.
- Previous injury, usually considered the most important factor.
- Bad recovery.
- Early incorporation.
- Alterations in strength or imbalance.
- A quick change of the phase of the concentric contraction eccentric contraction has also been suggested as the mechanism of injury (Hoskins & Pollard 2005).

All the above exposed allow professionals to measure and train specific deficits in each individual to create injury prevention programmes. Since the risk of injury depends on many variables, a proper study of the person and its individual risks should allow monitoring what deficits are present in each individual, and test and measure the effectiveness of the selected interventions (Witchalls et al. 2012). Understanding the injuries and knowing what role of the risk factors associated with the injury is fundamental in planning preventive strategies (Renström and Johnson 1985).

CHAPTER 3: PREVENTIVE METHODS

There are many methods and formulas seeking improvements in physical activity performance. The more factors that could be controlled the better the results in the athlete's performance, but if an athlete gets injured, his career has to stop, and often for a long period of time. The treatment of sports injuries is often difficult, expensive and time consuming, therefore the prevention strategies are justified for both medical and economic reasons (Hertel 2002).

Physical therapists and sports trainers focus much of their work in strategies on injury prevention. Table 4 shows the elements and techniques required by athletes for injury prevention treatment

Table 4. Preferred prevention techniques as requested by athletes (Saragiotto et al. 2014).

Interventions/ Resources	Nutrition	Equipment	Sport technique	Others
Muscle strength	Nutrition support	Tape	Correction/adjustment of the sport technique	Periodic physiotherapeutic evaluation
Sensorimotor training	Supplementation	Orthotics		Early diagnosis
Stretching		Adequate shoes		Routine tests
Use of ice after match/training		Use of protective equipment		Environmental supervision
Relaxing and rest		Proper clothes		Odontology
Warm-up		Use of mouth guard		Environmental security training
Physical conditioning Massage				
Active recovery				
Electrotherapy Hydrotherapy Osteopathy				

From a PT intervention point of view, probably it should be promoted an active method and to use passive methods as a supplement (Table 5, when strictly necessary, because qualified professional are needed for its application and not always are available. Also some authors recognized these active methods or exercises as the only effective technique for joint injury prevention, demonstrating that with a specific work for joint stability, injuries may decrease without any other preventive technique (Ashton-Miller 1996, Verhagen 2010).

Table 5. Summary of the preventive methods.

ACTIVE METHODS		PASSIVE METHODS	
Specific work	Stretching	**Post-effort recovery**	**Ice**
	Technique work		**Massage**
	Strength work		Hydrotherapy and/or Electrotherapy
	Core training	**Protections**	Taping or orthosis
	Sensorimotor work		Correct Equipment
		Other factors	Nutrition
			Rest
			Medical examinations

PTs prevention techniques are based in three main pillars:

(1) Improvement of the sensorimotor system or neuromuscular enhancement, with active (different exercises) and passive techniques (devices and material).

(2) Recovery techniques.

(3) Joint protection techniques such as taping techniques.

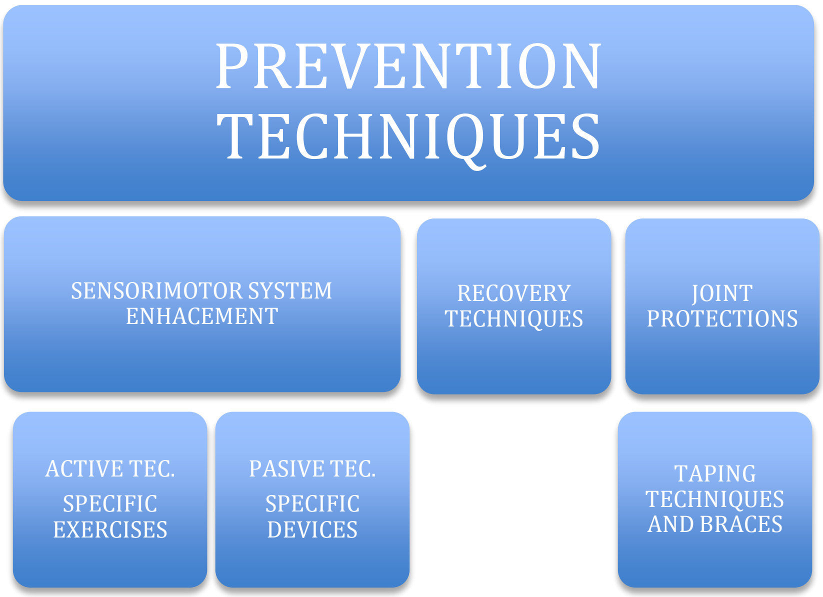


Figure 2. Preventive techniques in physical therapy.

3.1 SENSORIMOTOR SYSTEM ENHACEMENT

3.1.1 ACTIVE TECHNIQUES: PROPRIOCEPTIVE EXERCISES

Specific training techniques such as proprioceptive exercises are being used since 1965 when Freeman described the importance of specific exercises on unstable platforms to prevent instability on the foot.

Freeman noted that the recovery of joint stability after an injury of the ligaments of the tibio-peroneal-astragalus joint was not complete, even though the damaged structure (lateral ankle ligaments) recovered were apparently normal. In light of these results, Freeman concluded that although the total recovery of the tissue was completed, the injury had caused a disruption on the afferent proprioceptive system and this damage increased the joint instability (Freeman et al.1965).

Within the field of athletic training, neuromuscular training programmes that include balance exercises are often implemented with the aim of optimizing performance, preventing injury, or providing rehabilitation. Several authors have shown the effectiveness of these interventions in reducing sport-related injury risk as well as enhancing functional performance after sport injury (Zech et al. 2010).

On the basis of the results of seven high-quality studies, a meta-analysis showed evidence for the effectiveness of proprioceptive/neuromuscular training in reducing the incidence of certain types of sports injuries among adolescent and young adult athletes during pivoting sports (Hübscher et al. 2010). This meta-analysis revealed that multi-intervention training programmes were effective in reducing the risk of lower limb injuries by 39%, risk of acute knee injuries by 54%, and risk of ankle sprain injuries by 50%.

A more recent systematic review and meta-analysis of randomized controlled trials including 25 trials with 26,610 participants and 3,464 injuries, was analyzed. The overall effect estimated on injury prevention was heterogeneous. Stratified exposure analyses proved no beneficial effect for stretching [Relative risk (0 beneficial 1 no benefits) RR 0.963 (0.846–1.095)], whereas studies with multiple exposures (RR 0.655 (0.520–0.826)), proprioception training [RR 0.550 (0.347–0.869)], and strength training [RR 0.315 (0.207–0.480)) showed a tendency towards increasing effect. Both acute injuries (RR 0.647 (0.502– 0.836)] and overuse injuries [RR 0.527 (0.373–0.746)] could be reduced by physical activity programmes. Intention to treat sensitivity analyses consistently revealed even more robust effect estimates (Lauersen et al. 2013)..

Table 6. Injury prevention studies leading to a reduction in number of injuries after prevention programme

Pasanen et al. 2008. Finland	
Methodology	28 top level female football teams in Finland. One session.
Participants	457 players (mean age 24 years) - 256 (14 teams) in the intervention group and 201 (14 teams) in the control group followed up for one league season (six months).
Intervention	A neuromuscular training programme to enhance players' motor skills and body control, as well as to activate and prepare their neuromuscular system for sports specific maneuvers. The programme consisted of four exercises: running techniques, balance and body control, plyometric, and strengthening exercises. 20-30 minutes 3 days a week 1 season.
Outcomes and results	During the season, 72 acute non-contact leg injuries occurred, 20 in the intervention group and 52 in the control group. The injury incidence per 1000 hours playing and practice in the intervention group was 0.65 (95% confidence interval 0.37 to 1.13) and in the control group was 2.08 (1.58 to 2.72). The risk of non-contact leg injury was 66% lower (adjusted incidence rate ratio 0.34, 95% confidence interval 0.20 to 0.57) in the intervention group.
Olsen et al. 2005. Norway	
Methodology	120 team handball clubs from central and eastern Norway (61 clubs in the intervention group, 59 in the control group) followed for one league season (eight months).
Participants	1837 players aged 15-17 years; 958 players (808 female and 150 male) in the intervention group; 879 players (778 female and 101 male) in the control group.
Intervention	A structured warm-up programme to improve running, cutting, and landing technique as well as neuromuscular control, balance, and strength. 15 days then once a week 1 session.
Outcomes and results	During the season, 129 acute knee or ankle injuries occurred, 81 injuries in the control group 0.9 injuries per 1000 player hours; 0.3 in training *v* 5.3 during matches) and 48 injuries in the intervention group 0.5 injuries per 1000 player hours; 0.2 in training *v* 2.5 during matches). Fewer injured players were in the intervention group than in the control group (46 (4.8%) *v* (76 (8.6%); relative risk intervention group *v* control group 0.53, 95% confidence interval 0.35 to 0.81).

Hewett et al. 1999. USA	
Methodology	Female high school soccer, volleyball and basketball players. 1 session.
Participants	366 IG (females) 897 CG (463 females, 434 males).
Intervention	I.G.: 6 week preseason jump training programme, flexibility, plyometric and weight training. 3 sessions/week 60-90 min/day, total of 18 sessions.
Outcomes and results	0.43 female CG - 0.12 IG The untrained group had a knee injury rate, 3.6 times higher than the female intervention group

Mandelbaum et al. 2005. USA	
Methodology	Amateur female soccer players (ages 14-18 years) during 2 years
Participants	Year 2000: 1041 IG 1905 CG Year 2001: 844 IG 1913 CG
Intervention	I.G.:20 minute warm up prior to practices and games: 3 warm up techniques, 5 stretches, 3 strengthening exercises, 5 plyometric exercises, 3 soccer specific agility drills C.G: normal training.
Outcomes and results	Year 2000: 0.05/athlete/1000 IG, 0.47/athlete/1000 CG; Year 2001: 0.13/athlete/1000 IG, 0.51/athlete/1000 CG Significant differences was found between intervention and control groups with 88% reduction/athlete in 2000 season and 74% reduction/athlete in 2001 season.

Myklebust et al. 2003. Norway	
Methodology	3 seasons 1 control 2 intervention seasons. Female handball players.
Participants	1998/99: control season 942 participants 1999/00: intervention season 855 2000/01:: intervention season 850.
Intervention	15 minutes circuit floor exercises wobble board, balance mat. 3 times/week during 5-7 weeks training period then 1day/week during the season.
Outcomes and results	Number of injuries Control season: 29 (0,14/1000 player-hour) Intervention season 1: 23 (0.13/1000 player-hour Intervention season 2: 17 (0.09/1000 player-hour) No significant difference across the entire cohort but significant difference between those who completed the programme and those who didn´t in the elite division.

Petersen et al. 2005. Germany	
Methodology	Semi-professional ad amateur female hanball players 1 season.
Participants	IG: 134 players CG: 142 players.
Intervention	I.G.: Six phase balance board and jump exercise programme. 3 times/week preseason (8 weeks), 1 x week competitive season 10 min/ session. C.G.: no specific training.
Outcomes and results	1 intervention (0.04/1000 hours exposure*); 5 control (0,21/1000 hour exposure).

CG: Control group; min: minutes; IG: Intervention group..

3.1.1.2 PROPRIOCEPTIVE ABILITY ENHANCEMENT

Balance must be adapted to different situations, which are perceived through three sensory systems: vestibular, visual and somatosensory (which includes proprioception). The capture of the sensory information as the processing in a neural level involves the interpretation, conceptualization, planning, activation and execution of movement patterns that aim to react quick and coordinated by muscle activation against disturbances of the medium. If this sequence is altered, insufficient response is generated to maintain balance, which will increase stress and strain on the musculoskeletal system (Peterka & Loughlin 2003, Shumway-Cook & Woollacott 2007).

Although a person can lose balance due to a decrease in his visual system, a decrease in muscle strength, alteration of the vestibular system or due to joint instability, improving any of these factors can make enough influence to improve stability or balance (Lipsitz et al. 1991).

Recent studies demonstrated that balance exercises also improved strength and jumping abilities (Heitkamp et al. 2001, Bruhn et al. 2004, Gruber & Gollhofer 2004, Granacher et al. 2006, Kean et al. 2006, Myer et al. 2006, Gruber et al. 2007b, Taube et al. 2007) which influenced efficiently the maximum rate of force development (Gruber & Gollhofer 2004, Bruhn et al. 2006, Granacher et al. 2006, Gruber et al. 2007) and are capable of improving vertical jump performance (Kean et al. 2006, Taube et al. 2007).

Training also improves the interaction between sensory input and motor activity (Myer et al. 2006, Kean et al. 2006, Bressel et al. 2007) which is manifested in the improvement on balance, diminish muscle reaction time and improves the quality of the answer. It also decreases lower extremity injuries such as ankle sprains and muscle injuries (Myer et al. 2006, Kean et al. 2006, Alexandrov et al. 2005, Silsupadol et al. 2006), decreased falls (Suteerawattananon et al. 2002), improves the use of postural strategies (Olsen et al. 2005), and optimizes the position and symmetry of the weight load (Peterka & Loughlin 2003). The neuromuscular training can be use in early puberty to help preventing the development of a high risk biomechanical knee injuries that occur during this period of maturation (Ford et al. 2004).

Stability of the knee is provided through both preparatory and reactive muscle activity involving both feedforward and feedback processing (Solomonow & Krogsgaard 2001). Increased muscle activity can offer greater protection from the forces and loads experienced by lower-extremity joints during landing (Kellis 1998). The observed post intervention reduction in postural sway, together with the increases in jumping height and in rate of force development of the leg extensors, may contribute to improve performance in selected sport-related activities (e.g. long and high jump, 100m sprint, cutting movements in ball games, rebounding in basketball, blocking and smashing in volleyball, etc) (Granacher et al. 2010).

Since it has been observed that active methods as proprioception training programmes can reduce the number of sports injuries, researchers have tried to evaluate if this human quality could be enhanced by specific exercise work. The table below shows some examples of these types of studies and how they can be improved

Table 7. Literature Review on Neuromuscular Improvement (17 years span).

Bernier & Perrin. 1998. USA	
Methodology	3 groups duration: 6 weeks.
Participants	45 males and females 18 to 32 years old. With ankle instability 3 groups: CG (N=14) Sham Group (N=14) IG (N=17).
Intervention	CG: no specific work SG: Sham treatment of electrical EG: 10 minutes/3 sessions/week during 6 weeks: Single leg stance on stable and unstable surfaces increasing time from 15-30 sec per exercise. 9 exercises increasing difficulty. Eyes open and closed were also used stimulation to the peroneus longus and brevis muscles.
Outcomes and results	**JPS:** No significant differences between groups postural stability Experimental Group: Significantly better ($p < .05$) than CG and SG.

Heitkamp et al. 2001. Germany	
Methodology	2 groups. duration: 6 weeks.
Participants	EG (N=15) 7/8 female/male 31.7+-5. CG (N=15) 8/7 female/male 31.2±4.7 years.
Intervention	E.G.: balance training (25 min/ 2-3 session/week for 6 weeks); till 12 training units with Rubber ball, unstable plate. CG: strength training (25 min/ session, 2-3/week for 6 weeks) till 12 training units with leg press-leg curls.
Outcomes and results	**Outcome and results:** NC for Standardized Mean Difference (95% Confidence Interval) **Single-leg stance time on a small edge:** Improvements in EG ($P < .01$) and CG ($P < .05$) **Single-leg stance on unstable platform:** Improvement in EG ($P < .01$) No changes over time (number of ground contacts) in CG **Isokinetic MVC** (knee flexion-extension): Improvements in both muscles in EG and CG ($P < .01$).

Emery et al. 2005. Canada	
Methodology	2 groups. **duration**: 6 weeks.
Participants	EG (N=66) Healthy High school students girls and boys CG (N=61).
Intervention	EG: Balance training (20min/ session, 3sessions/week for 6 weeks, home based balance training using a wobble board CG: no specific work.
Outcomes and results	**Outcomes and Results:** (NC for Standardized Mean Difference (95% Confidence Interval) **Single-leg stance time on hard surface** (Eyes Closed): Improvement ($P < .001$) for EG **Single-leg stance time on balance pad** (Eyes Closed): Improvement ($P < .001$) for EG.

Yaggie & Campbell. 2006. USA	
Methodology	2 groups. **duration**: 4 weeks.
Participants	Males and females age = 22.7 +/- 2.1 years EG.(N= 18) CG (N= 18).
Intervention	EG: balance training (20 min/ session, 3sessions/week for 4 weeks). CG: no balance training.
Outcomes and results	**Single-leg dynamic postural sway (EO) on a force plate:** decrease in EG for total sway, no change in CG 0.65mm(-1.32, 0.03) **Single-leg stance time on a balance trainer:** decrease in EG and CG 0.37sec. (-0.29, 1.03) **Shuttle run time:** Decrease in EG and no change in CG 0.21mm (0-.44, 0.87) **Jump height (jump and reach):** no group x time interaction -0.64cm (-1.32, 0.03) .

Kean et al. 2006. Canada	
Methodology	3 groups. duration: 6 weeks.
Participants	All females 24.2 (4.1) years. EG 1: (N=11) balance training group EG 2: (N=7) jump landing training group CG: (N=6).
Intervention	EG1: fixed foot balance training (20 min/session, 3 sessions/week for 6 weeks) with wobble board EG2: jump-landing balance training (20 min/session, 3 sessions/week for 6 weeks) with functionally directed (landing from a jump) balance training CG: no balance training.
Outcomes and results	Outcomes and Results: NC for Standardized Mean Difference (95% Confidence Interval) Isometric MVC (knee flexion-extension, plantar flexion): No group x time interaction Pre landing EMG activity (for the quadriceps, hamstrings, plantar flexors): No group x time interaction Post landing EMG activity (mean RMS for the quadriceps, hamstrings, plantar flexors): Main effect (P .01) for reactive rectus femurs activity improvements (P >.01) for EG1 Jump height (contact mat): Improvement (P < .05) for EG1 20-m sprint performance Single-leg stance (No. of ground contacts during a 30-s wobble-board balance test) No group 3 time interaction Improvement (P <.05) for EG 1.

Myer et al. 2006. USA	
Methodology	2 groups **duration** 7 weeks.
Participants	All females. EG: (N=11) 15.9 ± 0.8 years. CG.: (N=8) 15.6 ± 1.2 years.
Intervention	EG: balance training (90 min, 3/wk for 7 wk); with Jumps/ box drops/bosu/swiss balls/single leg CG: plyometric training (90 min, 3/wk for 7 wk) with Leg press/squats/dumpbell/russian hamstring.
Outcomes and results	Outcomes and Results: NC for Standardized Mean Difference (95% Confidence Interval) Jump height No group Increases in EG and CG (P <.001) Single-leg postural sway after jump landing: No group Decrease for medial-lateral sway in EG and CG (P< .05) Isokinetic MVC (knee flexion-extension): No group Increases for knee-flexor peak torque in EG and CG (P<.01).

