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The Impact of Different Types of Core Training in Stable and Unstable Environments on Markers of Athletic Performance

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A dissertation submitted in fulfilment of the requirement for the Master of Arts in Strength and Conditioning

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Statement of Originality and Ownership of Work

Department of Sport and Leisure Studies

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Date: 11-6-2014

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Abstract

Background: Research suggests that core stability and strength is important in facilitating athletes to effectively transfer force to the lower and upper extremities of the body. The purpose of the current research was to evaluate the impact of an eight week intervention of core training on stable and unstable surfaces, and in vertical and horizontal alignments, on markers of athletic performance relevant to team sports.

Methods: The athletic performance markers selected were bounce depth jump, countermovement jump, agility (T-test), 10 meter sprint, 30 meter sprints, and 1RM leg strength as identified by Cressey (2007). Core stability and strength were measured using the McGill (2001) core stability tests, composed of combined time for trunk flexion, trunk extension, lateral right bridge and lateral left bridge. Participants, (N=89), were assigned to either an intervention group or control group. Intervention groups were divided based on their classification, i.e. exercising in (i) stable vertical, (ii) unstable vertical, (iii) stable horizontal and, (iv) unstable horizontal. Paired sample t tests and analyses of variance were used to assess the magnitude of change from pre to post intervention across each of the five groups.

Results: Significant changes occurred in core stability, post intervention across all groups with the greatest magnitude of change in the intervention groups. There was no significant difference across groups on the combined dependent variables, $(F24, 276) = 1.02, p = .44$; Wilks Lambda = .74, partial eta squared = .07. Data from a mixed between-within subject's analysis of variance revealed significant improvements in markers of athletic performance over time. No clear improvement was found in markers of athletic performance across each of the participating groups.

Conclusion: The study concluded that the 8 week intervention was effective at eliciting greater improvements in core stability. No difference in improvement was found however in markers of athletic performance between different participating intervention groups.

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Definition of Terms

The following section provides definitions of key terms used throughout the thesis.

Core Training: Exercising to develop the muscles of the core, which comprises the muscles in the centre of the body. The term was coined by Gajda & Dominquez (1982), and it aims to improve postural control in dynamic situations, as well as developing correct muscular proportionality around the lumbo-pelvic-hip complex.

Core Stability: The ability of the core muscles to act with stabilizing actions (as opposed to movement actions) while a person is sitting, standing or moving.

Core Strength: The muscular control that is required around the lumbar spine to maintain functional stability in single and repeated movements.

Vertical Core Training: Core stability or endurance exercises performed in a vertical position.

Horizontal Core Training: Core stability or endurance exercises performed in a horizontal prone or supine position.

Stable Surface Core Training: Core stability or endurance exercises performed on a stable surface and in a balance position.

Unstable Surface Core Training: Core stability or endurance exercises performed on an unstable surface where balance has to be maintained or re-established during the exercise.

Stable Vertical Core Training (SVC): Core stability or endurance exercises performed in a vertical position and in a stable environment.

Unstable Vertical Core Training (UVC): Core stability or endurance exercises performed in a vertical position and in an unstable environment.

Stable Horizontal Core Training (SHC): Core stability or endurance exercises performed in a horizontal position and in a stable environment.

Unstable Horizontal Core Training (UHC): Core stability or endurance exercises performed in a horizontal position and in an unstable environment.

Functional Training: Functional training involves an integrated approach to training involving movement in multiple planes of motion utilizing multiple body parts.

Functional Stability: A category of fundamental movement skills that incorporate balance, and involve movement with minimum or no movement at the base of support.

Neutral Zone: an area of high flexibility around the neutral spine.

Kinetic Chain: A combination of several successively arranged joints making up a complex motor unit.

Chapter 1

Introduction

Introduction

In the past number of years, there has been a significant increase in core stability training for both sports conditioning programmes and the general population as a result of fitness professionals emphasizing that the training of the core region of the body is of enormous importance (Willardson, 2007). Prior to this, core training exercises were reserved mainly for individuals with low back problems in physical therapy clinics (Chek, 1999; McGill, 2001; Saal, 1990). Despite the popularity of core stability training, there are still gaps in the scientific research that has been conducted to demonstrate the benefits for healthy athletes (Willardson, 2007).

The term core has been defined as the twenty nine pairs of muscles that support the lumbo-pelvic-hip complex (Fredericson & Moore, 2005). Saal, (1990) defined the concept of a neutral spine, as a position of good posture with the proper alignment of the three natural curves of the spine. This concept, may be largely responsible for the popularizing of core training exercises to a more commercialized setting (Liemohn, Baumgartner, & Gagnon, 2005). The application of core training is now a significant part of the work of physical therapists, personal trainers, strength and conditioning coaches and other fitness professionals. Many of the ideas and rationale behind this core training concept are propagated by the fitness media. The commercialization of equipment and the benefits of core training were not always matched by supporting research. Core training had become the newest 'buzz' word in the fitness and conditioning fields and magazine articles, seminars and work-shops, research articles, and even newspapers are offering information related to this training topic (Boyle, 2004; Chek, 1999; Gambetta & Clark, 1999; Johnson, 2002; Morris & Morris, 2001).

Core stability and core strength training has become the subject of increasing research interest. This is reflected by the comments of Boyle (2004) and Chek (1999) who are proponents of core stability and strength training. Other researchers however such as Marshall and Murphy (2005) argue that there is little scientific evidence to support some methods of core conditioning over other core training methods, in particular the use of the stability ball training. However core stability and strength training is now used widely throughout the medical world as a rehabilitative technique for lower back pain and motor control learning and in performance training by strength and conditioning professionals. Cook (2010) has highlighted the importance of both core stability and core strength training and emphasises the relationship between the two and their interdependence in relation to human movement. Functional control around the lumbar spine is essential to maintain functional stability and strength, (Cook, 2010; & Sahramm, 2006). Functional training is now a key concept in strength and conditioning and has been defined as a continuum of exercises that teach athletes to handle their bodyweight in all planes of movement (Boyle, 2010; Sahramm, 2006; Verstegen, 2008). The terms functional training and unstable surface training are not synonymous though unstable surface training is one part of a larger process that makes up functional training (Boyle, 2010). Increasingly sports coaches and trainers have begun to utilize the concept of functional training and core stability as training and conditioning concept for sports performance and fitness in general. Such training techniques can be traced back to Joseph Pilates who developed his Pilates system of body conditioning during the First World War and refined his technique over the next fifty years. Throughout the years, various different training plans have been developed, by numerous coaches and trainers, all of which support the idea that all muscles of the core are needed for optimal stabilization and performance. According to Santana (2003), core strengthening has received much attention in the past decade, this may be the result of strength and conditioning professionals buying into the notion that athletic power comes from the core.

Santana (2003) states that lower back pain occurs when the muscles of the back are unable to deal with the forces exerted upon it. One advantage that core stability offers sports performance is that it allows the athlete to maintain correct form and postural balance through the execution of technique. The need for core stability and strength is supported by Hodges and Richardson (1996) who found that the transversus abdominis, multifidus, rectus abdominis, and oblique abdominals were consistently activated before any limb movements occurred during whole body movements.

There has been a high level of interest in the strength and conditioning profession to determine if relationships exist between core stability and athletic performance, as well as between functional movement ability and components of performance such power, strength,
speed and balance (Baker 2000; Barry 2005). Evidence is lacking in this area and one of the reasons for the lack of evidence according to Tse (2005), Stanton (2004) and Baker (2000), is that universal definitions and testing methods do not exist. It is hypothesized by Tse (2005) and Stockbugger (2001) that significant relationships between core stability and functional movement and between functional movement and performance may exist and that there may also be, a positive relationship between core stability and functional movement.

The research question which the study seeks to examine is whether t core stabilization and core strength training of different types has an impact on markers of athletic performance. It asks if core training programmes carried out on stable and unstable surfaces, on selected performance markers of athletic ability. Though traditional core training was performed either in a horizontal position on a stable surface or in a vertical exercise in a stable position, in recent years unstable surface training (UST) has grown in popularity in strength and condition programming. The basis for this development has largely been based around rehabilitation of injuries and the reduction of injury occurrence (Boyle, 2010).

The study proposes to examine the impact of stable surface training (SST) of the core in vertical and horizontal alignments versus unstable surface training (UST) of the core in vertical and horizontal alignments, on markers of athletic performance relevant to team sports. Cressey (2007) identified these markers as appropriate markers of athletic performance in male soccer players. The sports teams used in the study are from elite male Gaelic football and hurling. The key research question will attempt to examine the impact of different types of core training programmes carried out on stable and unstable surfaces, on selected performance markers of athletic ability on senior intercounty GAA players. The primary aim is to identify the most effective core training methods that significantly impacts on athletic performance.

The following sections will be included in this review: (a) definition of the core, its anatomy and musculature, (b) the rationale for core training and the concept of core stability and strength, (c) a review of the literature pertaining to core training and its relationship to performance indicators such as acceleration, speed, power, agility and lower body strength, (d) stable and unstable surface training as it relates to the core and functional training.

Chapter 2

Literature Review

Literature

2.1. Definition of the Core

As the term core implies, it is the central portion of the body, or torso, where stabilization of the abdominal, paraspinal, and gluteal muscles are critical for optimal performance (Nadler et al., 2002). The term core has been used by several researchers such as McGill, (2001), Panjabi (1992) and Clark (2008), to refer to the trunk or more specifically to the lumbo-pelvic-hip complex (LPHC). The core had traditionally been thought of as the abdominal muscles but in fact it is much more than the abdominal muscles. In addition to the abdominal muscles (rectus abdominis, external oblique, internal oblique, & transversus abdominis), the core consists of four general muscle groups: (a) hip musculature, (b) lumbar spine musculature, (c) thoracic spine musculature, and (d) cervical spine musculature (Hedrick, 2000). Fredericson and Moore (2005) provided a more absolute definition that states: "the core musculature can be defined generally as the twenty nine pairs of muscles that support the lumbo-pelvic-hip complex in order to stabilize the spine, pelvis, and kinetic chain during functional movements." This definition shares common ground with a definition according to Tse (2005), who states that "the core musculature includes muscles of the trunk and pelvis that are responsible for maintaining the stability of the spine and pelvis and are critical for the transfer of energy from larger torso to smaller extremities during many sports activities." It seems it is theoretically agreed that if the extremities are strong and the core is weak, the decrease in muscular summation through the core will result in less force production and inefficient and even ineffective movement patterns, (Clark, 2008; Hedrick, 2000; Nadler, et al., 2002). Consequently, a definition offered by Kibler et al. (2006) defines core stability as "the ability to control the position and motion of the trunk over the pelvis to allow optimum production, transfer, and control of force and motion to the terminal segment in integrated athletic activities."

Sharrock, et al. (2011) however, argues that although current literature offers a variety of suggestions for defining core stability, it remains unclear on a precise conclusion. The complexity of the core and the inter relationship of its twenty-nine muscles in facilitating movement and the transfer of forces has made it difficult to define precisely and led to variations in definitions from different authors. To provide greater clarity it is necessary to define the core in the context of functional sports training. In this context the core stability was described as the ability of the torso to support the effort and forces of the arms and legs, so that the muscles and joints can perform in their safest, strongest and most effective positions (Elphinston & Pook, 1999). This view supports the strength training laws of Bompa (2009) in which the development of the core is recommended prior to the development of the limbs. Bompa (2009) also suggests that improved core function benefits the more efficient use of muscle power, reduced injury risk, greater capacity to generate speed, and improved ability to change direction and control body momentum.

2.1.1 Function of the core

Core muscles such as the rectus abdominis and erector spine may stabilize the spine and pelvis, and increase power transfer during functional movements (Fredericson & Moore, 2005). Core stability, strength and endurance are therefore held to be important both for athletic performance and overall general health, including prevention and treatment of low back pain (Biering-Sorensen, 1983). Cholewicki, Simons, and Radebold (2000), Hodges and Richardson (1996) and McGill, et al. (2003) all suggest that strong and endurable core muscles stabilize the spine favourably by providing greater passive support with effective mechanical integrity as well as facilitating the operation of the neuromuscular system. This contributes to effective activation of these muscles when exposed to forces and loads. This view has led to the description of the primary function of the core, as an anti-rotational and anti-extension devise (Boyle, 2010). The core according to Boyle (2010), plays a major role in preventing the body from over rotating during powerful movements such as a golf swing or striking the ball in hurling. The same applies with over extending the trunk, and both the anti-rotational and anti-extension role of the core facilitates the athlete in regaining balance and control of movements. Therefore, it appears that the stability of the lumbo-pelvic region is crucial to provide a foundation for controlling the movement of the upper and lower extremities, to support loads, and to protect the spinal cord and nerve roots, (Panjabi, 1992).

2.1.2 Stabilizing system

The core as a stabilizing system is divided into 3 distinct subsystems: the passive subsystem, the active muscle subsystem, and the neural subsystem. The passive subsystem consists of the spinal ligaments and facet articulations between adjacent vertebrae. The passive subsystem places restrictions on movement that allows the lumbar spine to support a limited load (approximately 10 kg), which is far less than an individual's body mass. These restrictions to motion imposed by ligaments structures, the nature of joint surfaces and the mechanics of joint cartilage, are factors that impose limitations that require the stabilizing system to maintain a neutral posture where minimum resistance is imposed by the passive spinal column. Injury and other physiological factors can also limit motion in the passive subsystem, (Panjabi, 1992). The active muscle subsystem has the function of supporting the body mass plus additional loads associated with resistance exercises and dynamic activities (McGill, 2001). Bergmark (1989) and Comerford (2001), (Table 1), divided the active muscle subsystem into "global" and "local" groups, based on their primary roles in stabilizing the core.

Table 1 Muscle Classification systems

Local Muscles	Global Muscles
• Deep cervical flexors • Rotator cuff • Rhomboids • Mid and lower trapezius • Transversus abdominis • Multifidus • Vastus medialis obliquus • Diaphragm • Muscles of the pelvic floor • Gluteus medius and minimus • External hip rotators	• External obliques • Erector spinae • Rectus abdominis • Gluteus maximus • Rectus femoris • Iliopsoas • Hamstrings • Levator scapulae • Pectoralis major • Latissimus dorsi • Adductors

The local muscle group consists of the small, deep muscles that control intersegmental motion between adjacent deep muscle layers that originate and insert segmentally, making them, primarily responsible for generating enough force for segmental stability of the spine. They are not typically movement producers, but provide stability to allow movement of a joint. They are located in close proximity to the joint and often have a poor mechanical advantage for movement production. These muscles are shorter in length and attach directly to the vertebrae offering spinal support by both passive and active mechanisms (Briggs, Greig, Wark, Fazzalari, and Bennell, (2004). Their activities precede motion, and are independent of the direction of movement, and are continuously engaged throughout movement by increasing joint stiffness and thus stability.

The global group consists of the large, superficial muscles that attach from the pelvis to the rib cage and the upper and lower extremities and are primarily in charge of producing movement. They act to increase intra-abdominal pressure (e.g., rectus abdominis, internal and external oblique abdominis, transversis abdominis, erector spinae, lateral portion quadratus lumborum). These muscles possess long levers and large moment arms, which allow them the capability of producing high outputs of torque, with an emphasis on speed and power while equalizing the external loads placed on the body, (Fredericson & Moore, 2005). The global muscles are generally the larger muscles of the trunk region, responsible for eliciting movement in a wider range of motion.

It is important to note that both the global and local subsystems are involved in both movement and stability. It has been proposed that one group is merely emphasized more with regard to their proposed function but both systems theoretically work in synergy, (Cholewicki & Van Vliet, 2002). Comerford (2001) further classified local and global muscles into stabilizers and mobilizers, (Table 2). The terms stabilizer and mobilizer refer to a specific action performed by the muscle, with the premise on the action of the muscle that can be directly influenced and changed by neural input.

Table 2 Stabilizers and Mobilizers

Local Stabilizers	Global Stabilizers	Global Mobilizers
• Transversus abdominis • Deep cervical flexors • Mid and lower trapezius • Multifidus (deep) • Vastus medialis obliquus • Psoas major	• Internal obliques • External obliques • Multifidus (superficial) • Gluteus medius • Serratus anterior • Longus colli (oblique fibers)	• Rectus Abdominis • Iliocostalis • Latissimus dorsi • Levator scapulae • Scalenus anterior • Hamstrings

The subsystem under neural control activates the active subsystem and is composed of receptors in skin, muscle, tendon, joint capsule, and the CNS. It controls the tension in the core muscles and as tension increases within the core muscles, compressive forces increase between the lumbar vertebrae and this tightens the lumbar spine to enhance stability, (Panjabi, 1992). The neural subsystem is continuously monitoring and making adjustments to muscle forces based on feedback it receives from the muscles spindles, Golgi tendon organs, and spinal ligaments. The demands to stabilize can change extremely quickly, depending on postural adjustments during movement or external loads taken on during activity. The stabilizing system and its subsystems are displayed in figure 1.

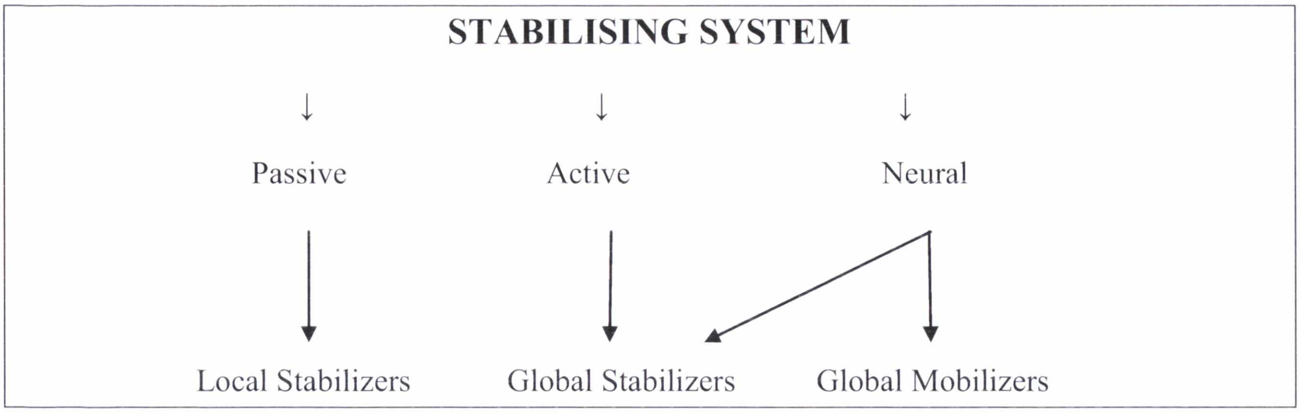


Figure 1 The Stabilizing System

The neural subsystem must provide adequate stability but also allow necessary joint movements to occur, (McGill, 2002), Panjabi (1992). Central to the neural subsystem providing the required stability is the transversis abdominis muscle. Creswell and Thorstenson (1994) highlighted the importance of this muscle functioning primarily to increase intra-abdominal pressure, which in turn reduced the compressive load on the lumbar spine. Further studies have supported the view that the transversis abdominis is the first muscle activated during unexpected loading, and self-loading of the trunk, (Creswell, 1994), and during lower and upper extremity movements, in any direction, (Hodges & Richardson (1997).

Hodges and Richardson (1997) used the term "feed-forward mechanism" to describe the neural function of the transversis abdominis. The neural subsystem utilizes feedback from previous movement patterns to coordinate and activate this muscle immediately prior to the preparation for postural adjustments or adjustments to external loads. Willardson's (2007) model of core stability is shown diagrammatically in figure 2.