Filipa et al. 2010. USA	
Methodology	2 groups **duration** 8 weeks.
Participants	20 females soccer players EG: (N=13) 15.4 ± 1.5 years CG: (N=7) 15.4± 1.5 years.
Intervention	EG: 45 minutes/2 sessions/8 weeks worked with strength/balance/core training/ Airex hop and hold / Swiss ball bilateral kneel CG: no specific work.
Outcomes and results	**SEBT** composite score (mean ± SD) on the right limb (pre training, 96.4% ± 11.7%; post training, 104.6% ± 6.1%; P = .03) and the left limb (pre training, 96.9% ± 10.1%; post training, 103.4% ± 8.0%; P = .04). The control group had no change on the SEBT composite score for the right (pre training, 95.7% ± 5.2%; posttraining, 94.4% ± 5.2%; P = .15) or the left (97.4% ± 7.2%; 93.6% ± 5.0%; P = .09) limb.

Granacher et al. 2010. Switzerland	
Methodology	2 groups **duration**: 4 weeks.
Participants	20 high school students. women (N= 14) and men (N = 6) EG: (N= 10) CG: (N=10).
Intervention	EG: specific balance training during physical education classes (e.g., soft mat, ankle disk, balance board, air-cushion). 3 days a week. CG: No specific work.
Outcomes and results	Postural sway on a balance platform: Significantly improved. Jumping height on a force platform: Increased. Maximal isometric leg extension force on a leg-press: Enhanced rate force.

Sukwon & Thurmon. 2012. South Korea	
Methodology	3 groups. duration 8 weeks.
Participants	2 males and 22 females started, 18 finished EG 1: (N=6) balance training EG 2: (N=6) strength training CG: (N= 6).
Intervention	EG1: Balance Training with Stability Trainer 11 exercises with 10 repetitions of 3 sec duration each. EG2: 5 weeks; 3 sets of 10 repetitions with 50% of maximum exertion for 2 weeks and 3 sets of 10 repetitions for 70% of maximum exertion for 3 weeks. Strength phase lasted for the last 3 weeks; 3 sets of 7 repetitions with 85% of maximum exertion. CG: no specific work
Outcomes and results	Ankle joint stiffness: only EG1 showed improvements Joint stability: both EG1 & EG2 groups showed improvements.
Gioftsidou et al. 2012. Greece	
Methodology	compare 2 different balance training programmes based on distinct frequencies to improve proprioceptive ability in professional soccer players.
Participants	38 professional soccer players divided randomly in 3 groups Group A: 6 times per week during 6 weeks Group B: 3 times per week during 6 weeks Group C: control group.
Intervention	Group A & B: 20 minute with different exercises on a hemi-cylindrical board and hemi-sphere board. Group C: no specific training.
Outcomes and results	Electronic stability: System: Both groups improved significantly compared to control group. Wooden balance time of balance: Both groups improved significantly compared to control group.
Sannicandro et al. 2014. Italy	
Methodology	2 groups. duration: 6 weeks.
Participants	EG: 4 females, 7 males; 13.2 ± 0.9 years CG: 4 females, 8 males; 13.0 ± 0.9 years.
Intervention	EG: 30 minutes/2 sessions/week 6 weeks with balance training bosus, dumbells, dina disk, squats on bosu, elastic bands/medicine balls CG: 30 minutes/2 sessions/week 6 weeks tennis drills.
Outcomes and results	one-leg hop test: EG improved ($p < 0.001$); Side-hop test: EG improved ($p < 0.001$); Side steps and forward 4.115-m test: EG improved ($p < 0.05$), 10 and 20m sprint test: no significant differences; Forearm test: No significant differences.

CG: control group; EG: experimental group; EMG: electromyogramme; EO: eyes open; JPS. Joint position sense,; MVC: maximum voluntary contraction; NC: no comment; SEBT: star excursion balance test; SD: standard deviation; SG: sham group

Many studies in the past two decades were reviewed to check if this type of specific training was able to improve proprioception or the sensorimotor system.

The first study tried to determine the effects of coordination and balance training during 6 weeks with 45 people with ankle instability. Subjects were divided into 3 groups, placebo, control and experimental group which trained 3 days per week for 10 minutes a day performing various balance and proprioception exercises. Postural sway and JPS were measured. It was found that the experimental group improved in balance in both anterior and medial directions and post-lateral, but did not improve in the JPS (Bernier & Perrin 1998).

Another study compared the effects of balance training versus strength training. 15 healthy participants trained balance and 15 trained strength for 6 weeks, twelve sessions of 25 minutes duration. Balance training was done on unstable surfaces. The force group trained in leg machines. Balancing on one leg and isometric strength in isokinetic were measured, as well as the muscular balance between dominant and non-dominant leg. The strength gain was similar in the two groups. The improved balance test was 100% in the balance group compared to the strength group and decreased the difference between dominant and non-dominant leg (Heitkamp et al. 2001).

Emery et al. studied the effectiveness of balance training programme at home using unstable tables to improve static and dynamic balance. 6 weeks training was applied, balance time in static and dynamic, 20 meters circuit and vertical jump was measured. The results showed an improvement in all aspects and decreased the number of injuries among those who performed the exercises (Emery et al. 2005).

Another study attempted to determine the effect of 4-week balance training on specific tasks. 36 subjects in both groups were selected. They trained using a bosu. The results showed an improvement over time in equilibrium, circuit race, and postural sway (Yaggie & Campbell 2006).

The aim of another study was to determine the effects of balance exercises with fixed feet or functional exercises in static balance, muscle activation in landing, vertical jump and time in a sprint exercise. 3 groups, balance, jump landing and control, trained 4 times a week for 6 weeks, except for the control group. The group trained with fixed foot balance improved stability by 33%, 9% the vertical jump and increased the reaction activity of the muscles on landing (Kean et al. 2006).

Neuromuscular training protocols that include plyometrics and dynamic balance improved biomechanics and neuromuscular performance and reduced the risk of ACL injuries in female athletes' knee. The purpose of this study was to compare separately the two types of exercise, dynamic balance and plyometrics to see the effect on power, balance, strength and landing force in female athletes. 19 athletes trained for 3 days a week for 7 weeks. Both groups decreased the impact force, the hamstrings force increased, diminished center of pressure deviation on the two axes. Increased vertical jump with the two types of exercise should be included in the preventive work (Myer et al. 2006).

Filipa et al. sought to test the effect of a neuromuscular training focused on core stability and strength of the lower limb in test execution SEBT. This test is used to measure the dynamic stability, to monitor the rehabilitation progress, to measure test deficits after injury, and to identify athletes at high risk of injury. They trained for 8 weeks and a significant increase was observed in the test SEBT for the trained group (Filipa et al. 2010).

After confirming that deficits in lower extremity strength and postural control have been associated with a high risk of sports injury and that many of them occur during physical education classes, a study was conducted to see the effects of balance training in postural balance, leg extensor strength and vertical jump in adolescents. Two groups control and exercise, of 10 subjects each, trained during 4 weeks three days a week. Postural control was measured in a balance platform, jump height on a force platform, and maximal isometric strength in a leg press. The trained group improved in all measured aspects. Physiological adaptations rather than learning effects appear to be responsible for these findings. These results may have an impact on the improvement of performance in different sports and the reduction in prevalence of lower limb injuries (Grancher et al. 2010).

Another study evaluated the effects of an 8-week training exercise balance or weight training on ankle joint stiffness and joint stability in elderly people. 18 participants were divided in 3 groups (balance, weight and control group). Balance and joint stiffness only improved in the balance group and both training groups improved in stability. These two aspects rigidity and stability have a probable effect on the likelihood of falls (Sukwon & Thurmon 2012).

Gioftsidou et al. in 2012 wanted to evaluate the if the training intensity could influence in the improvement of balance and stability, after a 6-week period training. They showed that the results were the same training 3 or 6 days a week.

The last study confirmed that balance training exercises are able to counteract/reduce the degree of asymmetry in lower-limb strength and balance in young tennis players. The experimental group (balance training) completed a total of 12 training sessions of 30 minutes duration, during a 6 week period. The control group followed an identical training schedule, but training sessions consisted on tennis-specific drills only. One-leg hop test (OLH), side-hop test (SH) and side steps and forward 4.115-m test (4m-SSF) were assessed. Performances in the 10 and 20m sprint tests and the Foran test were also assessed. The results revealed significant differences between pre- and post-training tests in the Experimental Group only: the degree of lower-limb asymmetry was decreased in the EG following completion of the training programme, as assessed using the OLH test ($p < 0.001$), SH test ($p < 0.001$) and 4m-SSF test ($p < 0.05$). A significant interaction and main effect of training was also observed in the EG: balance training led to a significant reduction in the percent of asymmetry in lower-limb strength, as measured using the SH ($p < 0.01$), 4m-SSF ($p < 0.01$) and OLH ($p < 0.05$) tests (Sannicandro et al. 2014).

An average of 32.55 minutes per session, 2.95 days a week and 6.3 weeks was used for this specific training in the papers reviewed above. The material used for the training was composed of unstable surfaces as wobble boards and bosus, and some of them used strength training.

Postural stability, one leg stance, SEBT test, shuttle run test, vertical jump and MVC were significantly improved.

3.1.1.3 TRAINING TIME

It has been demonstrated that active preventive techniques can avoid o diminish the number of injuries in sports, but the time of the training period remains unclear when de review was done.

In a systematic review about the neuromuscular improvement with balance or multistations training programmes, they concluded that the training programme periods vary from 5 to 90 minutes each training session and from 2 to 7 days a week. Training weeks were from 4 to 12 but no author examined the influence of the training doses, so we can just speculate about training time. The difference between people measured and time worked makes impossible to agree with a minimum work period (Zech et al. 2010). All the studies showed improvement.

It is also described in the literature that training periods vary from 4 weeks to months and days of performance during training weeks are very uneven (Sheth et al. 1997, Eils & Rosenbaum 2001, McGuine & Keene 2005, Mandelbaum et al. 2005, Kidgell et al. 2005, Fort et al. 2009, Hoffman & Payne 1995), showing the same results working 1 day/week than 5 days/week, and high/low loads (Kidgell et al. 2005), but methodological limitations in some cases and measurements and population differences makes approximations to time work difficult to stablish (Zech et al. 2010).

Subasi et al. (2008) study tried to determine the time effect in a specific warm up to improve balance and knee proprioception. 30 men and women (20.7 mean age) worked in 2 groups for 5 and 10 minutes, they assessed JPS at 15, 30 and 60 degrees of knee flexion and the balance was measured using a neuro balance master system. Both groups improved although the 10 minutes group improved more.

Several studies have shown results in four to eight weeks with an average time of three sessions a week, fifteen to thirty minutes per session for balance training (Gribble et al. 2004, Sinhvonen et al. 2004, Bellew et al. 2005, Emery et al. 2005, Kean et al. 2006, Plisky et al. 2006).

So far, there are no scientific guidelines concerning the optimal duration and intensity of these exercises and thus, there is large variation in these parameters (Taube et al. 2008). Despite these investigations, it has not been determined the time and minimum frequency required to obtain objective results, although Hertel et al. found that the postural control returned to normal values after 4 months (Hertel et al. 2001).

Table 8. Review of sessions and weeks based on table 7 studies.

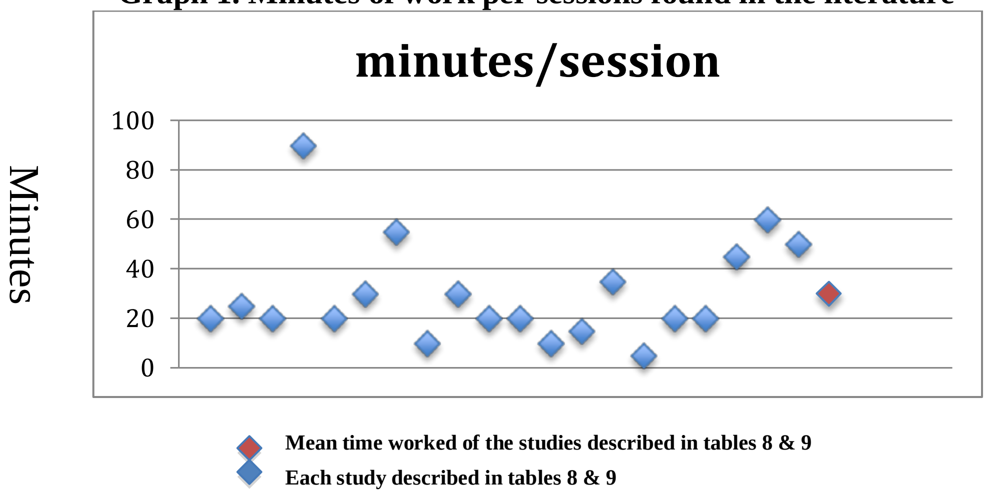
Authors	Time (minutes)	Sessions / week	Weeks	Total time recorded (minutes)	Results
Emery et al. 2005	20	3	6	360	Single leg stance on hard surface* Single leg stance on balance pad*Less injuries*
Heitkamp et al. 2001	25	2	6	300	Single leg stance on a small edge* and on unstable platform* MVC*
Kean et al. 2006	20	4	6	480	Single leg stance* Jump height*
Myer et al. 2006	90	3	7	1890	No improvements
Yaggie and campbell 2006	20	3	4	240	Single leg dynamic sway on force plate. Single leg stance. Shuttle run
Granacher et al. 2010	30	2	4	240	Improve ankle joint stiffness and joint stability*
Filipa et al. 2010	55	2	8	880	Improve in SEBT*
Bernier and Perrin 1998	10	3	6	180	Improve JPS, postural stability*
Sannicandro et al. 2014	30	2	6	120	One leg hop test* Side hop test* Side steps and forward 4.115-m test*
Gioftsidou et al. 2012	20	3	6	360	Balance improvement*
Gioftsidou et al. 2012	20	6	6	720	Balance improvement*

* significant results; JPS: joint position sense; MVC: maximum voluntary contraction; SEBT; star excursion balance test.

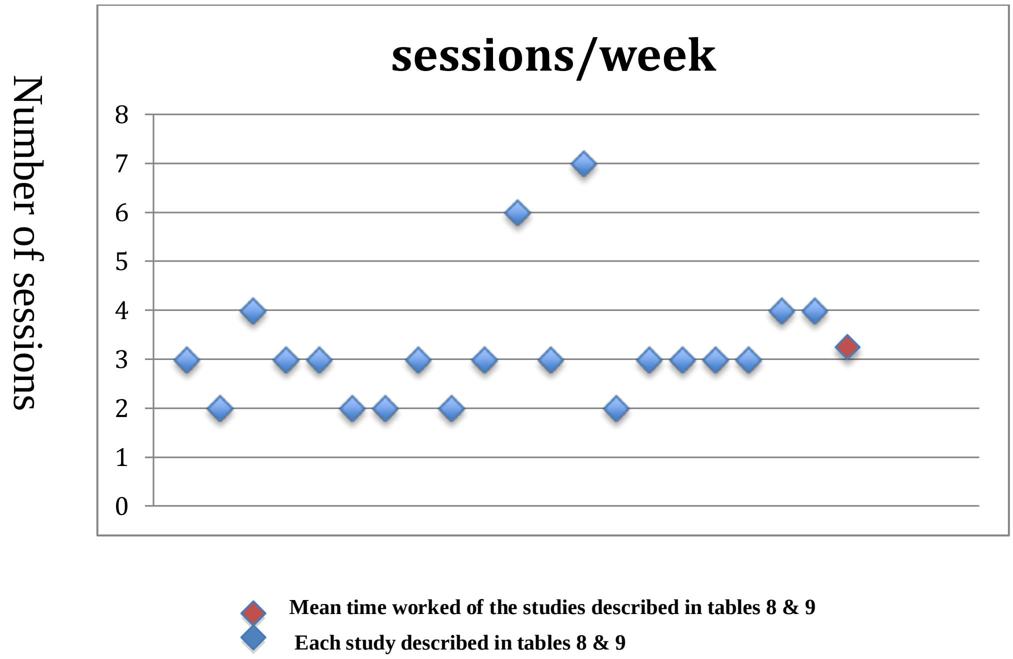
Table 9. Time used in other literature studies seeking proprioception improvement or injury prevention.

Authors	Time (minutes)	Sessions / week	Weeks	Total working time (minutes)
Hoffman and Payne 1995	10	3	10	300
Söderman et al. 2000	-15	7	4	420
Swanik et al. 2002	30 - 45	2	6	540
Riemann et al. 2003	10 x 3 repetitions 5 minutes	3	4	60
Kovacs et al. 2004	20	3	4	240
Gioftsidou et al. 2006	20	3	12	720
Taube et al. 2007	45	3	6	810
Gruber et al. 2007	60	4	4	960
Schubert et al. 2008	50	4	4	800

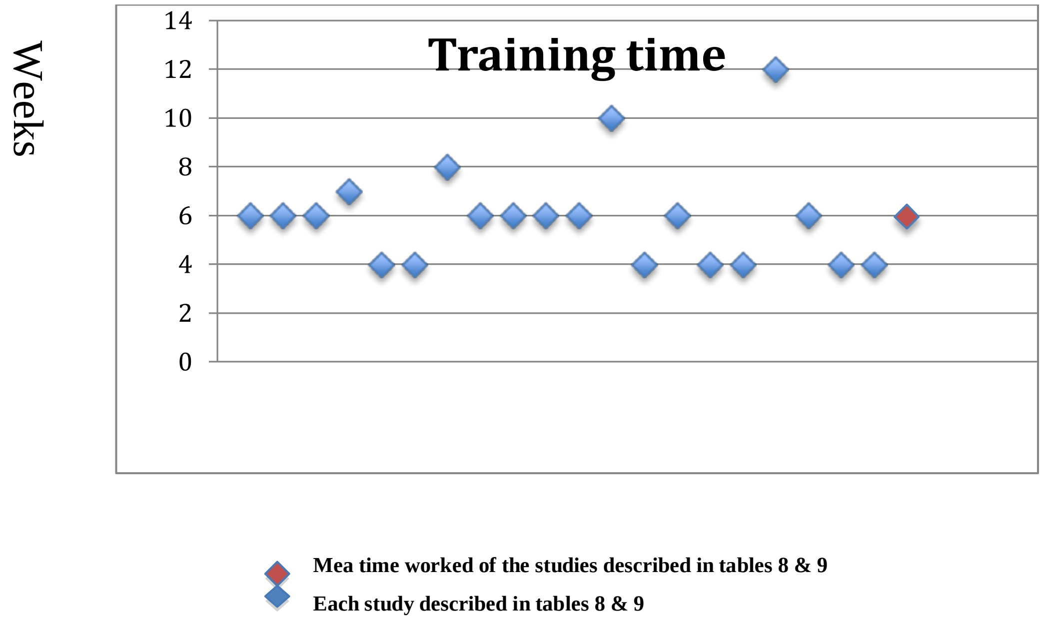
Graph 1. Minutes of work per sessions found in the literature



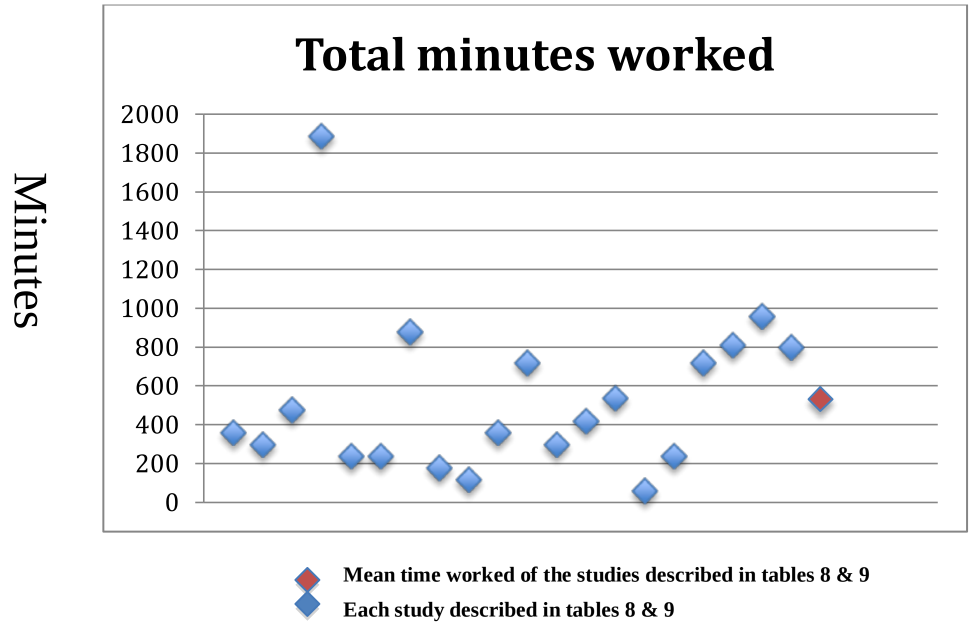
Graph 2. Total sessions per week of work found in the literature.