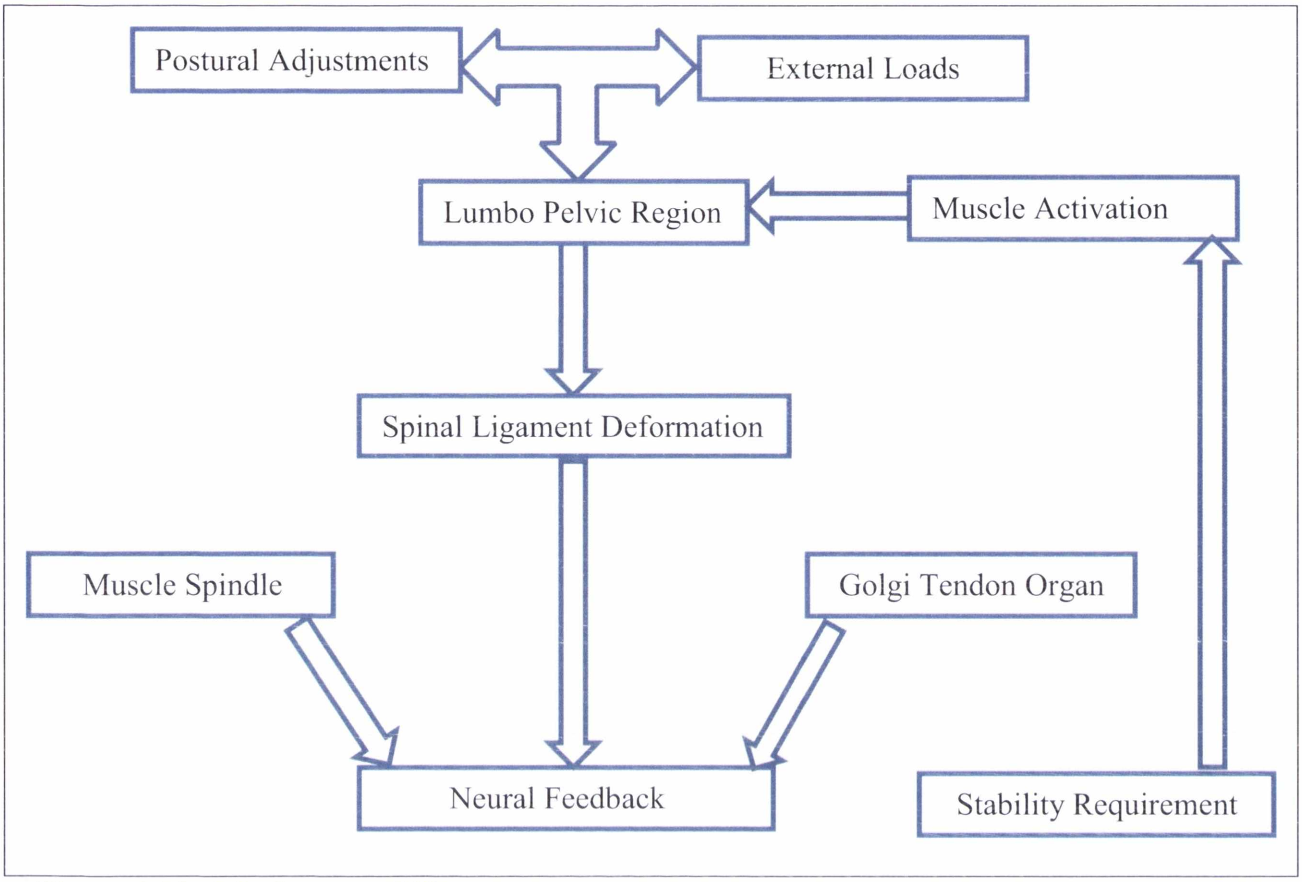


Figure 2 Model of core stability

In a follow up study, Hodges and Richardson (1997) demonstrated how a delayed activation of the transversis abdominis in subjects with low back pain, suggested deficits in neural control. If the view is taken that the smaller local muscles are involved primarily with core stability, whereas the larger global muscles are involved primarily with force production, then ineffective training strategies may be designed to train the local and global muscle groups separately and in non-functional positions. For example, the abdominal draw-in technique, performed as a stabilizing function of the transversis abdominis in the quadruped or supine body position, was widely accepted in core training exercises, by Boyle (2002), and by Verstegan and Williams (2004). However in their later writings, Boyle, (2010) and Verstegan and Williams (2004) found that although this muscle is a key stabilizer of the lumber spine, several other core muscles, both local and global, work together to achieve spinal stability during movement tasks (Cresswell, & Thorstensson, 1994). This corrected concept now supports the view held by Nitz, and Peck (1986), that, local muscles, such as the multifidus and rotators, which have high densities of muscle spindles and also function as movement monitors, provide the neural subsystem with proprioceptive feedback. This feedback facilitates the co activation of the global muscles, so they can adjust their contractions to meet the stability requirements of the movements being performed. This is an important adjustment as failure to make corrections in stability can result in inefficient or ineffective movements and skills. So as knowledge of the function of the core increases and adjusts based on continued research, it would seem that the relative contributions of each muscle is continually adapting throughout a movement. Hibbs et al. (2008), suggests that to improve the efficiency of core stability in performance settings, exercises must be performed that simulate the movement patterns of a given sport, which enables the core to make better and quicker adjustments.

2.2 Anatomy of the Core

The core or lumbo-pelvic-hip complex (LPHC) is a region of the body that has a massive influence on the structures above and below it. The LPHC has twenty nine muscles that attach to the lumbar spine or pelvis (Richardson & Jull, 1995). The LPHC is directly associated with both the lower extremities and upper extremities of the body. Because of this, dysfunctions of both the lower extremities and upper extremities can lead to dysfunction of the LPHC and vice versa.

In the LPHC region specifically, the femur and the pelvis make up the iliofemoral joint and the pelvis and sacrum make up the sacroiliac joint (Figure 3). The lumbar spine and sacrum form the lumbosacral junction. Collectively, these structures anchor many of the major myofascial tissues that have a functional impact on the specific movement of joint surfaces above and below them. These movements, known as arthrokinemtaics are rolling, gliding, and sliding motions at joint surface.

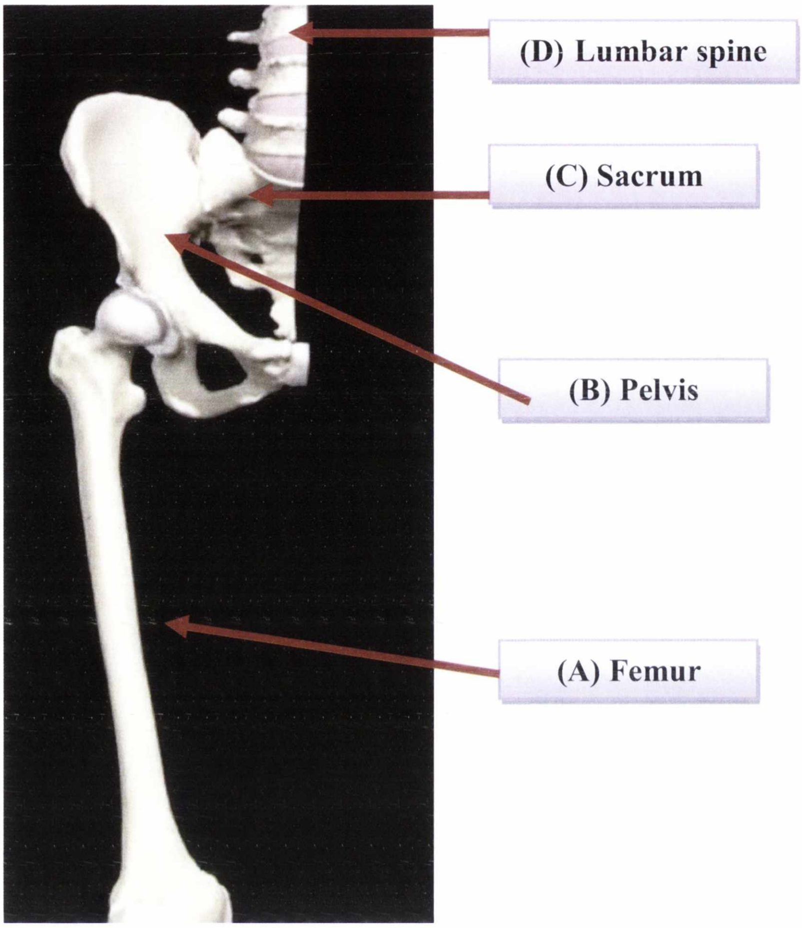


Figure 3 Bones of the LPHC.

(A) Femur. (B) Pelvis. (C) Sacrum. (D) Lumbar spine.

Above the LPHC are the thoracic and cervical spine, rib cage, scapula, humerus, and clavicle. These structures make up the thoracolumbar and cervicothoracic junctions of the spine, the scapulothoracic, glenohumeral, acromioclavicular (AC), and sternoclavicular (SC) joints (Figure 4).

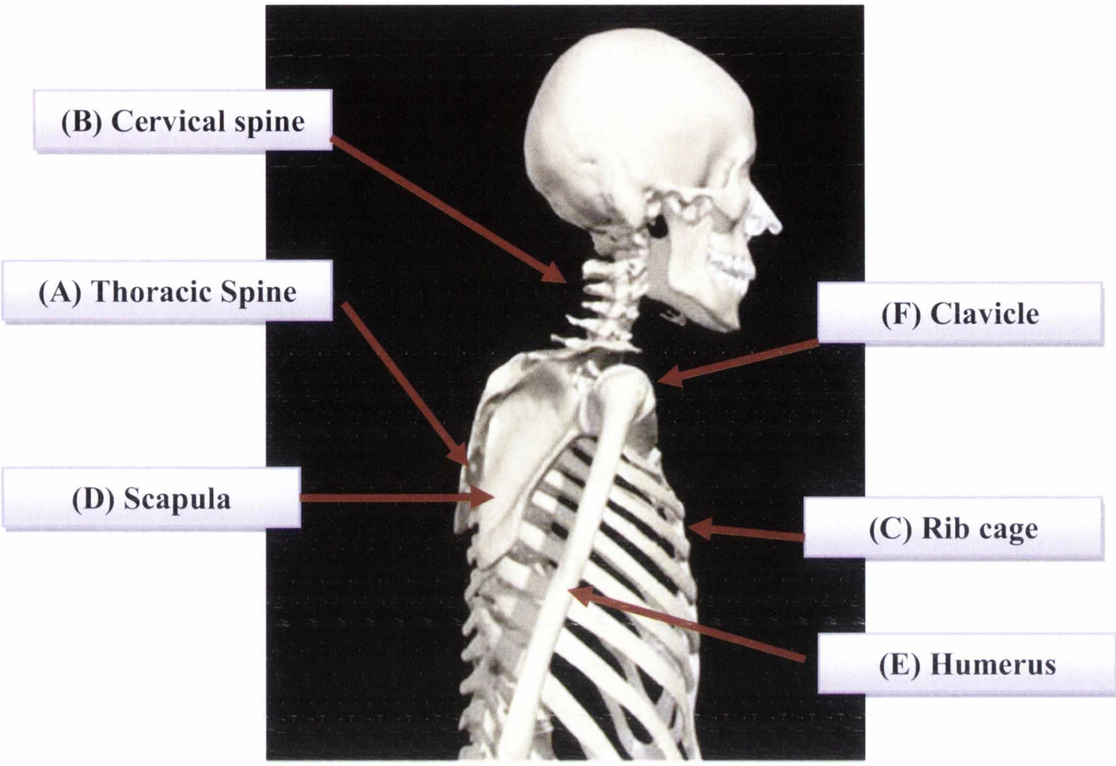


Figure 4 Bones above the LPHC.

(A) Thoracic spine. (B) Cervical spine. (C) Rib cage. (D) Scapula. (E) Humerus. (F) Clavicle. (Khuman et al, 2013)

Below the LPHC, the tibia and femur make up the tibiofemoral joint, and the patella and femur make up the patellofemoral joint (Figure 5). The fibula is also noted as it is the attachment site of the biceps femoris, which originates from the pelvis. It should also be noted that the tibia, fibula, (inclusive of the distal fibula and distal tibia) and talus help to form the talocrural (ankle) joint. Collectively, these structures anchor the myofascial tissues of the LPHC such as the biceps femoris, medial hamstring complex, and rectus femoris. These bones and joints are important because they can have a functional impact on the arthrokinematics of the LPHC, (Kaltenborn, 1989). Joint surfaces move with respect to one another by simultaneously rolling, gliding, and spinning. The rolling and spinning by a joint surface follows rules of concavity and convexity. Each joint or articulation involves two bony surfaces, one that is convex and one that is concave. When the concave surface is fixed and the convex surface moves on it, the convex surface rolls and glides in opposite directions. Functional impact occurs when there is normal joint surface movement that is necessary to ensure long-term joint integrity.

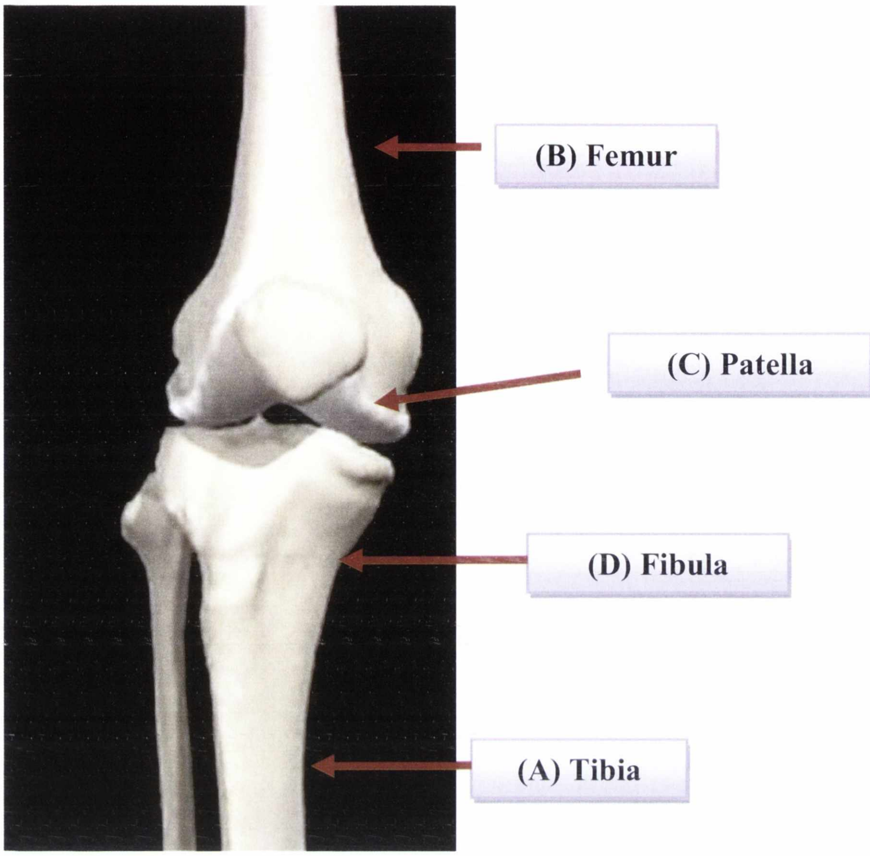


Figure 5 Bones below the LPHC.
(A) Tibia. (B) Femur. (C) Patella. (D) Fibula. (Khuman et al, 2013)

2.3. Musculature of the Core

In order to understand the concept of core stability, it is necessary to understand the role of the twenty nine muscles that compose the core and their role in the scheme of coordinated movement. Nichols (1994), expanded on Bergmark's work and divided the core musculature into muscles and their roles, in terms of the tension that develops in the muscle in relation to the length of the muscle, and the force it can produce by the velocity of its length change, (Table 2),. He elaborated stating that these muscle activation patterns that are length dependant muscles, i.e. only produce optimal force from its optimal length, occur in the small, short muscles with small lever arms, which typically span only one joint. The muscle activation patterns that are force dependent muscles cover multiple spinal segments, and produce higher levels of force, and coordinate multiple joints. Therefore, the control of the multi-segmented spine and the neutralizing of forces applied to them are controlled by the combination of both muscle activation patterns.

2.3.1. Muscles of the Core and their Roles

The muscles of the core can be divided into four muscle groups, the lumbar spine group, described in table 3, and displayed in figure 6; the abdominals, described in table 4, and displayed in figure 7; the psoas, described in table 5, and displayed in figure 8; and the glutes and hamstrings, described in table 6, and displayed in figure 9. Each group consists of several different muscles, each of which plays a specific role in core stabilization and activation.

Table 3 Lumbo Pelvic Hip Complex

Transversospinalis muscle group	Erector Spinae muscles group	Quadratus Lumborum	Latissimus Dorsi
The transversospinalis group generally has poor mechanical advantage relative to movement production. They are primarily Type I muscle fibers with high degrees of muscle spindles and are ooptimal for providing proprioceptive information to CNS and in relation to inter and intra segmental stabilization. They include the Rotators, Interspinales, Intertransversarii, Semispinalis and Multifidus.	The erector spinae muscles provide inter-segmental stabilization and they also eccentrically decelerate trunk flexion & rotation. They include the Iliocostalis, Longissimus and Spinalis	The quadratus lumborum is the stabilizer for frontal plane movement and works in conjunction with gluteus medius & tensor fascia latae	The latissimus dorsi acts as the bridge between upper extremity and the core musculature

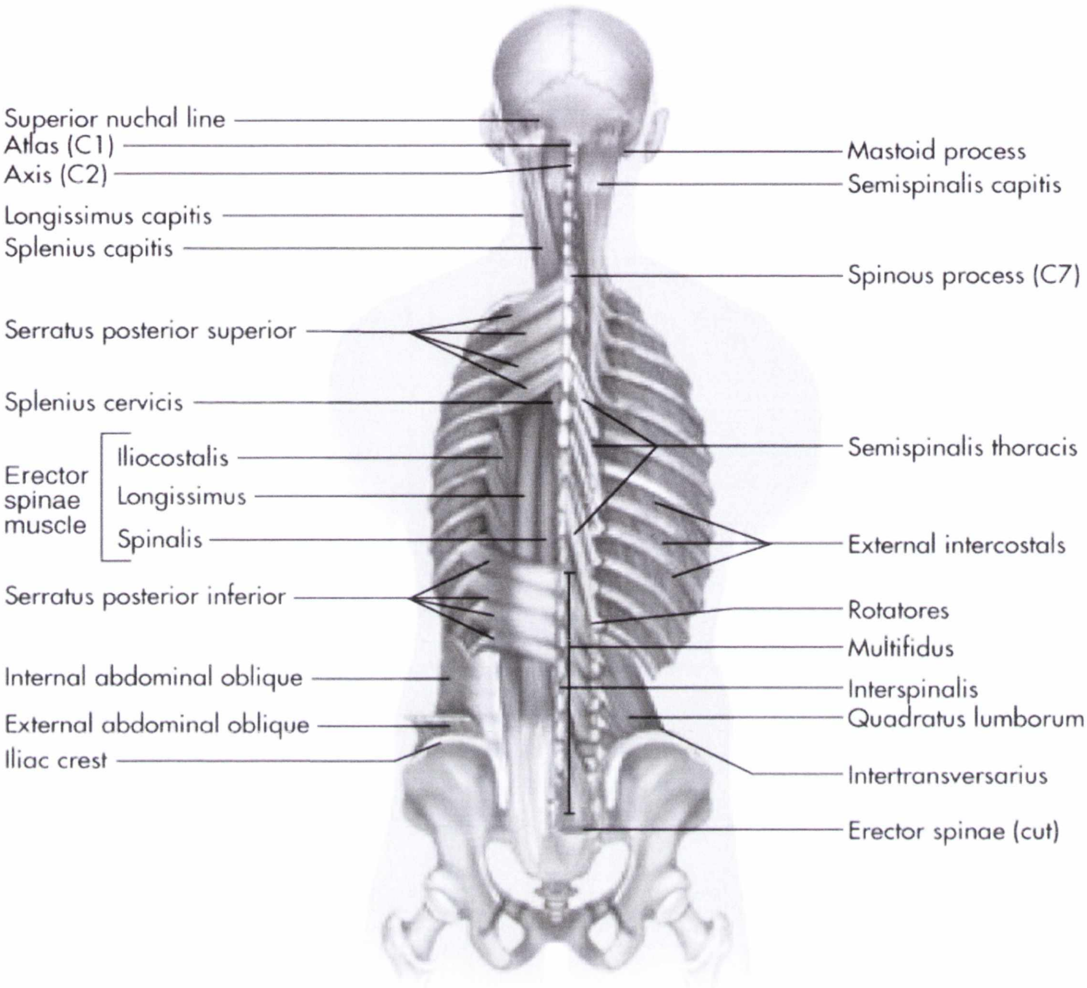


Figure 6 Lumbar Spine.

(Khuman et al, 2013)

Table 4 The Abdominal Muscles

The Abdominal Muscles
These muscles work to optimize the spinal mechanics and to provide stabilization during movement in the sagittal, frontal and transverse planes. The abdominal muscle group is composed of the rectus abdominus, the external obliques, the internal obliques, and the transverse abdominus, **(**Khuman et al., 2013).