Graph 3. Number of weeks used in the training programmes



Graph 4. Total time worked in the different programmes.



3.1.2 PASSIVE TECHINQUES

PTs also use other passive methods, besides electrotherapy. These methods can be used as an injury prevention technique with the same goal as the active methods (specific exercises) attempting an improvement on sensorimotor and proprioceptive system capabilities in order to avoid the neuromuscular risk factors described. These methods are:

- Whole body vibration platforms (WBV) (Moezy et al. 2008)
- Neuromuscular taping seeking a stabilizing effect on some of the joints of the body improving proprioceptive abilities (Biccici 2012, Morris et al. 2012). Several authors highlighted its use in amateur and professional athletes with an injury preventive purpose. (Williams et al. 2011, Thelen et al. 2008, Firth et al. 2010)
- Stochastic Resonance technique.

3.1.2.1 STOCHASTIC RESONANCE

Stochastic Resonance (SR) is a new therapy which has potential benefits for improving proprioceptive function and involves the use of subthreshold electrical stimulation. SR is a phenomenon in which the response of nonlinear systems (e.g. somatosensory) to weak input signals can be optimized in the presence of a specific low level of noise (mechanical or electrical). The net result of the SR stimulation is heightened somatosensory sensitivity. SR effects were initially shown to increase the sensitivity of cutaneous and muscle spindle receptor systems (Collins et al. 2009).

SR is a method by which subtle levels of additional stimulation are added to those normally presenting to the afferent peripheral nervous system during functional activities (Rosset al. 2007). The additional random noise associated with stochastic resonance can be delivered by mechanical (for example vibration) but must be at a level that is not perceived by the recipient (known as sub-threshold stimulation) and so is entirely painless to him/her (Ross 2007).

In other words, SR stimulation in the form of random sub sensory electrical noise causes sub-threshold sensorimotor signals to exceed threshold, allowing weak sensorimotor signals related to joint motion to become detectable (Cordo et al. 1996). SR introduces low levels of noise into the nervous system to enhance the detection of sensorimotor signals related to postural control (Gravelle et al. 2002, Priplata et al. 2002, Priplata et al. 2003, Collins et al. 2003).

3.1.2.2 STOCHASTIC RESONANCE BENEFICTS

SR has been causally related to enhancements in functional balance and postural sway parameters (Ross et al. 2007, Ross 2007). SR stimulation did augment also overall JPS performance compared with placebo and control; adding to the literature that SR stimulation may be effective at attenuating sensorimotor deficits (Collins et al. 2009). Evidence also indicates that SR stimulation enhances monosynaptic reflex responses generated by muscle spindles (Martinez et al. 2007). Thus, this information indicates that SR stimulation enhances the sensitivity of sensorimotor input and affects central nervous system output. SR stimulation therapy has been useful for improving postural stability in healthy young and elderly individuals when compared to postural stability tests without stimulation (Gravelle et al. 2002, Priplata et al. 2002, Priplata et al. 2003, Collins et al. 2003).

Gravelle et al. (2002) investigated the effects of SR stimulation applied at the knee and found a reduction in postural sway in elderly subjects. Enhancement of somatosensory function through the use of SR has also been tested in subject populations with diabetes, stroke patients, and functional ankle instability patients (Ross & Guskiewicz 2006, Collins et al.2009).

3.**1.3 JOINT PROTECTION: TAPING TECHNIQUES**

Preventive taping has become a common practice in sport and some studies that its use reduces the number of sports injuries (McIntyre 1983, Meana 2002, Mickel et al. 2006, Verhagen & Bay 2010, Franklyn-Miller et al. 2011, Cordova et al. 2011).

It is important to understand that preventive taping is defined as any tape made with rigid or elastic material designed to avoid one or more movements of a healthy joint that may be susceptible of injury (Bové 1989, Neiger 1990). With this definition, it is understood that preventive taping techniques will limit the ROM of the joint itself to prevent injuries (not cure). The preventive tape will be placed on healthy joints, joints susceptible to injury, or joints that have being injured before. If placed on an injured joint its function would be called therapeutic taping (Bové 1989, Neiger 1990).

Note that taping techniques are often used in sports indiscriminately, without any purpose, just as placebo to make athlete feel more secure (Abián et al. 2006, Pérez 1997, Camacho 2011). But taping techniques are a common practice among PTs, although subjects may find some disadvantages using them due to:

- Each athlete must have access to qualified professionals who conduct appropriate taping for the activity they performed.
- The economic cost of the material.
- Dependence.

- Most taping loses its effectiveness after 20 minutes of application (Vincenzino et al. 1997;Abián et al. 2006; Sacco Ide 2006; Nolan D.& Kennedy N 2009).

- Dependence of same therapist for the implementation of the taping.

Some authors defend the effectiveness of preventive taping in ankles, although it does exist some controversy on this (Cordova 2011). Among those who position themselves against these techniques are the ones who believe that is better to use external orthosis, proprioceptive work or less restrictive taping techniques (Nackean et al. 1995, Abián et al. 2009, Green & Hillman 1990, Verhagen & Bay 2010, Ashton-miller 1996, Mickel et al. 2006). There are also studies showing that taping can lose its effectiveness after 20 minutes of application (Abián et al. 2006, Nolan & Kennedy 2009) or, as a research by the University of Castilla la Mancha, others that proved taping with elastic materials to be more effective in terms of movement restriction and comfort than rigid ones usually used in sports (Abián 2009). Finally, other studies showed that with a specific work for joint stability, injuries may decrease without any other preventive technique (Ashton-Miller 1996, Verhagen 2010).

An incorrect application of the tape or an unspecific goal may predispose an athlete to suffer an injury or increase the severity of the existing one (Morris & Mellion 2000).

CHAPTER 4: TRAINING PROGRAMME

The expression proprioceptive training is incorrectly limited to the perception of afferent input and does not take into account adaptations occurring on the motor side (Ashton-Miller et al. 2001). The literature has tried to resolve this limitation on the nomenclatures by giving several names to these type of specific training;

- Proprioceptive training (Wulker & Rudert 1999, Chong et al. 2001).
- Balance training (Bernier & Perrin 1998, Heitkamp et al. 2001).
- Sensorimotor training (Banaschewski et al. 2001, Gruber & Gollhofer 2004).
- Neuromuscular training (Paterno et al. 2004).

All of them though refer to the same type of specific training that can be performed by athletes, children, elderly and disabled people making this training a beneficial tool adapted to multiple target groups (Heitkamp et al. 2001, Granacher et al. 2006, Myer et al. 2006, Yaggie & Campbell 2006, Beck et al. 2007, Gruber et al. 2007, Taube et al. 2007).

Conventional training programmes have included fixed foot balance exercises, or unstable balance exercises using bosu balance training, ankle disk training, which improves speed reaction (Kean et al. 2006), wobble board training, Swiss balls, and other equipment that challenge participant´s balance. They have been introduced as part of the rehabilitation and training programmes (Kean et al. 2006) and also included in proprioceptive training. Jump-landing training is also an important part of athletic training especially when considering activities that often lead to injuries (jump landings) and require strength and power (Bernier & Perrin 1998). During this type of work is required to include stable and unstable exercises to activate balance stressors (Suteerawattananon et al. 2002).

Nowadays preventive prorammes tend to be more precise (individualized) and specific (multifactorial training). Current studies focus on Proprioceptive training as a preventive measure. These training include strength, flexibility, plyometrics, sports specific agility drills, speed enhancement, balance, and athlete education as part of the programme (Hewett et al. 1999, Heidt et al. 2000, Myer et al. 2004, Holm et al. 2004, Myklebust et al. 2003, Paterno 2004, Mandelbaum et al. 2005). Other authors described

Proprioceptive training as a combination of balance, weight, plyometric, agility, and sport-specific exercises, biomechanics, core stability techniques to induce neuromuscular changes and potential injury prevention effects (Hewett et al. 1999, Engebretsen et al. 2008, Söderman et al. 2010, Mandelbaum et al. 2005, Myer et al. 2005).

Exercises such as jogging, swimming or cycling increase strength, but specific exercises are those that improve proprioception and thus the balance or stability (Xu et al. 2004). These specific exercises are usually known in clinical literature with the name of proprioceptive training.

The design of a proprioceptive training programme can be complex. Information about the individual, accident, severity of injuries and etiologic basis are key aspects to have into account when design a proprioceptive prevention programme (First World Congress on Sport Injury Prevention. Oslo, Norway 2005).

During proprioception exercises, notice of the rebalance therapy of the locomotive system (TRAL) is important. TRAL relates to the coordination and harmony of movements. Imbalance and patient's fear will increased stress and pain to avoid this breathing exercise are recommendable. The position of the head is another important aspect of TRAL workings. The eye reflexes are required to keep eyes on the horizontal (control midbrain) and the vestibular system determines the position of the head to the vertical (Stasinopoulos 2004).

It is important then to review the literature to observe all type of exercises used to improve neuromuscular performances or prevent sports injuries to create a proper training protocol. Neuromuscular training protocols can significantly improve biomechanics and neuromuscular performance and are effective in increasing measures of neuromuscular power and control (Myer et al. 2006).

4.1 STRENGTH TRAINING

The initial gain in strength during strength training is based on the improvement of neuromuscular function, morphologic or metabolic adaptations develop later. This initial gain in strength may be explained by the improvement of the intramuscular and intermuscular coordination, as well as by more economic activation of agonist, thus achieving a stabilization of the extremities (Heitkamp et al. 2001).

Strength training reduced sports injuries to less than one third (Lauersen et al. 2013). It has been demonstrated that joint instability can contribute to a lower force (Anderson & Behm 2004, Anderson & Behm 2005, Kornecki et al. 2001) and an increasing fatigue (Mattsson & Brostrom 1990). An incorrect ratio of agonists or antagonists may be the cause of an injury (Baumhauer et al. 1995, Fox 2008). Muscle training is therefore one of the exercise to be include in any proprioceptive training programme (Dvorak & Junge 2000, Docherty et al. 2006, Anderson & Behm 2005, Kornecki et al. 2001).

An increase in the joint muscles' demand to maintain joint stability may decrease the strength of these muscles. Stability improvements can reduce the work of the stabilizing muscles allowing them to contribute more to the propulsion of the body when jumping or running. An individual with an unstable base may not be able to optimally send their driving forces in one direction (Kean et al. 2006).

Balance training has been showed to improve strength and reduce muscle (Kean et al. 2006). Strength training is one of the main components of the functional recovery phase, besides being one of the determining factors in preventing injuries (Balduni et al. 1987, Holme et al.1999, Kaminski & Hartsell 2002, Willems et al. 2002, Madras & Barr 2003).

The progression of muscular training work requires a complete joint range and no pain present which ensure less chance of injury (Kaminski & Hartsell 2002, Mattacola & Dwyer 2002).

Static or isometric strength activities should be worked in different angles of movement in order to make gains in strength. The literature recommends a duration of 6 seconds on each maximal isometric contraction performed, as after 5 seconds of muscle contraction, strength decreases gradually due to the onset of muscle fatigue (Kaminski & Hartsell 2002).

For both isotonic and isokinetic exercises several authors recommend emphasizing the eccentric work character as this plays a key role in the stability and dynamic control of the joint. Baumhauer showed how patients with higher risk of sprain ankles were those with alteration in the evertors / invertors and flexor / extensors ratios (Baumhauer et al. 1995).

4.1.1 ECCENTRIC EXERCISES

The importance of eccentric contraction in joint stability has been argued by several authors such as Baumhauer et al. (1995), Yildiz et al. (2003) and Fox et al. (2008). The important role of eccentric contractions in the development of strength and muscle mass has also been noted; Roig et al. (2008), included in his review a meta-analysis of 20 randomized controlled studies. He showed how eccentric training was more effective than concentric training for increasing strength and muscle circumference. Possible implications of strength training, emphasizing eccentric muscle contractions, in the rehabilitation and prevention of sports injuries have been studied in detail (Roig & Ranson 2007).

4.1.2 PLYOMETRIC WORK

Plyometric exercise is an activity that involves and capitalize on the mechanisms of stretch-shortening cycling to increase the efficiency of force production at a joint or increase performance (Chmielewski et al. 2006).

Plyometric trains the neuromuscular system to operate more powerfully so that the muscles are able to perform better in less time (Newton et al. 1999). Submaximal effort level with an emphasis on good technique or body position is used to train dynamic balance and proprioception. The aim of progression is to increase load and speed of movement. Higher level plyometric drills that mimic the sporting environment may be included.

Plyometrics also improve neuromuscular function, including joint position sense (proprioception) and postural control (balance). Swanik et al. (1999) found that plyometric training improved joint position sense and, in a series of studies conducted from 2004 to 2006, it was shown that plyometric work improved postural stability in single-leg stance test, trunk stability when landing from a jump and biomechanical measures relevant to lower limb injury risk (Paterno et al. 2004, Myer et al. 2006).

Plyometric exercises submit the joint to rapid loads and can improve the feedback and feedforward through the adaptation of the muscle due to the stretch of the receptors (Mascaró 2007).

4.2 CORE TRAINING

Core stability is defined as the dynamic trunk control which allows the production transfer and control of force and motion to distal segments of the kinetic chain (Kibler 2006). Core muscle activity precedes lower extremity muscle activity in the temporal sequence of many athletic tasks (Hodges & Richardson 1997). Delayed reflex response of trunk muscles appears to be a preexisting risk factor. Similarly, abdominal muscle fatigue may be a contributing factor to hamstring injuries. Retrospective examination of patients with ankle sprains shows a delay in the onset of muscle activation of the gluteal muscles compared with uninjured control subjects (Bohdanna et al. 2007).

Core stability training has been shown to be effective for both preventing and rehabilitating shoulders and knees injuries (McGill 2010). There is strong evidence suggesting that neuromuscular control of the trunk and lower extremity can be improved with neuromuscular training (Bohdanna et al. 2007). It is logical to think that a specific training to give core stability may reduce injuries in the limbs (McGill 2001, Juker & McGill 1998, Van Dieen & Cholewicki 2003, Leetun et al. 2004) and help the optimum production, transfer and force control to the extremities during complex movements (Kibler et al. 2006).

Implementation of a proprioception training programme that focuses on core stability exercises is advocated to prevent lower extremity injuries in athletes who have deficits in trunk proprioception and neuromuscular control (Zazulak et al. 2007). Poor core stability and decreased muscular synergy of the trunk and hip stabilizers have been linked to decrease performance in power activities and to increase of injury, especially in female athletes (Zatsiorsky 1995, Hewett et al. 2005).

Other studies have also observed alterations in body stability in patients with injuries of the lower extremity (Leetun & Ireland 2004), these alterations include temporary dysfunction in muscle activation (Ebenbichler et al. 2001), alteration of intermuscular coordination (Hubley-Kozey & Vezina 2002) and a proprioceptive deficit due to muscle fatigue (Taimela et al. 1999). These studies suggest that trunk stability plays an important role in the transmission of forces to the distal segments. It is therefore logical to consider that specific muscle training provides stability to the trunk and pelvis to reduce the number of injuries to the extremities (McGill & Cholewicki 2001).

Sherry and Best (2004) compared the effectiveness of conventional treatment with a lumbar stabilization protocol for recidivism of hamstring injuries. Compared with the group following a standard training, the group that followed a lumbar stabilization program showed, after a year, fewer injuries ($p = 0.0059$).

It can be concluded that lumbopelvic exercises help to protect the joint (Mascaró 2007), and that the performance of the lumbopelvic musculature is related to the function of the lower limbs and injuries (Willson et al. 2005).

4.3 AGILITY EXERCISES.

Agility exercises, also called shuttle runs, involve changes of direction which make them slightly more sport specific than traditional track workouts. Participants must accelerate between marked lines and rapidly change direction. They are also used as tests on proprioceptive studies (Noyes et al. 2012, Yaggie et al. 2006). Shuttle Runs are a simple exercise that helps develop agility, quickness and cardiovascular strength. It can be performed either in a gym or outdoors, on grass, turf or pavement surfaces and its timing and intensity can vary. This is a versatile exercise, which emphasizes change of direction and acceleration, is a great addition to any short-term or long-range workout plan.

Agility training is one example of neuromuscular control exercise that has been recommended for improving hamstrings muscle activation and enhancing dynamic knee joint stability by allowing a more rapid muscle response. Combined with plyometric training has also improved knee joint neuromuscular control during jump landings. Agility training has also effects on neuromuscular control during alternative movements associated with noncontact ACL. It can be concluded that agility training may also help to reduce knee injuries (Wilderman et al. 2009). Agility exercises can be effective in neuromuscular adaptations as the strength training programmes to prevent knee injuries (Edward et al. 2009).