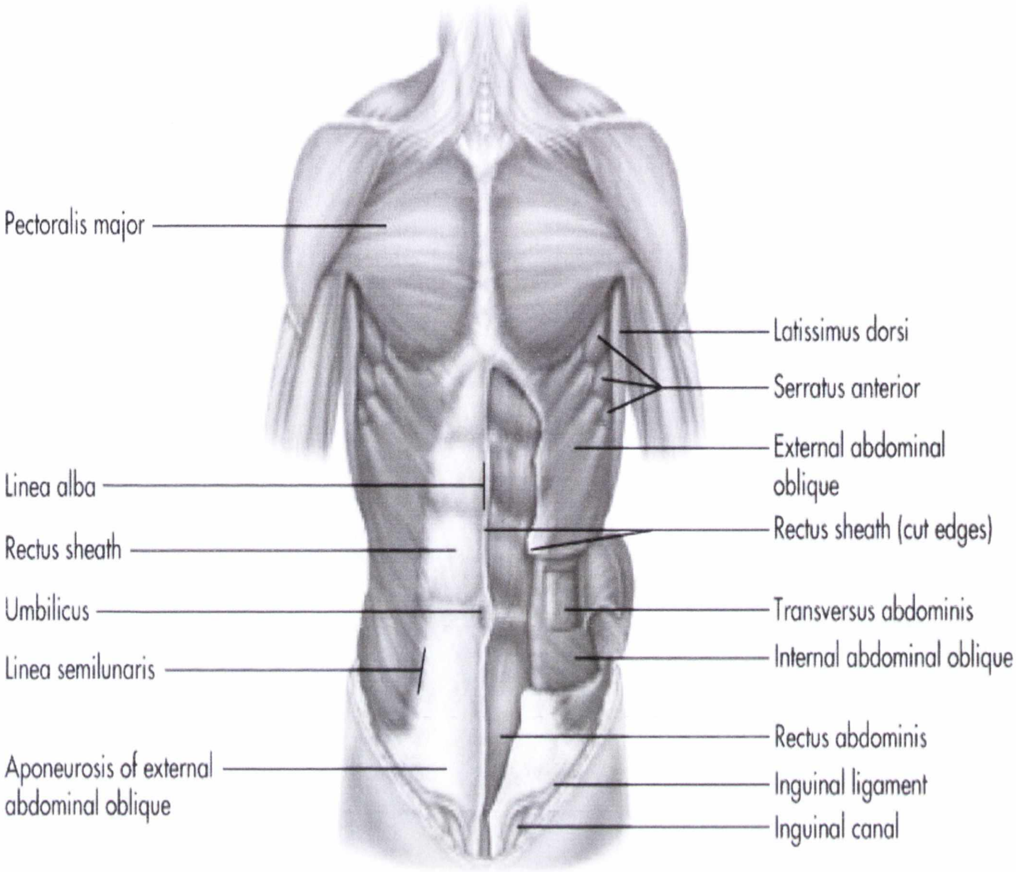


Figure 7 The Abdominal Muscles

Table 5 The Psoas

The Psoas
These psoas major and minor muscles are primarily concerned with closed chain as opposed to open chain functioning. Ellenbecker (2001) describes open chain movements as movements where the distal aspect of the extremity of the body, or the end of the chain farthest from the body, moves freely and is not fixed to an object. Examples would be exercises such as seated leg extension, leg curls or bench press. Closed chain movements, such as squats, lunges and press-ups, have the distal end of the extremity is fixed, causing joint compression and therefore, stabilize the joints The psoas major and minor therefore works with the erector spinae, multifidus and the deep abdominal wall to balance the anterior forces of the lumbar spine. If the psoas is tight it can reciprocally inhibit the gluteus maximus, multifidus, deep erector spinae, internal oblique and the transverse abdominus. This can cause a dysfunction of extensor mechanics and synergist dominance by the hamstrings & erector spinae during hip extension. Dysfunction during hip extension may alter the function of gluteus maximus, altering hip rotation, and gait cycle. (Khuman et al,. 2013)

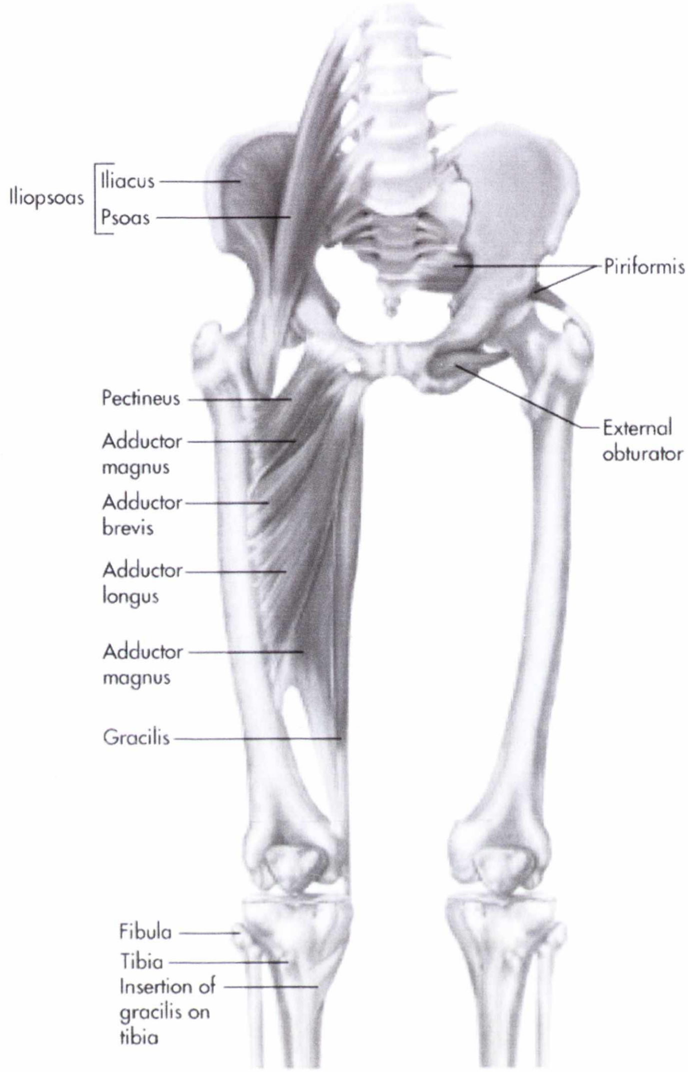


Figure 8 The Psoas

Table 6 The Glutes and Hamstrings

The gluteus maximus	The gluteus medius	The hamstrings
This gluteus maximus is responsible for hip extension and external rotation during open kinetic chain movement concentrically, and eccentrically, for hip flexion and internal rotation as well as for the deceleration of tibial internal rotation. It also stabilizes the sacroiliac joint. If there is faulty firing of the gluteus maximus it will result in decreased pelvic stability and reduced neuromuscular control	This muscle is the frontal plane stabilizer and weaknesses in the gluteus medius will increase frontal and transverse plane stresses (patellofemoral stress). It also controls femoral adduction & internal rotation. This is important because weaknesses femoral adduction & internal rotation would results in synergistic dominance of TFL & quadratus lumborum	The hamstrings concentrically flex the knee; extend the hip and rotate the tibia.They also eccentrically decelerates knee extension, hip flexion and tibial rotation. They work synergistically with the ACL to stabilize tibial rotation.

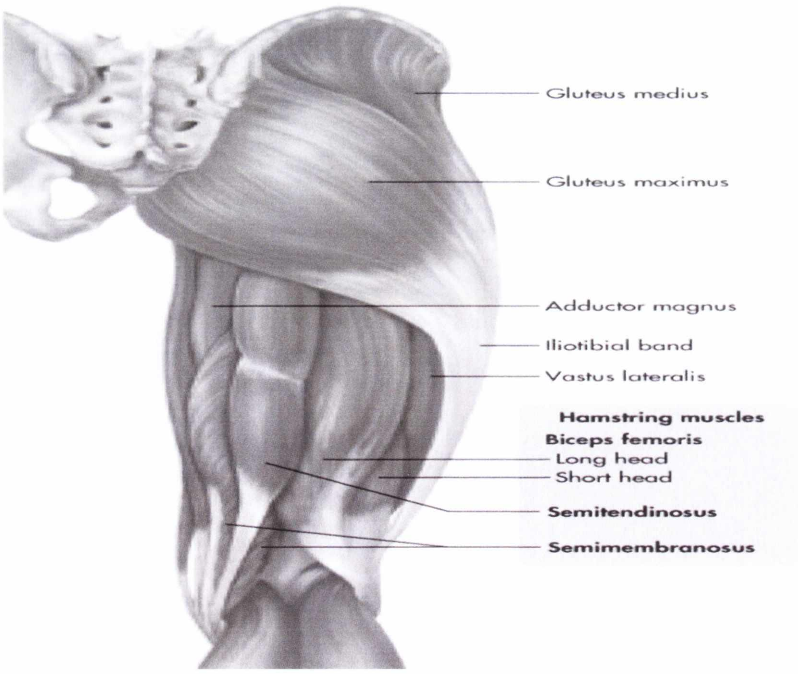


Figure 9 The Glutes and Hamstrings

Neuromuscular efficiency is the ability of the CNS to allow agonists, antagonists, synergists, stabilizers & neutralizers to work efficiently and interdependently. These inter and intra muscular coordination's are facilitated by the combination of both postural alignment and the strength of the stabilizing system. When postural alignment and stability are at their optimal level, the body's ability to generate force is optimized. Consequently dynamic stabilization is crucial for optimal neuromuscular efficiency (Clark, 2008).

2.4 Purpose and Rationale for Core Training

2.4.1 Core Strength and Sports Performance

McGill (2001) stated that, "any exercise that channels motor patterns to ensure a stable spine, through repetition, constitutes a core stability exercise". Strength and conditioning coaches and exercise professionals have recognized the benefits of a strong core in enhancing sports performance, general movement function, having positive effects on the activities of daily living, injury prevention, and some aesthetic benefits in the form of improved posture alignment. Rehabilitation professionals have highlighted the training of the core muscles for the treatment of injury and the prevention or re-occurrence of injuries related to poor core stability. Core strength is critical for performance because all movements either originate in, or are coordinated from the core (D. Brittenham & G. Brittenham, 1997). Therefore, to develop an athlete's full performance potential, core stabilization and strength is crucial in facilitating improved force output, (Hedrick, 2000; D. Brittenham & G. Brittenham, 1997).

The lumbo pelvic hip complex connects movements of the lower body and the upper body together. Force vectors are continuously being transmitted up and down the body when movements are being performed. The forces from ground reaction combined with forces generated by the lower body muscles, transfer up the body to the upper extremities during the course of physical activity, (Hedrick, 2000). Forces applied at the upper extremities also move through the body down to the ground and in both cases the forces traverse through the core. The lumbo pelvic hip complex is also responsible for generating a variety of movements in different planes of motion.

Nesser et al. (2008) stated that there are an insufficient number of studies that have quantitatively demonstrated the importance of core strength in sports performance. Studies that have examined core strength and sport-specific performance have often failed to find a relationship between these variables: Scibek et al. (2001) tested swimming performance and core strength in high school–level swimmers, Stanton et al. (2004) have reviewed running performance, economy, and core strength in high school football and basketball athletes, while Tse et al. (2005) tested rowing performance and core strength in college aged rowers. The results of these studies, though finding improvements in core strength, found no significant relationship between core strength training and the enhancement of swimming, running or rowing performance. Nesser (2008) indicated that the athletic performance variables being measured, the diversity in the sports population that are tested and an inconsistency in the methods used to measure core strength could be responsible for the lack of significant findings.

However, some studies have reported some links between core stability, core endurance and sports performance. Abt et al. (2007) studied the relationship between core stability and lower extremity mechanics in cycling. The results indicated a relationship between core fatigue and a change in cycling mechanics that increase the risk of injury by placing greater forces on the knees. Although no significant differences was observed in pedaling forces, fatigue did affect lower extremity alignment and mechanics, Abt and colleagues suggested that both core stability and endurance may improve both these measures.

Sato and Mokha (2009) studied the effects of a 6 week core stabilization training program on ground reaction forces, stability of the lower extremity, and running performance in both competitive and noncompetitive runners. Their finding showed a significant improvement in 5,000 meter running times for both groups, with no changes in ground reaction forces or leg stability. Sharrock et al. (2011), utilizing 35 collegiate athletes, compared their core stability using a double leg lowering test, to their forty yard dash scores, agility T-test, vertical jump, and medicine ball throwing ability. Correlations between the core stability test and each of the other four performance tests, demonstrated a link between the core stability test and athletic performance tests. However, Sharrock concluded that more research was needed to provide a definitive answer on the nature of this relationship. It was also suggested that future studies should examine if there are specific sub-categories of core stability which are more important in allowing for optimal training and performance in sport.

2.4.2. Core Strength and Lower Back Pain

Core training has also been identified as having benefits in improving poor posture by forcing it to transfer more efficiently through a straight line. Poor postural alignment causes movement impairments and a reduced force output (D. Brittenham & G. Brittenham, 1997). This concept can apply to performance in sport as well as functional activities. The benefits of a strong core may lead to an increase in power transfer involved in activities such as throwing, jumping, running, lifting, striking, and many sports specific movement patterns. Cholewicki and McGill (1996) and Crisco and Panjabi (1991), all found evidence to show that an under developed lumbo pelvic hip complex can be correlated with low back pain. They found that core muscles provide an important role in stabilizing the spine. As the spine is essentially unstable, an important role of the musculature system is to tighten the spine during movements that cause instability (McGill et al., 2003). McGill et al. (2003) found it is likely that spine stability results from well-coordinated muscle activation patterns that involve many muscles and that the recruitment patterns must be continually changing in response to the task being undertaken. A deficit in the timing of muscle activation in response to sudden loading of the trunk was found by Hodges and Richardson (1999) and Magnusson et al. (1996), to be associated with low back pain. McGill et al. (2003) stated that instability of the spine can be associated with both the cause and the result of injury. Core stabilization has applications in both the reduction of injury risk by the treatment of athletes who are at increased risk of sustaining an injury in activities occurring in unstable environments.

Several studies support the suggestion that muscles with good levels of strength and endurance in the lumbo pelvic hip complex can reduce the risk of low back pain (Biering-Sorenson, 1983; Luoto, Helioraara, Hurri, & Alaranta, 1995). The Biering-Sorenson (1983), study tested male subjects for core muscle strength and endurance and found that after a 1-year period that low back muscles with good isometric endurance was a significant predictor of reduced low back impairment. The implications are that good core strength and endurance reduces abnormal muscle recruitment and activation patterns, and improves the mechanical integrity of the core muscles and the passive structures that are responsible for stabilizing the spine.

The implications resulting from current research indicates that just one muscle with a sub-par level of activation can produce instability (McGill et al., 2003). He states that the relative contribution of each muscle will be constantly changing throughout the performance of a task and the most important stabilizing muscle is only dominant in a transient manner. It would seem therefore that there is a minimum level of muscular strength or endurance, in all core muscles, that is necessary to maintain good spinal stability. Consequently, stability training inevitable involves a degree of core strength endurance development, (Creswell, 1992; Hodges and Richardson, 1997).

2.5. Core Strength and Spinal Stability

Exercises to improve spinal stability are widely used in both rehabilitation and injury reduction programmes. There is however, a debate on which muscle groups (local or global) to target as well as exercise goals during spinal stability training (Richardson & Jull, 1995). This is because of the assumption that intervertebral stability is achieved automatically and that exercises should focus on improving lumbo pelvic stability to achieve spinal stability. Grieve (1982) pointed out that there are two primary differences in the approaches toward spinal stability training. First, there are differences in the target muscle groups for the prescribed exercises, specifically, exercises for local versus global musculature (Richardson & Jull, 1995). Second, there are differences in the type of exercises performed to target improved strength and power (abdominal bracing) versus exercises that focus on improving neuromuscular control (abdominal drawing-in or hollowing). Traditionally the approach to spine stability training used exercises that focus on the global stabilizers, but not necessarily the local stabilizers. Research had suggested that the global muscles are the most important for spinal stability (Grieve, 1982; McGill, 2001). However, this research assumes that intervertebral stability had been achieved, and as indicated by, Cholewicki and Van Vliet, (2002), both local and global muscles contribute to spinal stability and therefore exercises for spinal stability should target both local and global stabilizers. Both bracing and drawing-in manoeuvres can improve spinal stability. Because drawing-in can influence both intervertebral stability and lumbo-pelvic stability and because lumbo-pelvic stability is dependent on intervertebral stability, use of the drawing-in manoeuvre to train the local muscles and improve intervertebral stability may be considered the starting point for a spine stability training program, with a later progression to the abdominal bracing technique. However Faires et al., (2007), though supporting the idea that abdominal drawing in manoeuvre may be better suited for static exercises that focus on training the local muscle system, indicates that it may not be the most effective manoeuvre for core activation during the performance of activities in which the global muscle system is loaded. The drawing in manoeuvre isolates the transverse abdominus but happens at the expense of inhibiting the internal oblique, external oblique, and rectus abdominis. Bracing can be more effective when dynamic stability is required for compound and multi planar movements.

Clark (2008) refers to the core as an integrated unit, which allows the entire kinetic chain to operate in a coordinated or synergist manner, enabling it to produce force, reduce force and to dynamically stabilize against abnormal force. In a correctly developed core, each of the structural components or subsystems can operate at maximum effeciency through the proper distribution of weight and the absorption of force.This in turn allows for the transfer of ground reaction forces further up the kinetic chain. The entire kinetic chain must be trained in all three planes of motion for optimal functioning. Dynamic stabilization of the core enhances neuromuscular efficiency by improving the ability of CNS to allow agonists, antagonists, synergists, stabilizers & neutralizers to work efficiently and interdependently. The development in core stability results in enhanced postural alignment and spinal stability, which positively impacts on the athletes ability to adapt to forces and to generate force, whereas an underdeveloped core will lead to decreased force production, (Clark, 2008; Tse, et al., 2005).

2.6. Core Stability versus Core Strength and Endurance

The terms core stability and core strength and endurance are often used interchangeably, which can cause confusion. Core stability occurs as a result of input from the passive spinal column, active spinal muscles, and neural control unit, which maintain intervertebral range of motion within a safe limit in response to internal and external perturbations (Borghuis, 2008). Alterations in the core system can be expected or unexpected and occur as a result of internal and external forces due to movement patterns at the extremities of the body. In order to provide sufficient stability to protect the spine from perturbations, input from the passive, active, and neural subsystems are needed. These conceptually separate but functionally interdependent systems work together to provide core stability.

Similarly, core strength and endurance provides the muscular control required around the lumbar spine to maintain functional stability, Tse et al. (2005) and Okado (2011). One of the three subsystems of core stability is the active control of the muscles surrounding the spine and the ability of these muscles to produce the forces needed to provide spinal stabilization that make up core strength. Therefore, it is through the contractile forces created by the active muscles surrounding the spine that core stability is provided. The close relationship between core stability and core strength and endurance could be the reason as to why they may be confused for one another in the literature

Another source of confusion between core stability and core strength and endurance stems from the sectors in which they are used: rehabilitation versus sport performance. The demands placed on core stability and core strength and endurance are vastly different within these sectors, (Hodges & Richardson, 1999). In rehabilitation, core fitness focuses on the ability to perform pain-free activities in daily life with an emphasis placed on the control of spinal loading. In sport performance, core fitness focuses on the ability to maintain stability during highly dynamic and sometimes loaded movements, Kibler (2006). It would seem that when sports performance is the focus, core stability and core strength are often used interchangeable or combined into a single term, core fitness (Tse et al., 2005).

2.7 Measuring Core Stability, Strength and Endurance

Knowing that endurance is essential for maintaining stabilizing patterns of muscle activity (McGill, 2007); several studies have assessed athletes for core stability using the McGill protocol (Durall et al., 2009; Nesser & Lee, 2009; Nesser et al., 2008; Tse et al., 2005). Performing the lateral trunk endurance tests in the protocol requires the activation of "local" muscles, mainly the quadratus lumborum and abdominal wall (McGill et al., 1996). The flexor endurance portion of the McGill test targets the major trunk flexor, the rectus abdominis, which is a "global" muscle (McGill, 2007). The back extensor test, which is was modified from the classic Biering-Sorensen test (Biering-Sorensen, 1984), activates the major extensors of the spine, the longissiuus and multifidi, which are part of the "local" stabilizing system (McGill, 2007). The time is recorded for each test and the final score is the total time for all four tests. Results from a previous study by McGill, Childs, and Liebenson (1999), showed the 4 trunk isometric muscle stability and endurance tests, to have excellent reliability coefficients.

2.8 Guidelines for Core Training

For the purposes of this study, core stability will be, as defined by Kibler (2006), 'the ability to control the position and motion of the trunk over the pelvis to allow optimum production, transfer, and control of force and motion to the terminal segment in integrated athletic activities' whereas, core strength and endurance is defined by Faries (2007), 'as the ability of the musculature to generate force through contractile forces and intra-abdominal pressure'.

Prior to undertaking a core training programme it is necessary to perform a comprehensive evaluation that assesses muscles imbalances, myokinematic deficits where the myofascial structures have been affected by previous injury the reduces the athletes capability to deal with the transfer of loads, arthrokinematic deficits affecting surface movement of the joints, core strength, neuromuscular control and power, and overall kinetic chain function. Tests of core stability, functional movement screening and assessment of postural alignment may be necessary to create a comprehensive picture. Muscle imbalances and any arthrokinematic deficits must be corrected prior to initiating aggressive core training. Program requirements for core training require a systematic, progressive, and functional strategy. It is necessary to emphasize muscle contraction across the whole spectrum of concentric contraction (force production), eccentric contraction (force reduction), and isometric contraction (dynamic stabilization), Clark (2008).

The objective of a core training programme is to develop optimal levels of functional strength and stability with a focus on neural adaptations as opposed to absolute strength gains and an increase in proprioceptive demands. A programme should emphasize quality over quantity and attempt to eliminate poor technique that may impinge on neuromuscular control resulting in poor motor patterns. (Gambetta, 2007)

Core stability and strength training predominantly consists of torso training, but also includes training the stabilizing muscles of the hips, lumbar, thoracic, and cervical spine. The design of a performance specific core training programme should comply with the variety principle of training and involve a variety of exercises that demand the athlete to move dynamically in the frontal, sagittal, and transverse planes of motion (Szymanski, 2010). Frontal plane exercises would involve lateral flexion on both sides of the body, while sagittal plane exercises would require flexion and extension of the trunk. Transverse plane exercises would involve rotational movements on both sides of the body. The incorporation of all three types of exercise would lead to optimal core performance (Szymanski, 2010).

According to Willardson (2007) core training should be challenging on both stable and unstable surfaces. Programmers should have controlled progression through the functional continuum. In recent years traditional resistance exercises have been modified to emphasize core stability, and these adjustments have included performing exercises on unstable rather than stable surfaces. Chek (1999) suggests performing exercises in vertical stances rather than horizontal positions, using free weights rather than machines based weights, and using unilateral rather than bilateral exercises.

Gambetta (2007) prescribes core stability exercises based on the periodised phase of training and the ability level of the athlete. During preseason and in-season monocycles, free weight exercises performed while standing on a stable surface are recommended for increases in core strength and power. These exercises should be specific to the core stability requirements of sports-related skills that impose moderate levels of instability and high levels of force production. Conversely, during postseason and off-season mesocycles, unstable surface exercises involving isometric muscle actions, small loads, and long tension times are recommended for increases in core endurance. Furthermore, exercises, to improve proprioceptive and reactive capabilities are recommended, (Boyle, 2010). Core training programme should incorporate variations in exercises and cover all of planes of motion, and incorporate good range of motion. Loading should be based on the use of appropriate equipment, (Swiss balls, medicine balls, tubing, wobble boards, BOSU, etc.). Exercises should be performed in both horizontal and vertical positions and the tempo (time under tension), duration and frequency of the training cycle are also important considerations, Gambetta (2007).