4.4 MOVEMENT AWARENESS: reproduce and visualize the movement

The key training principle of specificity dictates that training for a sport should replicate the movement patterns and energy systems required for that sport (Benjaminse & Otten 2011). The ability to detect joint movement and be able to make postural adjustments in response to those movements is crucial in injury prevention. The ability to detect foot position before the backfoot touches the ground in the beginning of the stance phase is also crucial (Bernier & Perrin 1998).

Cells in the ‘mirror system’ acivate not only when an individual performs an action but also when one observes the same action performed by another agent (Iacoboni et al. 1999, Ferrari et al. 2003). These results indicate that the mirror properties of the mirror system are neither wholly innate (Meltzoff & Decety 2003) nor fixed once acquired; instead they develop through sensorimotor learning (Heyes 2001, Keysers & Perrett 2004). The addition of proprioceptive training can augment motor learning, and this benefit is greatest when the subject passively experiences the goal movement (Wong et al. 2012).

One goal of functional training is to practice movements in order to make them automatic. Ives and Shelley (2003) advocated that skilled motor performance can be best achieved if learners adopt a nonawareness type strategy. Nonawareness means having the athlete focus on solving a particular movement task rather than focusing on how they should move “correctly.”

Zoch et al. (2003) demonstrated the importance of the recovery of kinesthetic awareness in the rehabilitation of ankle injuries and Baltaci and Kohl (2003) confirmed this assertion and added that it is the only therapy with significant results (Baltaci & Kohl 2003, Zoch et al. 2003).

4.5 WORK PROGRESSION

After analyzing the parameters that need to be included in an injury preventive programme, it is also necessary to know the working progression for a neuromuscular improvement.

Although proprioceptive work after an injury cannot be the same as a preventive training, both must follow a progressive order. Proprioception exercises are useful for preventing injuries in low, moderately high and even high intensity activities. Work will be performed from analytically to global, from simple to complex, from low to high load, and joint mobility and muscle strength must be included, as Neiger suggests in his proprioceptive job advices (Neiger 1999).

A normal progression for proprioceptive work is moving from a position of no load to full load, from bilateral support to unilateral support, eyes opened to eyes closed, firm to unstable moving surfaces or irregular surfaces. The variation of surfaces and conditions is vast which gives the therapist a wide range of possibilities to offer new challenges to the subject during the period of rehabilitation or training. Also the therapist can play passive and active movements in the joint of the patient and ask him to reproduce them for improving joint receptors.

A common mistake in preventive programmes is the lack of variety of exercises and the speed and intensity of implementation (Neiger 1999, Carl et al. 2002).

The programmes must be individualized. In advanced stages the exercises should be focused on activities including exercises to earn the normal function of the specific sport. The therapist must choose exercises that challenge the neuromuscular coordination increasingly (Carl et al., 2002) hence the aforementioned importance of good analysis and good data of the activity (Van mechelen 1992).

4.6 MATERIAL AND EXERCISES

There are many types of exercises and material proposals on the Literature (table below) that can be used in neuromuscular training. These prevention or rehabilitation programmes can be accomplished with minimal investment. Exercises can be performed on stable surfaces, floors or playgrounds, unstable surfaces or platforms such as wobble boards that can be moved in different axes, given the therapist endless opportunities to vary an exercise program (Kean et al. 2006).

Table 10. Literature review - Exercises and material.

Exercises described in the literature	Material commonly use in the literature
The “11” (Soligard et al. 2010, Impellizzeri et al. 2013).	Wobble boards (Kean et al 2006, Emery et al 2005, Heitkamp et al. 2001, Rosenbaun 2001).
The harmoknee (kiani et al. 2010).	Stable surfaces (Kean et al. 2006).
Balance training (Filipa et al. 2010).	Own body (Herman et al 2012).
Shuttle runs (Mandelbaum 2005).	Unestable surfaces (Cressey et al. 2007).
Different Jumps exercises (Hewett 1999, Mandelbaum 2005, Kean et al. 2006)	Bosus (Myer 2007, Yaggie & Campbell 2006, Sannicandro et al. 2014).
Hops (Hewett 1999, Myer 2007,Mandelbaum 2005, Myer et al 2006,Filipa et al. 2010)	Air cushions airex (Myklebust 2003, Peterson 2005, Filipa et al. 2010, Grancher et al. 2010).
Box drops (Myer et al. 2006, kean et al. 2006).	Dina disk (Sannicandro et al. 2014).
Movement awareness (Benjaminse & Otten 2011).	Box (Myer et al 2006).
Sports techniques Strength exercises (Filipa et al. 2010, Cressey et al. 2007, Koppack et al. 2011).	Balance board (Grancher et al. 2010).
With elastic bands (Rosenbaun 2001, Beker et al 1998).	Ankle disk (Grancher et al. 2010).
Squats (Myer et al. 2006, Sannicandro et al. 2014).	Soft mats (Grancher et al. 2010, Rosenbaun 2001).
Russian hamstring curl (Myer et al. 2006).	SEBT or star excursion balance test, Freeman and boheler disks, Therabands (Sannicandro et al. 2014, Rosenbaun 2001, Beker et al. 1998).
Strength in unstable surfaces (Mandelbaum 2005).	Boxes and Sweden bench, Cones and strips, Weights or dumpbells (Myer et al 2006, Sannicandro et al. 2014)
Leg press leg curls (Heitkamp et al. 2001).	Swiss ball (Myer 2007,Heitkamp et al 2001, Filipa et al. 2010).
Plyometrics (Myer et al 2006, Mandelbaum 2005, Kidgell et al. 2005, Gilchrist et al. 2008, La bella et al. 2011).	Medicine balls (Sannicandro et al. 2014).
Core training (Myer 2007, Filipa et al. 2010,kiani et al. 2010) .	Aerobic step (Rosenbaun 2001).
Core training in unestable surface (Mandelbaum 2005).	
Excentric exercises (Baumhauer et al.1995, Yildiz et al.2003, Fox et al. 2008).	
Eyes open /close (Emery et al. 2005).	
Single leg stance (Myklebust 2003, Peterson 2005,Myer et al. 2006, Rosenbaun 2001).	
Jump landing (Kidgell et al. 2005).	
Agility training (Kidgell et al. 2005, Gilchrist et al. 2008, Labella et al. 2011).	
Stretching (Mandelbaum 2005, Gilchrist et al. 2008).	
Different Running Strides (Kean et al. 2006).	

Training programmes can also be designed with no devices, in fact, there are studies that show improvements in neuromuscular qualities without additional material (Herman et al. 2012).

There are also specific programmes recommended in the literature, which have proven good results to prevent injury, such as the "11+" (Impellizzeri et al. 2013) or “The harmoknee” (Kiani et al. 2010). Both the 11+ and the harmoknee programmes were proven to be useful as warm-up protocols improving proprioception at 45° and 60° knee flexion as well as static and dynamic balance in professional male soccer players (Daneshjoo et al. 2012).

Therefore, the conventional clinical work should always include exercises to improve joint stability (Ross 2007).

The literature has shown that deficits on athletes proprioception, balance, strength or ROM can lead to injury. Multidisciplinary training programmes have demonstrated not only the ability to reduce the number of sports injuries, but also the ability to enhace the mentioned injury risk factors. Despite a wide variety of exercise protocols have improved participants’ neuromuscular and balance habilities, it is unknown which is the time frame needed to gain those benefits.

CHAPTER 5: AIMS AND HYPOTHESIS

Objetivos:

1. Ser capaces de elaborar un programa de ejercicios específicos para la mejora de las capacidades propioceptivas y neuromusculares basándonos en la evidencia científica.

2. Comprobar si un entrenamiento intensivo mejora la conciencia del movimiento en sujetos sanos.

3. Comprobar si un entrenamiento intensivo mejora la fuerza y la conciencia de la misma en sujetos sanos.

4. Comprobar si un entrenamiento intensivo mejora el equilibrio en personas sanas.

5. Comprobar si como dice la literatura, el uso de resonancia estocástica mejora las capacidades propioceptivas en sujetos sanos.

6. Comprobar si sujetos entrenados con ejercicios específicos son más precisos en los test de propiocepción con resonancia estocástica.

Hipótesis

A) Un periodo corto e intensivo con un programa de entrenamiento multidisciplinario mejorará el equilibrio, la capacidad propioceptiva y neuromuscular de la pierna dominante de sujetos sanos.

B) Un periodo corto e intensivo con un programa de entrenamiento multidisciplinario sumado al efecto de la resonancia estocástica mejorará la capacidad propioceptiva de una forma más acentuada que el entrenamiento o la resonancia estocástica por si solos en la pierna dominante de sujetos sanos.

CHAPTER 6: RESEARCH

The acute effects of proprioception conditioning and stochastic resonance on functional balance and neuromuscular performance.

6.1 INTRODUCTION

As previously stated, there are many reasons to participate in sports and to practice regular physical activity. Bar et al named some, such as pleasure, relaxation, competition, socialization, maintenance, and improvement of fitness and health (Bar et al, 2003). Regular physical activity reduces the risk of premature mortality in general, and that of coronary heart disease, hypertension, colon cancer, obesity, and diabetes mellitus in particular (Warburton et al., 2005). The growing number of sport participants inevitably will increase the probabilities of injury occurrences. As some epidemiological studies have shown, musculoskeletal injuries constitute a major public health burden in many developed countries (Belechri et al. 2001, Conn et al. 2003). Although the benefits of sport practice surpass the cost of musculoskeletal injuries, the World Health Organization estimates that an investment of US$ 1 (time and equipment) leads to US$3.2 in medical cost savings.

As some authors have pointed out, sport injuries are not a randomized occurrence but, on the contrary, specific risk factors play a specific role (Bahr & Holme, 2003). Threats of injury are commonly grouped as Intrinsic and Extrinsic risk factors (Bahr & Krosshaug, 2005). The former refer to those factors that predispose the athlete to injury and influence the risk. The latter refers to all those factors that may modify the risk.

Table 11. Extrinsic and intrinsic risk factors for sports injuries (adapted from Bahr & Krosshaug 2005).

Intrinsic factors		Extrinsic risk factors			
Physical characteristics	**Psychological profile**	**Exposure**	**Training**	**Environment**	**Equipment**
Age	Motivation	Type of sports	Type	Type of playing surface	Protective equipment (e.g. helmet, shin guards)
Gender	Risk taking	Exposure time	Amount	Indoor vs outdoor	Playing equipment (e.g. footwear, clothing, racket, stick)
Body composition (e.g. body weight, height, BMI, anthropometry)		Position in the team	Frequency	Weather conditions	
Health (e.g. previous injuries)		Level of competition	Intensity	Time of season	
Physical fitness (e.g. muscle strength, aerobic fitness, joint range of movement				Human factors (coaching, referees, rules, team mates, opponents)	
Anatomy abnormalities					
Motor abilities and sports-specific skills					

Persisting functional deficits, such as limited postural control, decreased maximal strength, or prolonged muscle reaction time, after structural damage in lower extremity joint receptors, result from injuries or overuse (Zech et al. 2010). Alterations of the neuromuscular recruitment patterns compromise the active structures, subjecting the passive structures of the joint to a bigger load, a diminished stability and a higher injury risk (Mascaró 2007).

Within the field of athletic training, proprioception training programmes are often implemented with the aims of optimizing performance and preventing injuries, but the extent of variance in time and volume recommended for training by the literature, hinders identifying minimum periods for effective delivery of conditioning. Murphy et al. states that assessing neuromuscular performance and ordering specific multifaceted training programmes is necessary to prevent lower limb injuries (Murphy et al. 2003). Similarly, Bernier and Perrin assert that having greater proprioception capabilities enables the athletes to land after jumping more accurately and to prepare for impact, aiding in injury prevention (Bernier and Perrin 1998).

Proprioception is the awareness, both conscious and unconscious, of body extremity position (Riemann & Lephart, 2002). Knee proprioception deficits have a role in several clinical conditions or injuries (Cerulli et al., 2001). Knee proprioceptive deficits are known to occur after anterior cruciate ligament tears (Barrack et al. 1989) and proprioceptive training has been investigated as a means of preventing these injuries (Cerulli et al, 2001). Traditionally proprioception has been measured by a Join Position Sense test (JPS) (Beynnon et al, 2000).

The proprioception system is responsible for maintaining functional joint stability by integrating afferent and efferent signals with central information to activate dynamic restraints surrounding joints (Riemann & Lephart, 2002). Integration of afferent information from peripheral mechanoreceptors, central processing and efferent information contribute in a major way to effective muscular activation and joint acuity (Lephart & Fu 2000).

Proprioceptive training programmes have evolved to become more individualised and specific to the needs of the athlete and these are commonly named as “Multifaceted Training”). Current studies focus on proprioceptive training as a preventive measure, and these programmes of training include strength, flexibility, plyometrics, sports specific agility drills, speed enhancement, balance, and athlete education (Hewett et al.1999; Heidt et al. 2000; Myer et al. 2004; Holm et al. 2004;Myklebust et al. 2003; Paterno 2004; Mandelbaum et al. 2005). Other authors have described proprioceptive training as multi-intervention programs with a combination of balance, weight-lifting, plyometric, agility, and sport-specific exercises (Hewett et al.1999; Engebretsen et al. 2008; Söderman et al. 2010), while others focus attention on the use of biomechanics, technique and core stability training to induce neuromuscular changes and potential injury prevention effects (Mandelbaum et al. 2005; Myer et al. 2005).

Although the literature has different names for proprioceptive training, such as “Balance Training” (Bernier and Perrin 1998, Heitkamp et al. 2001), “Sensorimotor Training” (Banaschewski et al. 2001, Gruber and Gollhofer 2004) or “Neuromuscular Training” (Paterno et al. 2004), the aim is always the same; to improve the neuromuscular system and balance.

As previously shown, several authors have studied the effectiveness of poprioceptive training in reducing sport-related injury risk as well as in enhancing functional performance after sport´s injury. As a result of the low methodologic quality and training differences, within contemporary research, further research is strongly recommended (Zech et al. 2010). For example, a couple of recent reviews demonstrated that many of the interventions published in the literature have rated poorly for the inconsistent use of scales with which to judge the likelihood of methodological research bias. Stojanovic & Ostojic (2012) could only consider 9 studies out of 708 articles that had met the inclusion criteria using the McMaster Occupational Therapy Evidence-Based Practice Research Group scale. Consensus scores ranged from 3 to 8 out of 10. Nevertheless even seven out of nine studies demonstrated that training interventions have a preventive effect on ACLinjuries Collectively, the studies indicate that there is moderate evidence to support the use of multifaceted training interventions, which consisted of elements of condition such as stretching, proprioception, strength, plyometric and agility drills with additional verbal and/or visual feedback on proper landing technique to decrease the rate of ACLIs in team sport female athletes. The paucity of data preclude any conclusions for male athletes. In a more recent review, the authors were only able to locate and report on seven moderate-to-high quality randomized controlled trials, involving 3726 participants. (Schiftan et al., 2015) Results of the meta-analysis combining all participants, irrespective of ankle injury history status, revealed a significant reduction of ankle sprain incidence when proprioceptive training has been performed compared to a range of control interventions (relative risk= 0.65, 95% CI 0.55–0.77). Results favouring the intervention remained significant for participants with a history of ankle sprain (relative risk = 0.64, 95% CI 0.51–0.81). Results looking exclusively at primary prevention in those participants without a history were also statistically significant (relative risk = 0.57, 95% CI 0.34 to 0.97) (Schiftan et al., 2015).

This review concludes that poprioceptive training programmes are effective at reducing the rate of ankle sprains in sporting participants, particularly in those with a history of ankle sprain.

On the basis of the results of seven high-quality studies a systematic review with meta-analysis showed evidence for the effectiveness of proprioceptive training in reducing the incidence of certain types of sports injuries among adolescent and young adult athletes during pivoting sports (Hübscher et al 2010). This meta-analysis revealed that proprioceptive training programmes were effective in reducing the risk of lower limb injuries by 39%, the risk of acute knee injuries by 54%, and the risk of ankle sprain injuries by 50% (Hübscher et al 2010).

Balance training has the potential to reduce injury rates in the lower extremities (Emery et al. 2005; McGuine & Keene 2006). Those with poor balance (higher sway values) experience increased injury rates (Yaggie & Campbell 2006). Recent studies demonstrated that balance exercises are statistically significant in improving strength and jumping abilities (Heitkamp et al. 2001, Bruhn et al. 2004, Gruber & Gollhofer 2004, Granacher et al. 2006, Kean et al. 2006, Myer et al. 2006, Gruber et al. 2007b, Taube et al. 2007b), influenced the efficiency of maximum rate of force development (Gruber & Gollhofer 2004, Bruhn et al. 2006, Granacher et al. 2006, Gruber et al. 2007a), and were capable of improving vertical jump performance (Kean et al. 2006, Taube et al. 2007b).

Stochastic resonance (SR) is a new therapy which has potential benefits for improving proprioceptive function and involves the use of subthreshold stimulation by means of electrical or mechanical sources (Priplata et al. 2002). The literature confirms the isolated effectiveness of SR for improving proprioceptive parameters, and recently studies have focused more on the interactive or additive effects of SR in combination with exercise conditioning.

The SR devices produce oscillations that cannot be detected by the receptor, these constant stimuli force stiffness on the muscles, its randomness avoids the accommodation effect on the muscular system (Haas et al. 2004). The SR can be delivered by mechanical stimulation such as vibration, but must be at a level that is not perceived by the receptor (known as sub-threshold stimulation) and therefore senseless (Ross 2007). The SR application enhances the afferent information during functional activities (Ross et al. 2007).

SR systems are either sinusoidal, when a constant vibration frequency is delivered, or stochastic resonance vibration with random vibration frequencies and harmonics (Rogan et al., 2012). SR introduces low levels of noise into the nervous system to enhance the detection of sensorimotor signals related to postural control (Gravelle et al. 2002; Priplata et al. 2002; Priplata et al. 2003; Collins et al. 2003).

Proprioceptive training with SR stimulation has been reported to improve dynamic postural stability earlier and more efficiently than proprioceptive training alone (Ross &

Guskiewicz. 2006). In their study, participants had been divided into two groups, with both required to wear SR stimulator units during proprioceptive training sessions, although just one group had their units activated. Participants were blinded to their training group, the conclusions were statistically significant.

SR effects were initially shown to increase the sensitivity of cutaneous and muscle spindle receptor systems (Collins et al. 2009). Some authors have revealed that sample groups exposed to SR during training, had shown a statistically significant in functional balance and postural sway parameters compared to those groups that had undergo training alone (Ross et al. 2007; Ross 2007). SR stimulation had also augmented overall Joint Position Sense (JPS) performance for the experimental groups compared with placebo and control groups, adding to the literature that SR stimulation may be effective at attenuating proprioceptive deficits (Collins et al. 2009).

Thus, this information indicates that SR stimulation enhances the sensitivity of proprioceptive sensory apparatus input and affects central nervous system output. SR stimulation therapy has been useful in improving postural stability in healthy young and elderly individuals when compared to postural stability tests without stimulation (Gravelle et al. 2002; Priplata et al. 2002; Priplata et al. 2003; Collins et al. 2003).

A previous study investigated the effects of SR stimulation applied to the knee and found a reduction in postural sway in elderly subjects (Gravelle et al., 2002). Enhancement of somatosensory function through the use of SR has also been tested in subject populations suffering from diabetes, stroke, and functional ankle instability (Ross and Guskiewicz 2006; Collins et al., 2009).

A great deal of discrepancy exists in the literature regarding the timing and patterning of specific training needed to reduce the number of injuries in sport-related practices. The span of training sessions can vary from 4 to 12 weeks, repetitions vary from 2 to 7 sessions per week and the duration of individual sessions fluctuate from 5 to 90 minutes (Zech et al. 2010). Despite these differences, all studies had shown improved rates of injuries after the diverse range of training session were completed by the participants.

Another study tried to determine the effect of duration of specific warm up to improve balance and knee proprioception (Subasi et al., 2008). A sample of 30 men and women (with mean age = 20.7 years) worked in two groups for 5 and 10 minutes. The study assessed JPS at 15, 30 and 60 degrees for knee flexion and balance was measured using a Neurocome Balance Master system. Both groups improved but the 10 minutes group shown a higher statistical improvement (Subasi et al. 2008).

So far, there are no scientific guidelines concerning the optimal duration and intensity of these exercises and thus, there is large variation between these parameters (Taube et al. 2008).

The present study was designed to study a short, intense and multidisciplinary training programme conditioning with adjunct stochastic resonance on the functional balance, proprioception and neuromuscular performance of the dominant leg in asymptomatic individuals

6.2 HYPOTHESES:

C) A short, intense and multidisciplinary training programme will improve functional balance, proprioception and neuromuscular performance on the dominant leg in asymptomatic individuals.

D) A short, intense multidisciplinary programme of training (SIMPT) with adjuct stochastic resonance will improve proprioception performance to a greater extent than with SIMPT alone.

6.3 METHODOLOGY:

6.3.1 STUDY DESIGN

The study´s experimental design involved a prospective repeated-measure, controlled trial evaluating the effects of a proprioception conditioning programme conducted over a total period of 4 weeks. The conditioning programme (SIMPT) incorporated 18 sessions of specific multifaceted training delivered over a 6 day period. A corresponding control period of no exercise had preceded the experimental intervention to assess for potential carry-over effects within the repeated measures design.

Participants undertook prescribed exercises at a frequency of 3 sessions per day. For reasons of safety and experimental rigour, sessions were prescribed and overseen by a specialist physiotherapist, certified in exercise conditioning. Exercises were completed within a dedicated and controlled study' space either within the institution, or at an alternative gymnasium to which the subject had access.

Each session lasted between 10 and 20 minutes with an overall daily duration of training of between 40 and 60 minutes. Inter-session rest periods were at least three hours each.

Participants were instructed to refrain from strenuous physical activity for the 24 hours prior to testing. The design of the programme of conditioning was modelled on evidence derived from a systematic review of the literature involving nine RCT studies that had reported moderate to large effects for proprioceptive conditioning within their results. The latter effective conditioning programmes had comprised an average of 17.6 training sessions and a modal exercise session duration of 20 minutes(Kathleen et al. 2002; Kean et al. 2006; Gregory et al. 2006; Dawson et al. 2005; Granacher et al., 2010; Filipa et al 2010; Yaggie et al., 2006; Emery et al. 2005; Heitkamp et al., 2001).

The multifaceted programme for proprioception conditioning (Table 12) consisted of a standard formulation of warm-up followed by balance and agility exercises used routinely in exercise and clinical practice (Bernier & Perrin 1998; Heitkamp et al. 2001; Emery et al. 2005; Kean et al. 2006; Gregory et al. 2006; Yaggie & Campbell 2006; Garancher et al. 2010; Filipa et al 2010; Kim & Tockhart 2012) and which have been deemed safe with a minimal risk of musculoskeletal stress/injury. Exercises such as those involving jumping, cutting maneuvers, core stability training, plyometric and movement awareness were included within the programme and in varied patterns amongst the sessions of conditioning. Participants undertook these exercises with eyes open and closed and on unstable floor surfaces (dimpled matting or with varied cushioning, for example) to further challenge the participant's proprioception performance and neuromuscular capabilities. Exercises were undertaken at intensities of effort that were sub-maximal (participants perceived exertion using the Borg scale of perceived exertion (Appendix 1a), scoring 3 to 6 (Borg 1982) and each exercise was followed by rest period equal to or greater to the exercise execution time, to minimize the likelihood of fatigue. The emphasis of each exercise was the enhancement of the precision of movement. The requisite ‘overload’ associated with conditioning stimuli during the programme was delivered by (i) challenging participants progressively to achieve increasing levels of precision in movement within a given period of time to execute the movement, or (ii) by requiring that the participant achieved a criterion level of precision but with an enhanced scope/range of movement. Exercise sessions were separated by at least three hours to aid recovery.

Stochastic resonance mechanical stimulation device was applied to the distal tendon of the participants’ dominant biceps femoris muscle during JPS and FE assessments tasks. while performing 3 repetitions (one with no device and the other one with a placebo) of the force error and JPS test to check if the interactive or additive effects of stochastic resonance with increased conditioning status was higher than before the training period, and if so, if these benefits lasted at least one week after the training period. The SR was administered by initiating the operation of the device to its maximum performance capacity (hyper-sensory level), and then subsequently reduced in its intensity until the subject reported no longer able to feel vibration (sub-sensory level of stimulation). Exactly the same standardized procedure was used during the administration of the ‘No SR’ (vibration reduced to zero) and ‘Placebo SR’ (vibration reduced to zero but subject deceived verbally into expecting sub-threshold intensity).

A brief scheme of the studies designs is attached for a better understanding (Appendix 1b).

Table 12. Training programme exercises assigned to each session.

Training day	Session 1	Session 2	Session 3
Day1	BALANCE One leg stance Eyes Open - 10 seconds 5 repetitions Movement awareness One leg stance Eyes Open paint numbers.15 seconds, 3 repetitions 1 leg stance and pass ball	PLYO & BALANCE Kanguroos - 10 per 3 repetitions Lateral jumps 12 per 3 repetitions Hop stance - 10 per 3 repetitions One leg stance Close Eyes - 10 seconds, 5 repetitions Reach one point - 20 seconds, 5 repetitions Sumo game	CORE TRAINING Bird dog - 15 seconds, 3 repetitions Dorsal bridge - 20 seconds, 2 sessions Ventral bridge - 20 seconds, 2 sessions Lateral bridge - 20 seconds, 2 sessions Camel - 10 repetitions Airplane - 15 seconds, 4 repetitions Crunches - 20 per 2 repetitions Side crunches - 2 per 15 repetitions Reverse crunch 1 per 6 repetitions
Day 2	BALANCE & SHUTTLE RUN Shuttle run exercises 1 leg stance on an unstable surface - 10 seconds, 5 repetitions 1 leg stance on an unstable surface and pass ball 20 seconds, 3 repetitions Movement awareness	STRENTGH Flexion/ Extension and Eversion/ Inversion - 4 by 8 repetitions Front kick 10 per 3 repetitions Back kick 10 per 3 repetitions Squats couples Swiss ball between 10 per 3 repetitions Movement awareness	BALANCE One leg stance Eyes Open perturbations 1 leg stance Eyes Close - 10 seconds, 5 repetitions Reach one point - 20 seconds, 5 repetitions Pass ball one leg stance unstable surface - 20 seconds, 5 repetitions Hop stance different directions - 10 seconds, 2 repetitions Leg stance game with theraband
Day 3	PLYO & BALANCE Kanguroos 10 seconds, 3 repetitions Lateral jumps 12 seconds, 3 repetitions Hop stance 10 seconds, 3 repetitions One leg stance Eyes Close - 10 seconds, 5 repetitions Reach One point 20 seconds, 5 repetitions Sumo game Box jump - 10 seconds, 3 repetitions	BALANCE Hop stance Eyes Close One leg stance unstable perturbations One leg stance perturbations Eyes Close Pass ball unstable perturbations	CORE TRAINING Bird dog - 15 seconds, 3 repetitions Dorsal bridge - 20 seconds, 2 sessions Ventral bridge - 20 seconds, 2 sessions Lateral bridge - 20 seconds, 2 sessions Camel - 10 repetitions Airplane - 15 seconds, 4 repetitions Crunches - 20 per 2 repetitions Side crunches - 2 per 15 repetitions Reverse crunch 1 per 6 repetitions Theraband for lateral crunches work in couples.

Table 12. Training programme exercises assigned to each session.

Day 4	**SHUTTLE RUN & BALANCE** **Shuttle run exercises** **One leg stance on an unstable surface - 10 seconds, 5 repetitions** **One leg stance on an unstable surface and pass ball 20 seconds, 3 repetitions** **Movement awareness**	**STRENGTH** **Flexion/ Extension and Eversion/ Inversion - 4 by 8 repetitions** **Front kick 10 per 3 repetitions** **Back kick 10 per 3 repetitions** **Squats couples Swiss ball between** **10 per 3 repetitions** **Movement awareness**	**BALANCE** **One leg stance Eyes Open perturbations** **1 leg stance Eyes Close - 10 seconds, 5 repetitions** **Reach one point - 20 seconds, 5 repetitions** **Pass ball one leg stance unstable surface - 20 seconds, 5 repetitions** **Hop stance different directions - 10 seconds, 2 repetitions** **Leg stance game with theraband** **Hop stance 1 leg different directions** **Paint numbers unstable Eyes Close**
Day 5	BALANCE Hop stance Eyes Close One leg stance on unstable perturbations On leg stance on perturbations Eyes Close Pass ball unstable	PLYO & BALANCE Kanguroos 10 seconds, 3 repetitions Lateral jumps 12 seconds, 3 repetitions Hop stance 10 seconds, 3 repetitions One leg stance Eyes Close - 10 seconds, 5 repetitions Reach One point 20 seconds, 5 repetitions Sumo game Box jump - 10 seconds, 3 repetitions	CORE TRAINING Bird dog - 15 seconds, 3 repetitions Dorsal bridge - 20 seconds, 2 sessions Ventral bridge - 20 seconds, 2 sessions Lateral bridge - 20 seconds, 2 sessions Camel - 10 repetitions Airplane - 15 seconds, 4 repetitions Crunches - 20 per 2 repetitions Side crunches - 2 per 15 repetitions Reverse crunch 1 per 6 repetitions Theraband for lateral crunches work in couples.
Day 6	MISCELLANEOUS Rescue game but on one leg stance Shuttle run exercses Airplane, all directions	STRENGTH Flexion/ Extension and Eversion/ Inversion - 4 by 8 repetitions Front kick 10 per 3 repetitions Back kick 10 per 3 repetitions Squats couples Swiss ball between 10 per 3 repetitions Movement awareness	One leg stance Eyes Open perturbations 1 leg stance Eyes Close - 10 seconds, 5 repetitions Reach one point - 20 seconds, 5 repetitions Pass ball one leg stance unstable surface - 20 seconds, 5 repetitions Hop stance different directions - 10 seconds, 2 repetitions Leg stance game with theraband Shuttle run circuits Rescue game moving

Plyo: plyometrics; each session had a 5 minutes standard warm up.

6.3.2.1 EXPERIMENTAL DESIGN

Assessments of sensorimotor (blinded force and limb position replication errors) and neuromuscular performance (peak force and electromechanical delay [volitional and magnetically-evoked]) capabilities of the knee flexors of the preferred leg were made prior to and immediately after a short-term sensorimotor conditioning intervention and a week after. All participants were regularly involved in exercise (at least 3 times per week) and were asymptomatic at the time of assessment. Participants were instructed to refrain from strenuous physical activity for the 24 hours prior to testing. Assessment and intervention protocols were approved by the Institutional Ethics Committee for Human Testing at Queen Margaret University.

The short-term sensorimotor conditioning intervention of the preferred leg (defined as the preferred leg for ball-kicking with maximum velocity) although part of the training was bilateral, due to the balance tests where the whole body coordination was required, comprised 3 sessions per day during 6 days on week 2. Assessments were undertaken after a matching antecedent period of control, after the training period,and a week after the training period, where the participant had no training..

Tests were performed at the beginning of each week during the 3 weeks period of investigation. Participants had a familiarization period prior to testing in order to orientate them in regards to the testing protocol and to gather anthropometrics. All participants wore gym clothing with shorts length finishing above the knee to reduce the potential of mechanical noise impacting of the study, and all wore their own athletic shoes on the days of the testing.

Tests were performed using participants preferred leg, this was determined according to the Lateral Preference Inventory (LPI) (Emery et al.2005). The LPI is a questionnaire designed to measure lateral preference, the participants were asked which foot would you use to kick a ball or hit a target?, If you wanted to pick up a pebble stone with your toes, which foot would you use?, Which foot would you use to step on a bug?, and When stepping up onto a chair, which foot would you use first (Coren 1993).

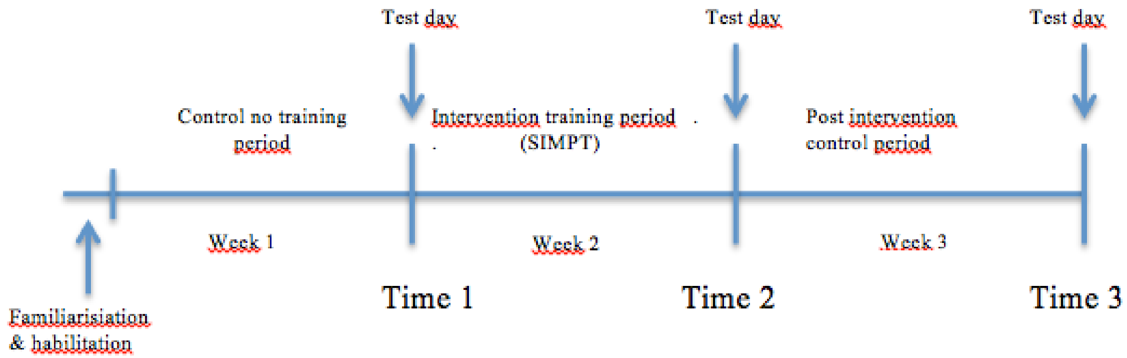


Figure 3. Test Chronogram

Each participant was assessed prior to and after the first control week, during which participants had no training, after the intervention week, consisting of 6 days of multifaceted specific training, and one week after the post training period test (participants had no training during this period) to see if the training effects lasted one week (in case significant results were achieved) (Figure 3). Testing protocol included:

- Measures of functional balance (including tests of dynamic and static functional balance)
- Measures of proprioception performance (including tests of Joint Position Sense)
- Measures of Force Error and neuromuscular performance (including tests of strength and indices of muscle activation performance using commonly-used non-invasive surface electromyography*)* (Riemann et al. 2002).

The order in which participants undertook the multiple assessments was randomized. In order to minimize the intrusion of assessments on participant's time, the assessment of neuromuscular performance (Peak Force) preceded those for proprioception performance (FE and JPS). However, these latter assessments and those for functional balance were presented in a random order in order to minimize the intrusion of systematic carry-over effects.

A standardized warm-up consisted in cycling for 5 minutes on a Monark Model 828E Ventura at an exercise intensity of 60 Watts and balance exercises preceded each session of assessment. Warm up was designed to avoid injuries (Dvorak et al. 2000;

Verrall et al. 2005), adapt the subject's body to the tests demands and to psychologically prepare the participants so they perform their tasks in the best conditions (Calleja et al. (2008).

6.3.2.3 STOCHASTIC RESONANCE STIMULUS

The following experimental conditions were delivered in a random order to assess the independent (during control period) and adjunct effects of SR with conditioning on participants' proprioception performance (JPS and FE).

(i) Stochastic resonance stimulation (mechanical vibration [~25 Hz; sub-threshold amplitude [imperceptible to recipient] and verified by accelerometry]

(ii) Non stochastic resonance stimulation (no vibration)

(iii) Placebo (a deception condition in which the participant wrongly assumes concurrent stochastic resonance to be occurring during the assessments of proprioception performance)

The SR mechanical stimulation device (Letong™ Mini Massager; model no: LT-E-007B, attached to Mascot switching adapter, Type: 9885 at ~ 25Hz) was positioned via Velcro™ to the participants dominant leg. The SR was administered by initiating the operation of the device to its maximum performance capacity (hyper-sensory level), and then subsequently reduced in its intensity until the subject reported no longer able to feel vibration (sub-sensory level of stimulation). Exactly the same standardized procedure was used during the administration of the 'No SR' (vibration reduced to zero) and 'Placebo SR' (vibration reduced to zero but subject deceived verbally into expecting sub-threshold intensity). Vibration intensity at tissue site had been verified previously by accelerometry.

6.4 TESTS

6.4.1 BALANCE TESTS

Participants were familiarized with all the equipment that would be used on the day of testing inclusive of the force plates (Kistler Type 9281B11, Kistler Instrumente AG, Switzerland). The participant was familiarised and accommodated to the assessment procedures. One leg stance eyes-opened, one leg stance eyes-closed were the tests for this section. A randomized application of order of conditions (eyes opened, eyes closed) was followed, taking a paper with the test name written from a bag. Each participant performed a trial of each test to make sure they performed it in a correct way.

There were two static tests of 30 seconds of duration each. The static balance test required the participant to use a one leg stance (dominant leg) with eyes-open and with eyes-closed (McGuine and Keene 2006). Each participant had a 2 minute rest between tests. Variation in millimeters in x and y axis were measured. Their dominant knee was slightly bent to make sure their knee muscles also contribute to their balance. The non-dominant leg was at 45 º hip flexion and 70 º knee flexion. Their arms were crossed over their chest and they had to look to a fixed point in front of them.

Same posture was followed for the one stance leg with eyes closed. A person was close to the participant just in case he needed help and avoid falling.

The participant was allowed to use all of his/her body to maintain the balance but was not allowed to land the non-dominant foot. If this occurred, the participant was retested. Participants did not have any information about the results to avoid any corrections in the next weeks' tests.

6.4.2 JOINT POSITION SENSE (JPS) TEST

The joint movement accuracy test for knee flexion was also measured. Participants were asked to detect a passive movement performed by the researcher in their knee. Two angles (25 and 40 degrees) were applied for the SR and Placebo situation and three angles (25, 40 and 60 degrees) for the control situation (no device on). 60 degrees target was not used with the SR and placebo condition because the patients´ leg touched the

SR device when reproducing the knee flexion movement. Angles were measured with an analogic goniometer with 1 degree scale (Pro Level Angle Finder) attached to the lever arm. (picture 2) Similar studies have used target angles 20 to 40 degrees of knee flexion since this range is functionally specific to stance phase positions during walking, and is reported to be strongly associated with proprioceptive feedback during normal walking (Gardsen et al. 1999; Collins et al. 2009).