The selection of exercises must ensure that the programme has proprioceptive variety, is safe, and is sport specific. Progressions are from slow to fast, from the simple to the complex, from familiar to unfamiliar environment or surface, from static to dynamic, with eyes open to eyes closed and from low levels of force to high levels force. Szymanski (2010), Gambetta (2007), and Boyle (2010), identified the off season, preseason, in season and active rest period as the four different phases of an annual periodized programme for core training.

Programme design for core stability training should be based on the periodized phase of training and the ability of the athlete. Garhammer (1981) and Sale (1988) suggest that during the preseason mesocycles, increases in core strength, endurance and stability should be the primary goal. The development of core power can follow this during the latter stages of the preseason and the early phase of in season training. Because the majority of sports performances are ground based, with moderate degrees of instability, core stability and training exercises should aim to achieve the highest possible transfer to performance, (Bompa & Haff, 2009).

Conversely, during postseason and off-season mesocycles, increases in core endurance and stability should be the primary focus (Carter et al., 2006). Cosilima (2003) recommends core resistance exercises performed on a BOSU, stability discs or on a Swiss hall should involve isometric muscle actions, small loads, and long tension times to achieve these aims. Furthermore, the performance of exercises on balance boards, wobble boards and stability discs, during this period of training can reduce the occurrence of lower extremity injuries later on as they bring about a heightened sensitivity in the muscle spindles and a greater degree of postural control, (Schibek, 2001; Yaggie, & Cambell, 2006).

To improve core performance, a series of general, special, and specific core programme should be implemented into a progressive periodized programme. General programmes would focus primarily on muscular development, progressing to special programmes that incorporate movement patterns along with muscle development and culminating in sport specific programmes that focus predominantly on movement patterns relating specifically to the patterns involved in executing sports skills. Progression means incorporating movements from simple to complex, known to unknown, low force to high force, static to dynamic, lying to sitting, kneeling to standing, and on two legs to standing on one leg, (Clark, 2008). Many sports movements occur through sequential, coordinated muscle contractions that require timing and balance. The system by which this occurs is called the kinetic link. If the multi-planar human movements are not coordinated to allow the forces generated from the lower body to be transferred through the torso to the arms, then sports performance will not be optimal, (Clark, 2008). To optimize sports performance, Gambetta (2007), recommended the distribution of core training throughout the season which should be based over four periods that correspond to those of Szymanski but uses different terminology. Gambetta also recommends the number of training units per microcycle;

- General preparation; six sessions per microcycle
- Specific preparation; four sessions per microcycle
- Peak competition; three sessions per microcycle
- Transition phase; two sessions per microcycle

Although there is some consensus among researchers that greater core stability provides a foundation for greater force production in the upper and lower extremities, (Willardson, 2007; Yessis, 2003), several questions still remain as to what types of resistance exercises best train core stability in athletes and under what conditions effective exercises produce the optimal results.

2.9 Stable versus Unstable Surface Training

Boyle (2004) and Chek (1999) have suggested that the unstable surfaces offered by Swiss ball exercises are the most effective for training core stability. Research by Vera, Garcia and McGill (2000), have demonstrated higher core muscle activity when resistance exercises were performed on the unstable Swiss ball than on a stable surface. Behm et al. (2005) studied muscle activation levels in the core musculature during six standard trunk exercises, and the use of bilateral and unilateral dumbbell shoulder press and chest press exercises performed on a Swiss ball in comparison to the stable surface of a weights bench and the floor. Surface electromyographic (EMG) activity of core muscle activation was measured in the upper lumbar erector spinae, the lumbosacral erector spinae, and the lower-abdominal muscle regions. Muscle fibres contractions were captured by electrodes, and the signal was amplified and filtered by sensors before an encoder converted to a digital signal and sent it to the computer software to be processed and displayed. Results demonstrated that the use of Swiss ball for trunk exercises resulted in significantly greater activation of the lower abdominal region. The highest level of activity recorded for the lower abdominal region was for the side bridge exercise. There was no significant difference in core muscle activation in the shoulder press exercise, between the Swiss ball and stable bench conditions. The chest press exercise on the Swiss ball resulted in significantly greater activation in the upper lumbar erector spinae and lumbosacral erector spinae regions than on the stable bench. It was found that performing the shoulder press and chest press exercises unilaterally, regardless of the surface condition, had a significantly greater activation levels than when performed bilaterally. The study concluded that for enhanced core stabilization and strength, exercises should involve a destabilizing component.

The technical purpose of training on an unstable surface is to decrease the points of contact the body has with a solid surface. According to Behm, Anderson, and Curnew (2002), the neuromuscular adaptation required to train on unstable surface is associated with increases in strength, because the unstable training surface provides an additional stimulus above that of a stable surface to bring about a greater training adaptation. Numerous studies have examined the performance of exercises on unstable surfaces and the impact they have on the local muscles. Several studies have assessed these effects on muscle activation through the use of EMG. A summary of these findings is provided in Table 7.

Table 7 Muscle Activation for Stable versus Unstable Surfaces

Authors	Purpose	Methods	Exercise	Muscles	Summary of results
Anderson and Behm (2005)	Evaluate differences in EMG activity of various muscles while performing squats of varied stability and resistance	14 healthy men Stability was altered by performing squats under 3 conditions with varied loads	1. SMS 2. FS 3. SBD	SOL VL BF AS ULES LSES	Activities of the SOL, AS, ULES, and LSES were highest during SBD and lowest with SMS
Behm et, al (2005)	Evaluate the effect of unstable and unilateral exercises on trunk muscle activation	11 healthy men and women Unilateral and bilateral exercises on stable or unstable bases	1. Bridge 2. Pelvic tilt 3. AALE 4. PH 5. SB 6.Superman 7. CP 8. SP	ULES LSES LA	Instability generated greater activation of the LA with the trunk exercises and all trunk stabilizers with the chest press Unilateral shoulder press produced greater activation of back results stabilizers and unilateral chest press resulted in higher activation of ES
Norwood, et al., (2007)	Investigate the effectiveness of instability training in recruitment of core stabilizing muscles during varying degrees of instability	15 healthy men and women EMG measured While subjects Performed bench press exercise on stable or unstable surfaces	1. SSSF 2. UBI 3. LBI 4. DI	LD RA IO ES SOL	Significant increases in EMG with increasing instability resulted in greatest mean muscle activation of 3 conditions. Single instability conditions significantly greater than stable condition

- *EMG = electromyography; SMS = Smith machine squat; FS = free-weight Squat; SBD = squat on balance discs; SOL = soleus; VL = vastus lateralis; BF = biceps femoris; AS = abdominal stabilizers; ULES = upper lumbar erector spinae; LSES = lumbo-sacral erector spinae; AALE = alternate arm and leg extension; PH = parallel hold; SB = side bridge; CP = chest press; SP = shoulder press; LA = lower abdominals; SSSF = stable surface for shoulders and feet; UBI = upper body instability; LBI = lower body instability; DI = dual instability; LD = latissimus dorsi; RA = rectus abdominis; IO = internal oblique; ES = erector spinae; AD = anterior deltoid; BB = biceps brachii; TB = triceps brachii; PM = pectoralis major; RA = rectus abdominis; TA = transversus abdominis*

Several studies have found that unstable surface training elicits a great degree of muscle activation in the rectus abdominus, erector spinae and the internal and external obliques, (Arkoski, Valta, Airaksinen, & Kankanpaa, 2001; Behm, 2005; Marshall & Murphy, 2006; Norwood, Anderson, Gaetz & Twist, 2007). A study by Kohler (2010) was designed to compare the impact of different resistance exercises targeting core muscle activity, while being performed on stable versus unstable surfaces, and also to assess the effect of different relative intensities on core muscle activation levels. Subjects performed the back squat, military press, deadlift, and curl up. Surface electromyography (EMG) was utilized to assess the activity of the rectus abdominis, external oblique, transversus abdominis, and erector spinae muscles. Subjects were tested on a) standing on stable ground with 50% of their one repetition maximum (1-RM), b) standing on a BOSU balance trainer with 50% of their 1-RM and, c) standing on stable ground with 75% of their 1-RM. There was greater EMG activity during the 75% 1-RM condition than all other conditions in the rectus abdominis during the back squat, in the transversus abdominis and external oblique muscles during the deadlift, in the transversus abdominis, external oblique and rectus abdominis during the shoulder press, and in the transversus abdominis, and erector spinae during the curl up. In the BOSU 50% 1-RM condition, the erector spinae muscle was more active during the shoulder press movement and the external oblique during the squat movement when compared to the 50% 1-RM stable condition. The findings concluded that athletes stable surface training with higher intensities create better core muscle activation for the back squat deadlift shoulder press, and curl up exercises.

Vera-Garcia et al. (2000) evaluated muscle activation in the rectus abdominis during a curl-ups exercise carried out on a stable bench and on a Swiss ball. The stable bench group had lower amplitude of activation in the abdominal muscle recording 21% of maximal voluntary contraction (MVC). Conversely, the Swiss ball condition produced higher amplitude with 50% MVC. Vera-Garcia concluded that muscle activation levels on the Swiss ball suggested a greater demand on the motor system created greater stimuli to increase both the endurance and strength of the muscle. However it is not clear if the level of muscle activation is related to the potential for force production. Exercises performed on an unstable surface have a reduced potential for force production and may subsequently limit the potential of these exercises to transfer to sports performance. Some studies however have not supported these findings. Behm et al. (2002) examined the relationship between isometric muscle force activation of the leg extensor (LE) and plantar flexor (PF) muscle groups and stable and unstable surface training. The unstable condition resulted in isometric force output being 70.5% (LE) and 20.2% (PF) less than when performed in the stable condition. In a similar study, Anderson and Behm (2004) concluded that maximal isometric force output of the pectoralis major decreased 60% when the chest press exercise was performed on an unstable surface than on a stable surface.

These findings were further supported in another study by Kohler (2010), who evaluated muscle activity of the prime movers and core stabilizers while exercising with stable and unstable loads on stable and unstable surfaces during the seated overhead shoulder press exercise. Thirty subjects performed the shoulder press exercise for 3 sets of 3 repetitions at a 10 repetition maximum relative intensity, in bilateral and unilateral manner and on an unstable (Swiss ball) and stable (bench) conditions. Surface electromyography (EMG) measured muscle activity for 8 muscles (rectus abdominis, external obliques, erector spinae, anterior deltoid, middle deltoid, trapezius, triceps brachii,). The results demonstrated that as the instability of the exercise condition increased, the external load decreased. The bilateral bench condition had the greatest EMG activation and the unilateral Swiss ball condition had the least. The erector spinae had greater muscle activation when performing bilaterally on the Swiss ball compared to the bench. The findings provide little support for training with a lighter load unilaterally or on unstable surfaces. Though these finding go against the trend of other literature, there are factors relating to body position which could explain Kohler's results. Arokoski et al. (2001), found exercises performed in a standing positioned generated greater core activation when measured by EMG, than exercises performed in a horizontal position, as in Koehler's study. It is also noted that Cholewicki and Van Vliet (2002), found the direction and magnitude of the load affected muscle activation in the core with no single muscle group accounting for more than 30% of the activation.