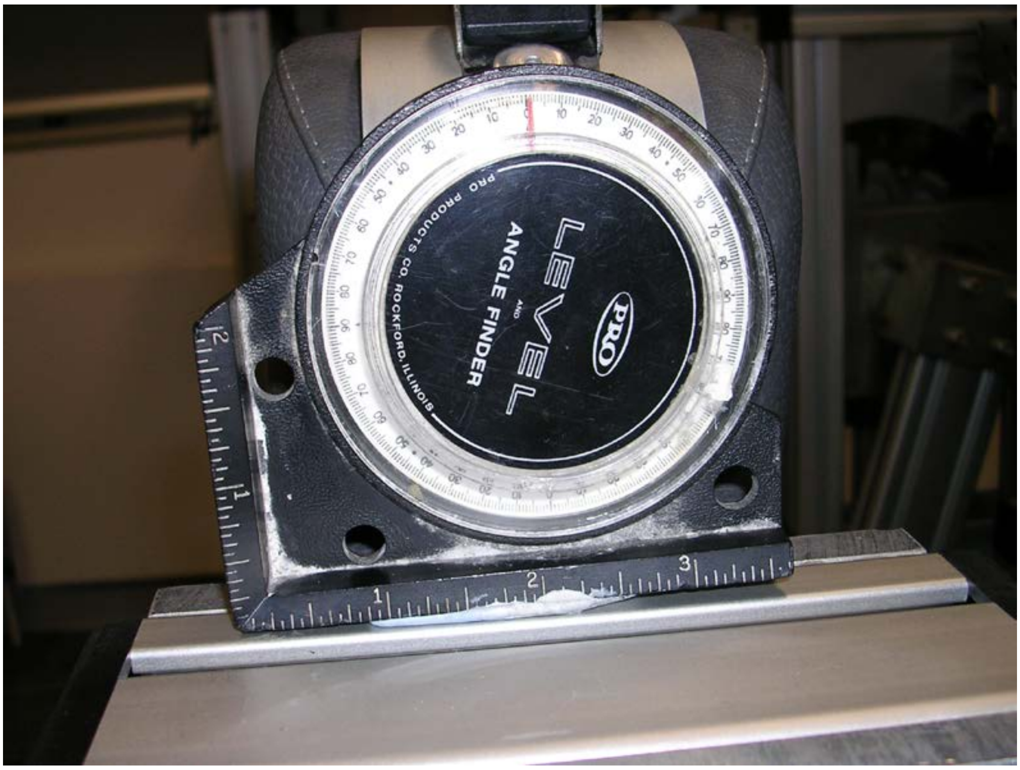


Figure 3: goniometer attached to the lever arm used for the JPS tests.

Participants had to reproduce 3 ‘random target’ (25, 40 and 60 degrees) knee positions without visual feedback. The procedure was as follows: after a passive movement done by the investigator, they were asked to remember that angle, and the participants’ leg was set back to the initial position (prone with knee extension). Then participants were moved passively again towards the target, and asked to indicate with the command “stop” when they had reached the set reference angle.

6.4.3 NEUROMUSCULAR AND PROPRIOCEPION TEST

Participants were habituated to and positioned prone on a purpose built dynamometer(picture 3) for which all assessments took place (Gleeson 2001).

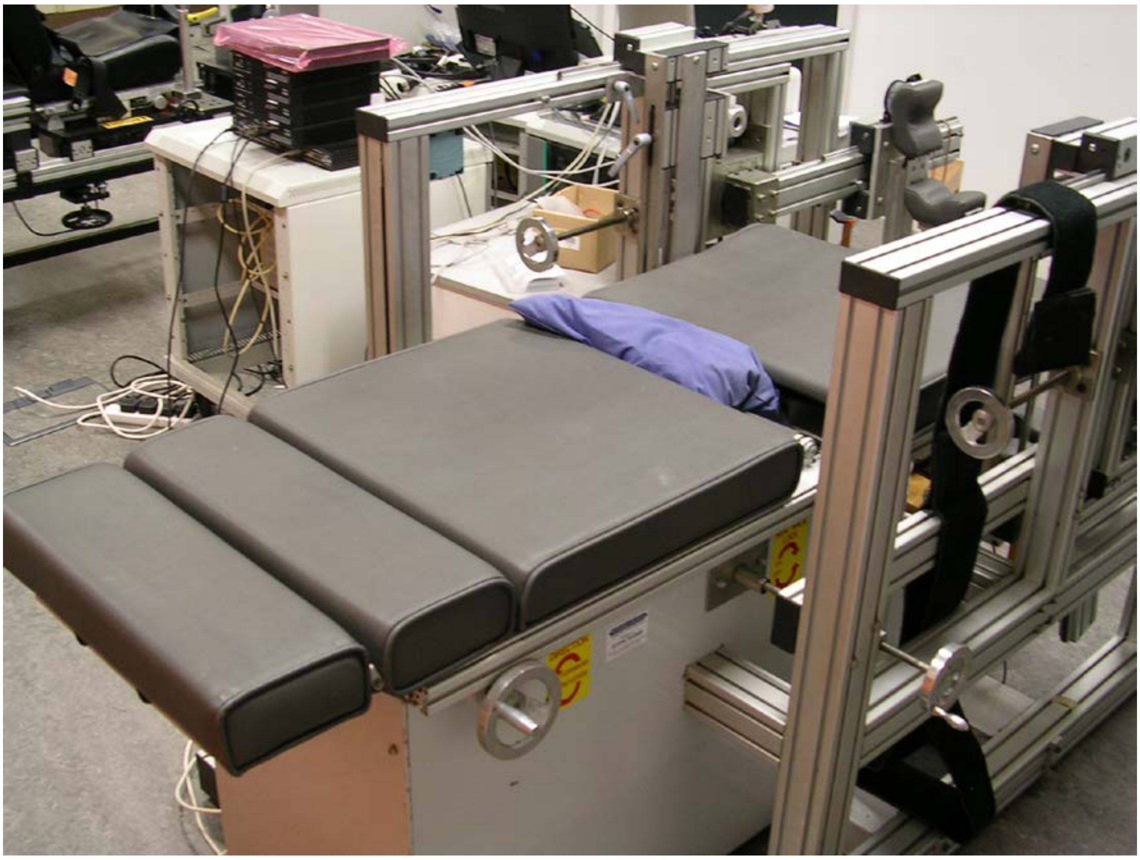


Figure 4: built dynamometer

The subject's dominant leg was fixed to the lever arm of the dynanometer via a padded cuff and strapping attached proximal to the lateral malleolus. The non-dominant knee joint was lined as closely as possible with the axis of the lever arm. Velcro™ strapping applied to the mid thoracic spine was used to stabilize unwanted trunk movement. The dominant knee joint was positioned at 30^{o} flexion measured via a goniometer system (Pro Level Angle Finder) attached to the lever arm. Measurements of Peak Force (PF) and all Force Error (FE) tests were undertaken at this angle. Angles between 0^{o} extension and 28.9^{o} knee flexion, are correlated with the greatest amount of mechanical stress applied to ligaments, therefore angles between $0\text{-}30^{o}$ have been regularly utilized in neuromuscular and sensorimotor testing (Minshull et al 2009; Beynnon and Johnson 1997)

The force transducer/load cell (Tedea Huntleigh 250kg) contained in the padded cuff was connected to a voltage signal recording system and interfaced to a data acquisition system (Cambridge Electronic Design, 1902 medically isolated programmable amplification/filter; 1403-1 data acquisition unit). All data was captured and interpreted on computer software (Spike 2, version 5.16, Cambridge Electronics Design Ltd., UK). Similar standardized and validated dynamometer procedures have been utilized with knee flexors in previous studies (Gleeson et al 2008).

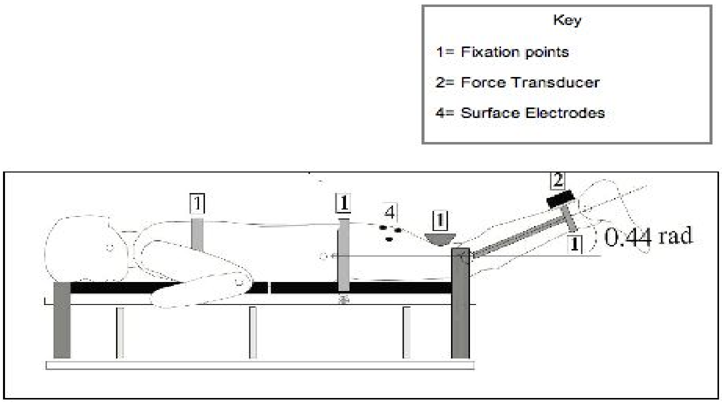


Figure 5. Participants test position on the dynamometer.

6.4.3.1 PEAK FORCE (PF) TEST

This assessment was calculated measuring the participants' knee flexion and extension PF. Participants were secured in a prone position on the purpose-built dynamometer (Minshull, Eston, Bailey, Rees, and Gleeson, 2012) with the knee flexed to a functionally relevant angle of 30 degrees which is associated with the greatest mechanical strain on key ligaments (Beynnon and Johnson, 1996; Minshull et al. 2009). The lever-arms of the dynamometer were attached to the leg of the participant by padded ankle-cuffs and adjustable strapping just proximal to the lateral malleolus. Further strapping was placed across the mid-thoracic spine, pelvis and posterior thigh proximal to the knee. The dynamometer's and knee joint's axes of rotation were aligned as closely as possible. Following a series of sub-maximal warm-up muscle activations (3 repetition to their 50% of their strength; then 3 more to their 75%; one more to the 90%; and then 3 maximum effort repetitions with 10 seconds rest between each one) an auditory signal was given randomly instructing the participants to flex the knee joint as rapidly and forcefully as possible against the im-movable restraint offered by the apparatus (load cell: 615, Tedea-Huntleigh Cardiff, UK). Another auditory signal was given to the participant after 2-3 seconds of maximal voluntary contraction (MVC) to instruct the participant to relax. Three MVCs were performed and each was separated from the next by at least 10 seconds. The same procedure was followed for knee extension. Data was collected in Newtons.

6.4.3.2 FORCE ERROR (FE) TEST

Participants performed an isometric knee flexion contraction on the build dynamometer. This assessment consisted of precise replication of a blinded target force with the knee flexors (set at a predetermined 50% of Peak Force, previously measured). Participants were verbally guided to the target force by examiner who monitors the force output on the data acquisition screen. Once participants attained the 50% target force, they were instructed to relax for 5 seconds at which they then had to achieve the target force on their own with no verbal guidance. Two bouts of five attempts were performed with one second rests between attempts and 10 second rest between bouts.

The FE knee flexion test was performed in three different contexts. Participant with no device, control situation, with a SR device on, and with a placebo, that consisted in the SR device but turned off, because the difference in sensation from the patients should be the same one between on and off, so the participant could never know if it was recording data for a placebo situation or a SR application situation. The SR mechanical stimulation device was attached to the subject´s dominant leg with a pressure of 7 N, and the third FE test situation would be without any device on. They had to repeat the target strength for 5 times with one second rest between each contraction and rest 10 seconds to repeat it one more time. Two attempts were recorded. The same procedure was followed for the 3 different contexts (SR, placebo, control).

JPS test and FE test were common for both experiments, were the control condition of the three situations proposed for the SR experiment was used to collect the data of the first experiment (intense dose of proprioceptive training). The results were collected as the difference beteween the target and the participants score (target marked by the examiner – participant´s score) in degrees for the JPS tests and Newtons for the FE tests.

6.4.4 DATA ANALYSIS

In order to assess the effect of a short, intense and multidisciplinary training programme will improve functional balance, proprioception and neuromuscular performance on the dominant leg in asymptomatic individuals with healthy joints (hypothesis A), separate experimental condition (SIMPT; control) by time (pre; post-1; post-2) ANOVAs with repeated measures on both factors, were used for each index of proprioception (JPS; FE; static balance; functional balance).

Similarly, in order to assess whether a short, intense multidisciplinary programme of training (SIMPT) with adjunct stochastic resonance will improve proprioception performance to a greater extent than with SIMPT alone (hypothesis B), separate experimental condition (SIMPT; control) by adjunct resonance (SR; No-SR; placebo-SR) by time (pre; post-1; post-2) ANOVAs with repeated measures on all factors, were used for each index of proprioception (JPS; FE; static balance; functional balance).

Data were processed using IBM SPSS Statistics version 22. Means and Standard deviations are presented. Shapiro-Wilk test was used to determine normal distribution of data. If data were normally distributed, parametric tests were used; the paired *t* test was used to compare two means (within-group comparisons), and repeated-measures ANOVA was used to compare three means. On cases where the null hypothesis of normality distribution was violated non parametric tests were used; The Friedman test was used to evaluate repeated measures of variances. When Eta values were calculated used the following guidelines to interpret ETA squared; 0.01 small effect, 0.06 moderate effect, 0.14 large effect (Cohen 1988)

6.5 RESULTS

6.5.1 PARTICIPANTS

The sample comprised by twelve young and healthy students, recreationally active in sport, (8 Males and 4 Females), with a mean age of 21.3 ± 3.7 years, mean weight of 73.3 ± 12.1 kg and mean height of 179.2 ± 8.5 cm. Participants descriptive statistics are presented in Table 13.

Table 113. Descriptive Subject statistics

	Female (N=4)	Male (N=8)	Group (N=12)
Age (years)	20.5 ± 2.5	21.7 ± 4.3	21.3 ± 3.7
Mass (Kg)	61.8 ± 2.0	79.1 ± 10.8	73.3 ± 12.1
Height (cm)	171.7 ± 7.0	182.9 ± 6.6	179.2 ± 8.5
BMI (Kg/m^2)	21.0 ± 1.3	23.6 ± 2.9	22.8 ± 2.7

Participants were included if they were asymptomatic at the time of testing therefore displaying no acute signs and symptoms such as pain, loss of function, mild point tenderness, swelling and abnormal range of movement within the lower limb.

The Queen Margaret University (QMU) Ethics committee granted ethical approval. All participants were informed through an informative sheet (Appendix 3) approved by the QMU ethics committee which contains all the research parameters. All participants included on this study gave their consent to participate signing a consent form (Appendix 4).

6.5.2 THE EFFECTS OF MULTIDISCIPLINARY TRAINING ON FUNCTIONAL BALANCE

Balance outcome X Axis Eyes open:

Results from factorial ANOVA involving condition (SIMPT; control) by time (pre; post-1; post-2,corresponding to time 1,time 2, time 3) showed non-significant 2-factor interaction for balance A, Wilks´Lambda = 0.73 $F(2, 8) = 1.480$, $P = 0.284$, multivariate partial squared = 0.270. There is not enough evidence to reject null hypothesis of no interactions for functional balance outcomes.

Although the results were not statistically significant, they indicate that the mean scores of the participant improved over time (Time 1 = - 0.024 mm, Time 2 =-0.013 mm, Time 3 = -0.012 mm). The interval of variance shown also an improvement over time (Time 1 = -0.049/0.000, Time 2 =-0.028 -0.002, Time 3 = -0.029/ -0.005).

Balance outcome X Axis Eyes Closed:

Results from factorial ANOVA involving condition (SIMPT; control) by time (pre; post-1; post-2) showed non-significant 2-factor interaction for balance A, Wilks´Lambda = 0.681 F (2, 8) = 1.873, P = 0.215, multivariate partial squared = 0.319. There is not enough evidence to reject null hypothesis of no interactions for functional balance outcomes.

Although the results were not statistically significant, they indicate that the mean scores of the participant improved over time especially at Time 3 (Time 1 = - 0.023 mm, Time 2 =-0.020 mm, Time 3 = -0.009 mm). The interval of variance shown also an improvement over time (Time 1 = -0.056/ -0.010, Time 2 =-0.033/ -0.007, Time 3 = -0.021/ -0.003).

Balance outcome Y Axis Eyes Open:

Results from factorial ANOVA involving condition (SIMPT; control) by time (pre; post-1; post-2) showed non-significant 2-factor interaction for balance A, Wilks´Lambda = 0.735 F (2, 8) = 1.442, P < 0.292, multivariate partial squared = 0.265. There is not enough evidence to reject null hypothesis of no interactions for functional balance outcomes.

The results indicate that the mean scores of the participant were better at Time 1 prior conditioning (Time 1 = - 0.001 mm, Time 2 =-0.014 mm, Time 3 = -0.015 mm). The interval of variance shown a better result in Time 3 (Time 1 = -0.020/ 0.017, Time 2 =-0.036/ 0.008, Time 3 = -0.024/ -0.006).

Balance outcome Y Axis Eyes Close:

Results from factorial ANOVA involving condition (SIMPT; control) by time (pre; post-1; post-2) showed non-significant 2-factor interaction for balance A, Wilks´Lambda = 0.511 F (2, 8) = 3.831, P < 0.068, multivariate partial squared = 0.265. There is not enough evidence to reject null hypothesis of no interactions for functional balance outcomes.

The results indicate that the mean scores of the participant were better at Time 1 prior conditioning (Time 1 = - 0.001 mm, Time 2 =-0.008 mm, Time 3 = -0.026 mm). The interval of variance shown a better result in Time 1 (Time 1 = -0.018/ 0.019, Time 2 =-0.032/ 0.015, Time 3 = -0.050/ -0.002).

6.5.3 THE EFFECTS OF MULTIDISCIPLINARY TRAINING ON PROPRIOCEPTION.

The test results for the join position are divided by the three different degree targets measured. Table 14 shows the average asymmetry index for all participants on each of the degrees measured.

Table 14. Average Asymmetry index for all participants JPS Test in degrees

Target	Asymmetry index Week 1	Asymmetry index Week 3	Asymmetry index Week 4
25	0.67	0.25	0.91
40	0.08	0.25	0.82
60	-5.25	-1.75	3.09

Proprioception outcome JPS, angle 25º:

Results from factorial ANOVA involving condition (SIMPT; control) by time (pre; post-1; post-2) showed significant 2-factor interaction for proprioception outcome JPS, Wilks´Lambda = 0.449 F (2, 9) = 5.532, P = 0.027, multivariate partial squared = 0.551. The results suggest the best result achieved by the participants was on Time 2, after conditioning but this result was lost after a week of no conditioning at Time 3.

Table 15 Propioception outcome JPS angle 25º

	Mean (º)	Std. Deviation	N
Time 1	0.82	1.834	11
Time 2	0.27	0.647	11
Time 3	0.91	0.701	11

Proprioception outcome JPS, angle 40º:

No significant factor interaction was for proprioception outcome JPS was shown, Wilks´Lambda = 0.586 F (2, 9) = 3.182, P = 0.090, multivariate partial squared = 0.414.

Although the results were not statistically significant, they indicate that the mean scores of the participant improved after conditioning (Time 2), over confidence at Time 3 may explain the poor result a week after conditioning at Time 3 (Time 1 = 0.273º, Time 2 = 0.91º, Time 3 =0.818º). The interval of variance shown the largest variance on Time 1 and the smallest on Time 2 (Time 1 = -1.957/ 2.503, Time 2 =-0.468/ 0.649, Time 3 = 0.159/ 1.478).

Proprioception outcome JPS, angle 60º:

Results from factorial ANOVA involving condition (SIMPT; control) by time (pre; post-1; post-2) showed significant 2-factor interaction for proprioception outcome JPS, Wilks´Lambda = 0.224 F (2, 9) = 15.574, P < 0.001, multivariate partial squared = 0.776. The results suggest the best result achieved by the participants was on Time 2, after conditioning but this result was lost after a week of no conditioning at Time 3.

Table 16 Propioception outcome JPS angle 60º

	Mean (º)	Std. Deviation	N
Time 1	-4.27	7.431	11
Time 2	-1.91	2.343	11
Time 3	3.09	1.814	11

Proprioception outcome FE

Results from factorial ANOVA involving condition (SIMPT; control) by time (pre; post-1; post-2) showed non-significant 2-factor interaction for proprioception outcome FE, Wilks´Lambda = 0.761 F (2, 8) = 1.254, P = 0.336, multivariate partial squared = 0.239.

Although the results were not statistically significant, they indicate that the mean scores of the participant improved over time, The variance to target (1) was Time 1= 0.51, Time 2 =0.049 and Time 3 =0.038 (Time 1 = 1.051N, Time 2 = 0.951N, Time 3 = 0.962N). The interval of variance best at Time 3(Time 1 = 0.918/ 1.184, Time 2 = 0.900/1.002, Time 3 = 0.915 / 1.008).

Table 17 Means scores FE test in Newtons

	Mean (N)	Std. Deviation	N
Time 1	1.051	0.185	10
Time 2	0.951	0.071	10
Time 3	0.961	0.064	10

6.5.4 THE EFFECTS OF MULTIDISCIPLINARY TRAINING ON NEUROMUSCULAR PERFORMANCE.

Peak force:

Results from factorial ANOVA involving condition (SIMPT; control) by time (pre; post-1; post-2) showed non-significant 2-factor interaction for peak force Wilks´Lambda = 0.904 F (2, 8) = 0.426, P = 0.667, multivariate partial squared = 0.096. There is not enough evidence to reject null hypothesis of no interactions for peak force, null hypothesis retained.

Although the results were not statistically significant, they indicate that the mean scores of the participant improved from Time 1 to Time 2, and from Time 1 to Time 3 (Time 1 = 264.90 N, Time 2 = 271.16 N, Time 3 = 268.27 N. The interval of variance reduces over time (Time 1 = 209.60/ 320.20, Time 2 = 224.45/317.87, Time 3 = 228.13 / 308.40).

Table 18 peak force outcomes in Newtons

	Mean (N)	Std. Deviation	N
Time 1	264.90	77.31	10
Time 2	271.16	65.30	10
Time 3	268.27	56.11	10

6.5.5 THE EFFECTS OF MULTIDISCIPLINARY TRAINING AND ADJUNCT STOCHASTIC RESONANCE ON PROPRIOCEPTION.

6.5.5.1 JOIN POSITION TEST RESULTS WITH CONDITION

The design of the Stochastic Resonance Join Position Test was performed with three factors (Non- Stochastic Resonance, Stochastic Resonance and Placebo) and 3 time tests, Time 1, time 2 Time 3 corresponding to Week 1, Week 2 and Week 3. We used two factors ANOVA with repeated measures for both target degrees at 25 º and at 40 º.

A two-way analysis between groups with repeated measures analysis of variance was conducted to explore the impact of the application of Stochastic Resonance, non-Stochastic Resonance and placebo on asymmetry index from target at 25º and 40 º as measured by the Join Position Test. Participants were asked to perform a test on three different conditions; Without a Stochastic Resonance apparatus. with a Stochastic Resonance switch on and with a Stochastic Resonance switch off (placebo). There was a statistically significant interaction on time F(4.403) Sig. (0.014) and on Time*Condition F (3.486) Sig. (0.010) for target 25º. The Bonferroni test results indicates that asymmetry index from target at 25º has no statistical difference. Test Post-hoc comparisons using Tukey HSD test indicates that the mean score results for Condition factor do not differ significantly from the others. For target at 40º, there was a statistically significant interaction on time F (4.078) Sig. (0.017) but none for Time*Condition.

6.5.5.2 FORCE ERROR TEST WITH CONDITION

Table 19 shows the descriptive statistics for the Force Error with Condition results for all for times measured.

Table 19. Force Error Test with Condition Descriptive (Newton)

TEST CONDTION	NORMAL		PLACEBO		SR	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Time 1	0.5	22.9	0.6	15.2	-1.5	18.4
Time 2	- 7.3	12.9	-4.3	13.6	-8.9	12.6
Time 3	- 5.6	12.8	-10.6	14.0	-3.8	12.3

The Shapiro-Wilk test indicates that there is no violation of the assumption of normality as all the significance values are higher than 0.05.

The W Mauchly (Sig. = 0.045) rejects the null hypothesis of sphericity and therefore we should correct the F-ratios for the time effect.

The results for ANOVA (with corrected F value) show all significant values of F are less than $p < 0.05$ for time but not for Time*Condition which means we cannot reject the null hypothesis and suggest there is a statistical significant interaction between these two factors.

A two-way analysis between groups with repeated measures analysis of variance was conducted to explore the impact of the application of Stochastic Resonance, non-Stochastic Resonance and placebo on the Force Error Test. Participants were asked to performed a test on three different conditions; Without a Stochastic Resonance apparatus, with a Stochastic Resonance switch on and with a Stochastic Resonance switch off (placebo). There was a statistically significant time effect F (5.853) Sig. (0.003) but no for Time*Condition F (0.293) Sig. (0.905). The Bonferroni test statistical differences between, Time 1 and Time 2, Time 2 and Time 3. Post-hoc comparison test using Tukey HSD did not found a statistically differences for the Condition factor means.

CHAPTER 7: DISCUSSION

The results of the present study show that after a short and intense multifactorial training programme, healthy participants improved their propioceptive performance, as measured by the Joint Position Test, and, although no statistical significant differences were found for balance, force error and peak force tests, the participants' mean scores improved after the training period. The ability to detect joint angles movements after the training period had a statically significant improvement for two (25º and 60º) out of the three target tests. No significant statistical differences were found when looking at improvement on participant´s propioceptive system (JPS and FE tests) using a SR device, and adding its effect to a short intense proprioceptive training period, SR did not enhance participants' proprioceptive system.

The proprioception system has been described since 1906 but it was not until 1965 when Freeman started introducing proprioception exercises to recover joint stability. Many authors since then have studied the proprioceptive system to understand it better and to use it not only to recover from injuries but also to prevent them. The term "proprioception" has suffered a great evolution and nowadays it is just a part of a complex system called "The sensorimotor system" which, is important to understand how to enhance the athlete's intrinsic abilities to achieve joint stability. Lephart and Fu (2000) and Gleeson et al. (2001) included in this complex system not only the afferences or inputs (proprioception information), but also the outputs and the motor responses.

The literature review helped us to understand the sensorimotor system, its function, and the structures involved. It is important to remember that the sensorimotor system is a complex system part of the motor control, where the afferent paths should carry as much precise information as possible. For this purpose, all the receptors must be active and should work in a correct way, so that the central nervous system can have all the information to give a precise response, taking into account the feedback and feedforward, to give joints as much stability as possible to avoid joint perturbations (Lephart & Fu 2000).

This means that if you want to evaluate proprioception you must use specific tests such as Joint position test or force error test, and not only global tests as balance test

Reviewing the risk factors that can cause sports injuries, as Van Tiegel suggested, we find that there are many intrinsic factors, related to the sensorimotor system, such as movement awareness, strength perception, ROM, neuromuscular reaction, strength and in a more general way, balance.

Many studies in the literature already proved that by improving the sensorimotor system we can reduce the number of sport injuries (TABLE 6). And other studies also proved that we can achieve a sensorimotor enhancement by training athletes.

Table 20. Sport injury risk factors and studies showing the improvement of each risk factor.

INJURY RISK FACTORS	IMPROVEMENT WITH SPECIFIC TRAINING
Control deficits in center of gravity position (Matsusaka et al. 2001)	Postural stability Bernier and Perrin 1998 Balance (Lipsitz et al. 1991).
Strength alteration (Engstrom BK, Renstrom PA. 1998).	Strength improvement (Gruber and Gollhofer 2004, Bruhn et al. 2006, Granacher et al. 2006). eccentric contraction in joint stability has already been demonstrated (Baumhauer et al. 1995, Yildiz et al. 2003, Fox et al. 2008)
Bad biomechanical and neuromuscular control in lower limb (Benjaminse et al 2010).	Improved the interaction between sensory input and motor activity (Myer et al. 2006, Kean et al. 2006, Bressel et al. 2007),
Sensorimotor system alterations (Saxton et al 1995; Proske and Morgan 2001).	Improvement on balance, diminishing muscle reaction time and improving the quality of the answer, (Myer et al. 2006, Kean et al. 2006, Bressel et al. 2007),
Lack of dynamic neuromuscular knee control (Hewett et al 2005).	Joint stability Grancher et al. 2010
Alterations on the proprioception system (Engstrom BK, Renstrom PA. 1998).	Recovery of kinesthetic awareness in the rehabilitation of ankle injuries and Baltaci and Kohl and Zoch et al. confirmed as the only therapy with significant results (Baltaci and Kohl 2003, Zoch et al. 2003).
Lumbar-pelvic instability (Sherry and best 2004).	Core stability training to induce neuromuscular changes and potential injury prevention effects (Mandelbaum et al. 2005, Myer et al. 2005).
Movement awareness (Bernierand Perrin 1998)	Movement awareness Bernier and Perrin 1998

JPS measures the participant's ability to recognize his joint position without the need of the visual system. The literature suggests that an improper positioning of the foot just prior to, and at, heel strike (Bernier and Perrin 1998) or alteration of the knee proprioception (Powell et al. 2000) can be a predictive factor for lower limb injuries. Although the literature suggests that deficits in the proprioception system are a sports injury factor, athletes still chose proprioception training as their preferred method to prevent injuries. JPS or FE tests are not often used as tests in the literature on healthy population. As we can see on Table 7 just Bernier and Perrin (1998) measured JPS. Zech et al. (2010) in their systematic review: *"balance training for neuromuscular control and performance enhancement"* show that none of the 20 studies reviewed measured the JPS. In our research significant results were found for 25º knee flexion angle target after the intervention period at Time 2 (Time 1 0.82 ± 1.83º, Time 2 0.27 ± 0.65º, Time 3 0.91 ± 0.7º p< 0.027) and for 60º knee flexion angle target after the intervention period Time 2 (Time 1 -4.27 ± 7.43º, Time 2 -1.91 ± 2.34º, Time 3 3.09 ± 1.81º p< 0.001) and the variance diminished at 40º knee angle flexion target (interval of variance: Time 1 = -1.957/ 2.503, Time 2 =-0.468/ 0.649, Time 3 = 0.159/ 1.478), but no significant results were found for this angle.

The literature offers some studies that have found improvements in knee JPS tests, both in healthy and injured participants. Beriner and Perrin (1998) training programme included 18 sessions, and used balance and proprioception exercises. They did not find significant results in any of the 3 tests positions for ankles. Duracoglu et al. (2005) used a multifactorial programme (balance, proprioception and strength exercises) on patients with knee osteoarthritis, and after an 8 week training period obtained significant results for the angular error value for knee flexion joint position reproduction. The authors also found significant results for the group that just trained with strength exercises. No significant differences between the strength and the multifactorial programme groups were found. Predeep et al. (2016) tried to see the influence of dynamic stretch on knee JPS in healthy adults, they found significant differences for the combined (dynamic stretch of quadriceps and hamstring) (pre 5.07º ± 3.31º; post 2.47º ± 1.60º p<.012) and the hamstring groups (pre 6.53º ± 5.57º; post 1.93º ± 1.44º, p<.005), but not for the quadriceps group (5.73º ± 5.05º; post 4.80º ± 3.30º, p>.378) at target angle 70º.

Fisher-Rasmussen & Jensen (2000) compared the injured leg to the participant's un-injured leg as the control using a range of JPS procedures. Results provided a pooled standard mean difference of mean angle of error of 0.52° (95% CI [0.41 to 0.63]; p

<0.001) indicating that the un-injured leg had lower mean angle of error (better joint position sense) compared to the injured leg. They also compared the injured legs to an external control. Again, results of revealed that the control group had better joint position sense than ACL patients. Specifically, the pooled standard mean difference of the mean angle of error was 0.35° (95% CI [0.14 to 0.55]; p= 0.001) indicating that the control group had better joint position sense than ACL patients. They also compared ACL reconstructed (n=116) and ACL deficient (not reconstructed) legs (n=100). The pooled standard mean difference of the mean angle error was -0.62° (95% CI [-0.76 to -0.48]; P<0.001 reconstructed patients had better joint position sense.

The sense of tension or force, commonly assessed using force reproduction (force error test FE), has also been used as a measure of proprioception (Dover and Powers 2003). We considered important to assess the participant's ability to reproduce a specific force because strength alteration is a sports injury risk factor widely described. (Engstrom BK and Renstrom PA. 1998, Madras and Barr 2003; Kaminski and Hartsell 2003; Beynnon 2003). Our results did not show significance in the FE test, probably because the intervention was not long enough to achieve significance. Krishman & William (2003) measured the antagonist muscle activity in isometric knee strength contraction, showing a greater antagonist muscle activity during Knee flexion test that could lead to an underestimation of true agonist muscle strength. Proske (2006) indicates that all muscle spindles are recruited at just 25% of maximum contraction, (we used a target around 50% of the MVC) making them very sensitive to the stimulus. Alterations in synergistic activation and reductions in antagonist activation are neural factors that have been identified as changing during the early stages of resistance training which could contribute to maximal force generation, but these changes occur after 4-8 weeks of training (Griffin & Cafarelli 2005).

Results obtained using JPS test are not exactly the same as when using the FE test (Lin et al. 2016). Using the results of only one of the test methods to represent proprioception will not give us the exact information about the state of the proprioceptive system. Force sensation is related to the sensory input of information from the Golgi tendon organs, motion sense to the input information of the muscle spindles and position sense relies on the double input information of the muscle spindles and the Golgi tendon organs (Lin et al. 2016). Although the results were not statistically significant for the FE test, we observed that the mean scores of the participant and the interval of variance improved over time.

One of the main goals with proprioception and neuromuscular training is to improve participant´s balance and postural control. One week showed not to be enough time to improve participant´s sway even with an intensive dose of training as all the studies on Table 7 shown, where improvements on postural sway achieved significant results. Comparing the differences between Table 7 studies and ours, we conclude that we performed more exercises than the programmes presented by the authors, even more than Heitkamp (2001), Granacher et al. (2010), Myers et al (2006), or Kean et al (2006). Considering that our training programme included balance, neuromuscular and strength exercises we can conclude that the reason why we did not get significant results was not due to the training programme. Regarding balance, although we had no significant results we found improvements on the "x" axis or mediolateral axis with eyes open and closed and improved over time, and no differences on "y" axis. These results are in agreement with Myers et al (2006), who found significant results on the "x" axis, but not on "y" axis. Yaggie and Cambell (2006) checked if the results still remained after a week post intervention, and they found that although the strength results had disappeared, the balance improvement still remained. Despite our results were not significant, we also found that balance results remained one week after the intervention.

Muscle strength decrease is a sport injury risk factor, and participants' muscle condition can be explored not only by the sense of force tension (FE test) but also by isometric contractions. Although Zech et al. (2010) in their systematic review suggested the use of specific strength training to improve participants strength, many studies showed that balance training also improved muscle strength (Myers et al 2006, Yaggie and Cambell 2006, Keitkamp 2001). Therefore, we decided to cover both aspects in our training programme and, although we did not achieve significant results, the mean scores improved after training and the interval of variance was reduced over time. We did not expect significant improvements since the initial strength gain is due to a neuromuscular improvement, and not to biological muscle changes. The improvement occurs after 4-8 weeks of training (Kreamer et al 2002).

The creation of a preventive programme is a difficult task. The knowledge of the game and its rules, the sports gestures and the risk factors are crucial to determine which type of exercises must be designed for each athlete. The literature review done for this study did not find many specific sport training examples but a more generic training design that must be covered to achieve a sensorimotor enhancement and diminish the risk of injury. (TABLE 36)

Table 21. Specific drills that should be included in a training programme found in the literature.

SPECIFIC EXERCISES FOR SENSORIMOTOR ENHACEMENT
Bosu balance training, ankle disk training which improves speed reaction (Kean et al. 2006), wobble board training, swiss balls
Jump-landing training (Bernier and Perrin 1998).
strength, (Hewett et al. 1999, Heidt et al. 2000, Myer et al. 2004, Holm et al. 2004, Myklebust et al. 2003, Paterno 2004, Mandelbaum et al. 2005)
Core stability training (Mandelbaum et al. 2005, Myer et al. 2005).
Flexibility (Baltaci and Kohl 2003, Zoch et al. 2003).
Plyometrics (Baltaci and Kohl 2003, Zoch et al. 2003).
Agility drills (Baltaci and Kohl 2003, Zoch et al. 2003).
Speed enhacement (Baltaci and Kohl 2003, Zoch et al. 2003).
Sports technical education (Baltaci and Kohl 2003, Zoch et al. 2003).
Movement awareness (Baltaci and Kohl 2003, Zoch et al. 2003).
Eccentric contraction in joint stability has already been demonstrated (Baumhauer et al. 1995, Yildiz et al. 2003, Fox et al. 2008).

Specific training improves the interaction between sensory input and motor activity (Myer et al. 2006, Kean et al. 2006, Bressel et al. 2007), which is manifested in balance improvement, diminished muscle reaction time, improved quality of the answer, decreased lower limb injuries (Myer et al. 2006, Kean et al. 2006, Alexandrov et al. 2005, Silsupadol et al. 2006), decreased falls (Suteerawattananon et al. 2002), improved postural strategies (Olsen et al. 2005) and optimized position and symmetry of the weight load (Peterka and Loughlin 2003). The challenge comes when trying to find the requested specific training time to achieve this improvement. We did not achieve this improvement after one week of intensive training.

We applied a programme that combined the training exercises applied in other research studies that achieved significant results. We calculated the mean number of sessions and we condensed these sessions in one week to reduce as much as possible the time to gain preventive benefits. An average of 17.6 training sessions and a modal exercise session duration of 20 minutes (Kathleen et al. 2002; Kean et al. 2006; Gregory et al. 2006; Dawson et al. 2005; Granacher et al., 2010; Filipa et al 2010; Yaggie et al., 2006; Emery et al. 2005; Heitkamp et al., 2001) was obtained.

It might be presumed that training sessions should be performed for at least 10 min, more than once per week for at least 3 months, but the substantial variability in training parameters deserved further attention. For example, the training frequency and duration of the programmes ranged from one to seven sessions per week and between 3 and 12 months (Hübscher et al. 2010).

Although we found that with one-week workout neuromuscular parameters in healthy subjects improved, it was not enough time to achieve significant results in all the sensorimotor parameters. After analysing the differences with other studies, we conclude that the number of weeks was not enough to observe significant changes in healthy people. Total time worked and numbers of sessions were the same than previous studies finding significant results, but these studies implemented programs for a longer period of time.

Gioftsidou et al. (2012) wanted to evaluate if training intensity could influence the improvement of balance and stability after a 6-week period training. They showed that the results were the same training 3 or 6 days a week. Kidgell et al. (2005) showed the same results working 1 day/week than 5 days/week, and also the same results were obtained by including high or low load training exercises. Methodological limitations regarding measurements and population differences make calculation to time work difficult to stablish (Zech et al. 2010).

Sensorimotor improvements have been found to be independent of the training volume and do not differ with weekly training volumes of two, four or six sessions applied (Pohl et al 2015). Thus, in contrast to what it occurs in common clinical practise, greater volume of sensorimotor training during rehabilitation does not necessarily lead to better sensorimotor function. Further research investigating the effect of training volume and its long-term effects is needed, however, before giving definitive recommendations regarding optimal training stimulus (magnitude, frequency, duration) (Pohl et al 2015).

We could also follow Ashton-Miller et al. (2001) thoughts that conclude that, despite their widespread acceptance, current exercises aimed at "improving proprioception" have not been demonstrated to achieve that goal. They have outlined theoretical scenarios by which proprioception might be improved, but these are speculative.

This thesis demonstrates that proprioception, as measured by the JPS, can be achieved after an intense multimodal programme, but future studies should clarify which is the minimal training time to gain more benefits.

The use of specific devises for proprioceptive enhancement, such as SR or whole body vibration (WBV), are always welcome in daily clinic. Our research was seeking a proprioceptive enhancement in participants by using a cheap SR mechanical applied alone, as in other studies (Collins et al 2009, Gravelle et al.2002, Příplata et al 2002, Příplata et al 2003, Collins et al 2003), or applied in addition to a specific training programme. No statistical significant differences were found for the JPS test at 25º and 40º target. These results are in agreement with several studies that analysed the effect on the FE when using the electrical SR device (Gravelle et al.2002, Příplata et al 2002, Příplata et al 2003) or the SR device combined it with neoprene sleeves (Collins et al 2009).

Although subjects did not feel any vibration with the device used to apply the SR, the same results were found with vibratory tonic reflex (VTR) (Johnston et al 1970; Neiger et al 1983; Neiger et al. 1986). These authors argued that the sensitivity of each participant greatly influences the outcome of the application, and in some individuals has no effect. Our results do not support these arguments since participants did not feel the vibration. Although the strength of the response is highly variable between individuals, their response has been shown to be highly reproducible in all subjects (Johnston et al., 1970). The force response of VTR depends on four factors: location of the vibrator (on muscle or tendon), initial muscle length (the more stretched further response) (Johnston et al, 1970.), State of excitability of CNS and vibratory stimulus parameters.

Summarizing, we can say that intensive training time in one week it is not enough to achieve sensorimotor system enhancement. Significant improvement was only found for the proprioception test JPS at 25 and 60º. Although it is not significant, we could observe an improvement on proprioception tests (FE) and balance test.

Limitations

Our study presents several limitations. There was only one examiner for the whole intervention procedure, and it was not possible to control all the training session. A better monitoring of training exercises could have helped to improve final results.

Lack of experience in the use of stochastic resonance devices could let to intervention errors or difficulties explaining the participants what they might perceived.

The sample size could be a limitation, and we might repeat the research with a control group to compare results. We also suggest the split of the participants onto three groups, and apply one condition (Stochastic Resonance, Non-Stochastic Resonance and placebo) to each of the of the groups for better statistical study design.

This thesis was not sponsored and although a 3-month period investigation was calculated to carry out all the interventions and to complete the data analysis, we found the time limitations difficult to accomplish the research project at QMU.

CHAPTER 8: CONCLUSIONS

1. A short, intense and multidisciplinary training programme improved significantly proprioception, as measured by the Joint Position Test at 25º and 60º, on the dominant leg in asymptomatic individuals. The same test at 40º did not show significant results

2. A short, intense and multidisciplinary training programme did not improve significantly functional balance, as measured by the balance test, nor proprioception, as measured by the Force Error Test, on the dominant leg in asymptomatic individuals. These tests improved over time without achieving statistical significance.

3. A short, intense and multidisciplinary training programme did not improve significantly neuromuscular performance, as measured by the peak force test, on the dominant leg in asymptomatic individuals. This test improved over time without achieving statistical significance.

4. A short, intense multidisciplinary programme of training with adjunct stochastic resonance did not improve significantly proprioception performance to a greater extent than with SIMPT alone.

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Appendix 1a

MULTIFACTORIAL EXERCISES

For any enquiries please contact Alberto Sanchez at:
alberto.sanchez@uclm.es or 07766961829.

INSTRUCTIONS.

- Balance exercises should be carried out progressively so the order of execution is important.
- Exercises should be completed throughout the week. If you are not able to do one particular exercise do not worry, try another one.
- Try to work exercises from the 3 blocks: balance exercises, strength exercises and core training exercises.

IT IS JUST ONE WEEK. TRY YOUR BEST. THANK YOU FOR YOUR HELP.

BLOCK 1   BALANCE EXERCISES.

(dominant leg is on the floor as practice during the tests)

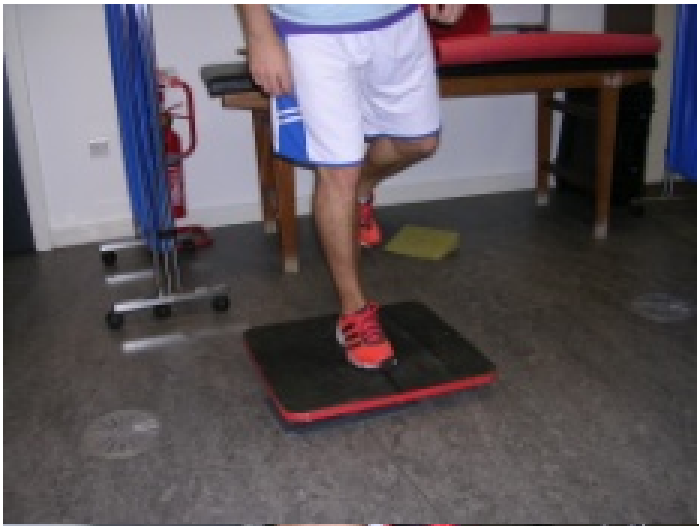
1. One leg stance eyes-opened. (10 seconds x 3 times)

2. One leg stance eyes-opened paint numbers in the air with the other leg. (1 to 10 rest, 10 to 20 rest, 20 to 30 rest)

3. Reach 1 point with two hands together, fast movements in different directions. Start and always come back to the starting position. (20 seconds x 3 times)

4. **Same 3 exercises with eyes closed**.

5. **Same 3 exercises on a bosu, or wabble board or a couple of pillows - eyes opened and eyes closed**



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BLOCK 2 STRENGTH AND PLYOMETRIC EXERCISES.

7. Kangaroos (8 x 2 times - 8 x 1 time) just with one foot (dominant).

8. Lateral jumps (10 x 2 times – 1 x 10 times) with one foot.

9. Frontal jumps. (8 x 3 times)

10. Hop and stance different directions. (10 x 2 times)


.

11. **Same exercise eyes opened and eyes closed**.

Theraband (elastic band) exercise (4 x 8 times each)

12. Feet extension

13. LATERAL MOVEMENT

14. Leg (eyes opened and eyes closed) (2x8 eyes opened 2x8 eyes closed)

15. Front kick 1 x 8 eyes opened 1 x 8 eyes closed

16. Back kick 1 x 8 eyes opened 1 x 8 eyes closed

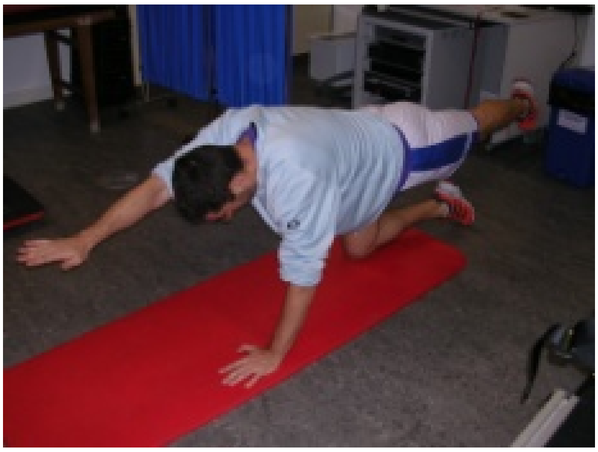
17. Squat two legs   1 x 8 eyes opened 1 x 8 eyes closed

18. Squat one leg 1x8 eyes opened 1x8 eyes closed

19. Walk on your toes 10 meters x 5 times. front and backwards.

BLOCK 3 CORE TRAINING

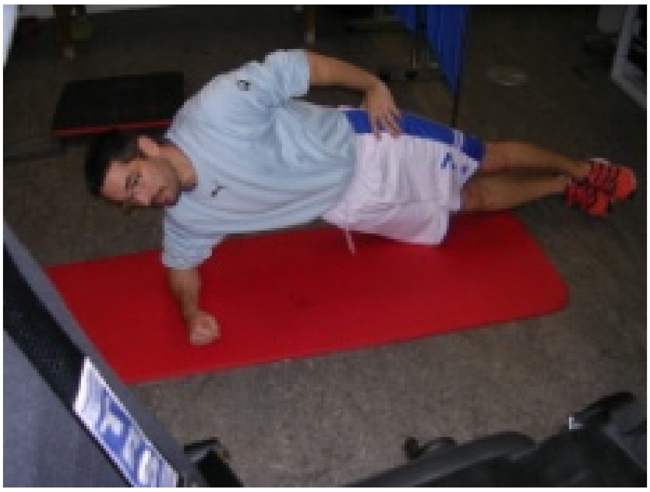
20. Bird dog 6 x 15 seconds



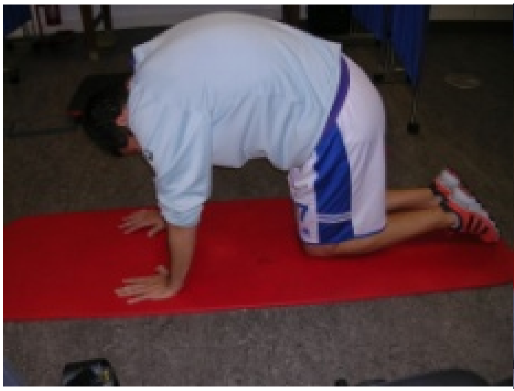
21. Ventral bridge 2 x 20 sec. can use a bosu if you are used to this exercise or ad more seconds.

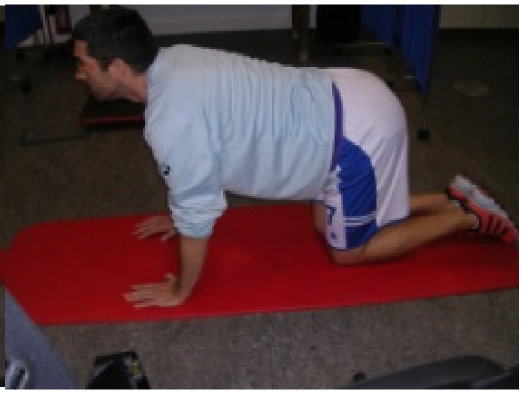
22. Dorsal bridge 2 x 20 sec. can use a bosu if you are used to this exercise or ad more seconds. or do it just with one leg.(dominant)

23. Lateral bridge 2 x 15 sec, each side.can use bosu or similar.



24. Camel 10 repetitions





25. Airplane (4 x 15 sec) 2 flex/ext of the leg   2 abd/add (lateral mov.)

26. Crunches 2 x 20 rep.

27. Side crunches 2 x 20 rep.

28. Reverse crunches 1 x 10 rep.

Appendix 1b

ESQUEMA DE LOS ESTUDIOS DE INVESTIGACIÓN

ESTUDIO 1.

Objetivo: Mejora de la capacidad propioceptiva, neuromuscular y el equilibrio.

Dosis: 18 sesiones de entrenamiento específico

Intervención 6 días de entrenamiento. 3 sesiones de 15-20 minutos de duración cada una por día.

N: 12 sujetos sanos (8 hombres y 4 mujeres).

Medidas: 1. Antes del periodo de entrenamiento.
2. Justo después del periodo de entrenamiento.
3. Una semana después del periodo del entrenamiento.

Variables: 1. Equilibrio (test estático a la pata coja en plataforma de fuerzas).
2. PF: Fuerza máxima (test dinamómetro de fuerzas).
3. FE: Error de fuerza (test en dinamómetro de fuerzas).
4. JPS; sentido de la posición articular (test con goniómetro).

ESTUDIO 2.

Objetivo: Comprobar los efectos de la estimulación con resonancia estocástica en sujetos sanos no entrenados y entrenados de forma específica e intensiva.

Dosis: aplicación de resonancia estocástica mecánica por debajo del umbral de sensibilidad consciente, durante los tests.

Intervención 6 días de entrenamiento. 3 sesiones de 15-20 minutos de duración cada una por día.

N: 12 sujetos sanos (8 hombres y 4 mujeres).

Medidas : 1. Antes del periodo de entrenamiento.
2. Justo después del periodo de entrenamiento
3. Una semana después del periodo del entrenamiento.

En cada intervención los sujetos son medidos en 3 condiciones distintas:

1. Con resonancia estocástica.
2. Sin nada.
3. Placebño (aparato de resonancia estocástica apagado).

Variables: 3. FE: Error de fuerza (test en dinamómetro de fuerzas).
4. JPS; sentido de la posición articular (test con goniómetro).

Appendix 2

BORG SCALE

Borg scale was explained and showed to each participant, and asked if any of the exercises in any session passed a score of 7, to tell the examiner to change the exercise or quit it (Borg 1982).

Appendix 3

EXAMPLE INFORMATION SHEET FOR POTENTIAL PARTICIPANTS

Queen Margaret University
EDINBURGH

My name is Alberto Sánchez and I am a Postgraduate student from the School of Health Sciences at Queen Margaret University in Edinburgh. As part of my PhD course, I am undertaking a research project for my dissertation. The title of my project is:" **"The acute effects of an intense dose of proprioception conditioning and stochastic resonance on functional balance and neuromuscular performance".**

This study will investigate the use of a 1 week condensed balance training programme for improving an athlete's postural sway and muscle work in joint stability.

The findings of the project will be useful as they may prove that with short periods of balance training people could improve their joint stability that will be beneficial to diminish risk of injury. The results may also enhance growing research specific balance training programs for injury prevention and treatment, and the use of new and almost imperceptible methods as the stochastic resonance for the same purpose.

I am looking for volunteers to participate in the project. Volunteers must be part of the sporting body of the university, or people that practice sports assiduously. If you are a healthy athlete who has had no hip, hamstring or knee/ankle injuries in the last year you are welcome to take part in this project.

If you agree to participate in the study, you will be asked to attend the performance lab up to 35 minutes of testing one day a week for three consecutive weeks. There will also be a familiarisation day prior to testing that will require your attendance up to half hour. Tests will consist in one leg stand and hop and stand in a force plate (flat surface at ground level) and a strength test in a dynamometer, a device that works as the weight lifting machines.

You will also have to perform a balance training program 3 times a day for 15 minutes each time during the second week, schedule will be flexible to not interfere in your daily activity. You will be always supervised and all exercises will be carefully explained. The exercises will consist in different types of jumps, cuts, one leg stand balance on flat and unstable surfaces and will follow a difficulty progression). The exercises will reproduce recreational physical activity in a submaximal effort and the programme has been designed to be varied, fun, and to challenge you within your own capabilities.

Warm up, an appropriate and individualized performance progression, explanations and demonstrations to solve doubts, and security measures will be carried out to minimize the possible risks of falling or lack of motivation.

You will be free to withdraw from the study at any stage and you would not have to give a reason.

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All data will be anonymised. Your name will be replaced with a participant number, and it will not be possible for you to be identified in any reporting of the data gathered.

If you would like to contact an independent person, who knows about this project but is not involved in it, you are welcome to contact Dr Nigel Gleeson. His contact details are given below.

If you have read and understood this information sheet, any questions you had have been answered, and you would like to be a participant in the study, please now see the consent form.

Contact details of the researcher

Name of researcher: Alberto Sánchez Sierra

Address: Postgraduate Student, Msc Physiotherapy, School of Health
Sciences, Queen Margaret University, Edinburgh
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Email: ASanchezSierra@qmu.ac.uk/ 07766961829

Contact details of the independent adviser

Name of adviser: Dr Nigel Gleeson

Address: Post, Subject Area, School
Queen Margaret University, Edinburgh
Queen Margaret University Drive
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East Lothian EH21 6UU

Email / Telephone: NGleeson@qmu.ac.uk / 01

Appendix 4

WRITTEN INFORMED CONSENT FORM

Queen Margaret University
EDINBURGH

"The acute effects of an intense dose of proprioception conditioning and stochastic resonance on functional balance and neuromuscular performance".

- I have read and understood the volunteer information sheet.
- I understand what the project is about, and what the results will be used for.
- I have completed the pre-test questionnaire.
- I am fully aware of all of the procedures involving myself, and of any risks and benefits associated with the study.
- I know that my participation is voluntary and that I can withdraw from the project at any stage without giving any reason.
- I understand that the results of the research may be published but that my personal details will not be revealed.
- I am aware that my results will be kept confidential.
- I understand that any questions I have concerning the research study before and after my consent will be answered by Dr. Nigel Gleeson, Reader in Rehabilitation Sciences, Physiotherapy Staff - School of Health Sciences, Tel: 0131 474 0000, ngleeson@qmu.ac.uk

Name of Participant …………………………………

Signature of Participant …………………………………

Date …………………………………

Signature of Researcher …………………………………

Name of Researcher: Alberto Sanchez Sierra

Address: Postgraduate Student, Msc Physiotherapy, School of Health Sciences
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A mis empleadas y compañeras de trabajo, por cubrir mis ausencias siempre con una sonrisa y con mucho esfuerzo.

A mis pacientes por creer y confiar en mis manos.

A mis directores de tesis por su infinita paciencia y por mostrarme el camino correcto.

A la Universidad Queen Margaret, a su departamento de fisioterapia y en especial a Tom Mercer por acogerme como uno más y dejarme desarrollar mi investigación en sus instalaciones.