External load is an important parameter in strength training as a minimum level of 60% of 1 RM is required for muscular adaptation to occur, (McDonagh & Davies, 1984). Consequently, performing strength training exercises below a 60% level of intensity is non-productive on stable ground. The 60% threshold for a training stimulus was only validated on stable surfaces, so the impact of intensity below 60% while exercise on an unstable surface and in a vertical position is less clear. Because there is a decreased capacity for force production on the unstable surface, a given percentage of stable 1 RM on an unstable surface would be relatively higher. For example, 50% of stable 1 RM would be relatively higher intensity than 50% unstable 1 RM. Studies by Marshall and Murphy (2006), Behm et al. (2005), and Norwood et al. (2007) found that repetitions of bench presses under unstable conditions increased core muscle activity more than bench presses under stable condition. Norwood (2007) more specifically observed that the relationship between the level of instability of an exercise and muscle activation levels is linear, with activation increasing as instability increases.

There is a gap in the research that has examined the effect of exercises on muscle activation level when the exercises are performed in a vertical position. Also, standing exercises tend to be more multi-joint exercises and be predominantly free weight in nature. This consequently may have greater implications for developing core stability and strength. In a study by Anderson and Behm (2004), subjects undertook exercises under three level of intensity; (a) no external resistance load (body mass), (b) a 29.5 kg load, and (c) a 60% of body mass load. Significant increases in EMG were recorded for all muscles with the exception of abdominal stabilizers and the biceps femoris. Anderson and Behm's suggested that there may be a threshold point that must be achieved for the abdominal stabilizers to increase in activation levels. They conclude that increased instability may help achieve that threshold but also suggest that more research is needed on both instability and multi-joint exercises as well as amount of resistance created by instability during the movements. In a follow on study, Anderson and Behm (2005) investigated the effects of squatting under three conditions of varying stability. They found the greatest degree of core activity occurred in the condition of greatest instability, (performed on balance discs), and as suggested, and supported by Arokoski et al. (2001), in a vertical position.

2.9.1 Balance Training

Training on an unstable surface is a common method used to train balance and the core region of the body. Balance exercises can be considered a type of core stability training in that these exercises activate the core musculature. Equipment used to create an unstable surface ranges from wobble boards, foam pads, Swiss balls, balance discs, suspended body weight training and balance trainers to non-equipment methods such as staggered stances, single leg stances, and techniques that challenge balance such as exercises with the eyes closed (Wedderkopp et al. (2003). Balance training has traditionally used unstable surfaces to improve balance. Poor balance was found by McGuine and Keene (2006) to be a predictor of increased lower extremity injury risk in athletes and non-athletes. Their research found that balance training created a perturbation of the body's centre of gravity and this facilitated the neuromuscular mechanisms that react to restore the centre of gravity back within the body's base of support.

Yaggie and Campbell (2006), and DiStefano et al. (2009), all found balance training on unstable surfaces correlated with improved postural and neuromuscular control that led to enhanced static and dynamic balance. Sudden adjustments applied to the body to avoid losing balance and falling, bring about postural adjustments to restore the centre of gravity back inside the base of support. These postural adjustments were found by Cosilima et al. (2003), Ruiz and Richardson (2005) and Santana (2001) to require activation of the core musculature to stabilize the lumbar spine. Because sports skills are often times performed off balance, greater core stability provides a foundation for greater force production in the upper and lower extremities. Ruiz and Richardson (2005) and Schibek et al. (2001) demonstrated that performance of exercises on unstable equipment significantly improved static balance and postural control measures. Behm and colleagues (2005) examined whether a relation would be found between ice hockey skating speed and the ability to balance on a wobble board, and they hypothesized that a high correlation would occur between these measures. However, for the most skilled players, hockey skating speed was not significantly related to wobble board balance ($r = -0.28$). These results indicate that performing balance exercises on a wobble board, which requires a high level of static balance, may not transfer to hockey skating speed, which requires a high level of dynamic balance and concluded that for optimum transfer, a wider variety of skills may need to be practiced in an unstable environment similar to what the athlete will perform on. Plisky et al. (2006), found a significant relationship between asymmetrical differences in the Y balance test and the risk of lower extremity injuries. Balance dysfunction resulting from poor stabilization and its link to increased risk of injury was supported by Hubbard (2010), and Herrington (2009).

2.10 Core Stability Training: Athletic and Sports Performance

Table 8 highlights the key findings of studies which have examined the relationship between core stability and athletic performance in sport.

Table 8 Summary of key studies on core stability and performance

Study	Measures	Data Collected	Subjects	Results	Key Conclusions
Reed, Ford, Myer, and Hewitt (2012)	Review of 24 key studies on core stability and athletic performance	24 studies met the inclusion criteria for the review from 179 articles examined	Not applicable	Many studies saw improvements in general strength in maximum squat load and vertical Jump. Not all studies reported measurable increases in specific core strength and stability measures following training	Targeted core stability training provides marginal benefits to athletic performance. Findings showed a lack of standardization for measurement of training and outcomes on core strength and stability.
Nesser et al. (2008)	Subjects were tested using strength, performance, and core stability variables	Strength variables (1RM bench, 1RM squat, and 1RM power clean), performance variables (vertical jump, 20- and 40-yard sprint, and 10-yard shuttle), and core stability variables (back extension, trunk flexion, and side bridges)	29 male collegiate football players	Core stability is moderately related to strength and performance but not to power	Increases in core stability contribute to improved strength but may not contribute to increased power output unless core training is the movement specific focus of power training.

Nesser and Lee (2009)	Subjects were tested using strength, performance, and core stability variables	Strength variables (1RM bench and 1RM squat), performance variables (vertical jump, 40-yard sprint, and 10-yard shuttle), and core stability variables (back extension, trunk flexion, and side bridges)	16 female collegiate soccer players	Core strength is not related to strength and power	Core strength does not contribute significantly to strength and power and should not be focus of strength and conditioning
Roetert, (1996)	Subjects were tested using isokinetic and functional trunk strength measures	Isokinetic trunk flexion and extension strength at angles of 60 and 120 degrees and functional trunk strength (forehand, backhand, overhead, and reverse overhead medicine ball throws)	60 male and female elite junior tennis players	Significant relationship between isokinetic trunk testing and functional movement patterns in tennis	The isokinetic and functional trunk strength tests would be useful additions to a tennis training program
Sato and Mokha, (2009)	Effects of 6-week core strength training (CST) on running performance	Ground reaction forces (GRF), star excursion balance test for lower leg stability, and 5000-m run.	28 runners, experiment group n=12 control group n=16	The CST experimental group showed faster times in 5000-m run but no influence on GRF or lower leg stability.	A high CST volume can have a significant effect on running performance
Stanton et al. (2004)	Effect of short term Swiss ball training on core stability and running economy	Core stability using Sahrmann's test, electromyographic activity of abdominal and back muscles, VO2max, and running economy	18 young male athletes, experiment group n=8, control n group n=10)	Swiss ball training positively affected core stability without concomitant improvements on physical performance	The Swiss ball training failed to follow principle of specificity. Training following this principle may have improved performance

Tse et al. (2005)	Examine effect of core endurance training on rowing performance	Trunk endurance measured using flexion, extension, and side flexion tests. Performance measured by vertical jump, broad jump, shuttle run, 40-m sprint, overheard medicine ball throw and 2,000-m maximal rowing ergometer test.	45 college-age rowers (core Training group n=25, Control group n=20)	No significant differences were found for any of the functional performance tests after the 8-week core endurance training program	Although core stability muscles have positive effects on reducing low back pain, it may actually be strength and power of the trunk muscles that influence physical performance tasks
Cressey, et al. (2007)	Examined stable and unstable lower body training on performance markers	A test re-test method to find the impact of stable versus unstable training on CMJ, BDJ, 10 meter & 40 meter sprint time and T-Test for agility	19 NCAA Div 1 soccer players (n=19) divided between stable and unstable interventio n groups	Dynamic flexibility warm-up and a resistance based speed and strength programme	Unstable training attenuated improvements in CMJ and BDJ and in 10 and 40 meter sprint times. No significant difference was found for agility

Based on the Cressey (2007) study that concluded that unstable training attenuated improvements in CMJ and BDJ and in 10 and 40 meter sprint times but showed no significant difference for agility, there may be an argument for core training to highly specific to the athletic requirement it seeks to enhance. Though there have been mixed finding relating to core training and performance enhancement, several studies have emerged that provide strong indicators as to potential benefits. Yessis (2003) and ACSM (2002) agree that core stability is necessary for successful execution of sports skills, and in developing core stability a functional training programme involving resistance exercises with a destabilizing component is necessary. Willardson (2004) suggested that the simultaneous development of core stability, along with upper and lower body strength, may have greater chance of transferring to sports performance. Consequently a specific training approach utilizing free weight exercises while standing on a stable surface, can develop moderate levels of instability and high levels of force production

McGill (2003) defined a core stability exercise as any exercise, through repetition, that channels motor patterns to ensure a stable spine. Traditional resistance exercises can constitute core stability exercises if modified to create some degree of instability. However, Willardson (2004) also argues that athletes who perform exercises, such as the deadlift, squat, power clean, push-press, may be developing sufficient core stability without requiring additional instability, due to the postural adjustments required to handle external loads in free weight situations. It would also seem advantageous to perform multi-joint, dynamic movements because these are the foundation exercises for most strength and power developments in most weight lifters and power athletes. To date, only one study has evaluated one exercise in this manner on an unstable surface. Clearly more research is warranted to evaluate the effects of performing other vertical, dynamic movements on an unstable surface on muscle activation of the core region, (Newton, 2006).

The performance of core stability and strength exercises on an unstable surface while in a standing or vertical position, is an area that has been investigated by relatively few studies, yet it is a condition that is most specific to sports, (Nesser, 2008; Boyle, 2010).When it comes to improving athletic and sports performance there are several variables that need to be considered. Okado et al. (2011) found that there were significant correlations between core stability and athletic performance tests. They examined the relationship between core stability and functional movement ability, of which high levels of efficiency are required for enhanced athletic performance. No significant relationships were found between any of the core stability and functional movement ability. The functional movement screen (FMS) is a dynamic set of activities and requires good stabilization of the core to complete the screens (Cook 2010). Therefore, the lack of significant correlations appearing between the core stability tests and the FMS tests such as the overhead squat and the trunk stability push up, were found by Okado to lack reason. Components of the FMS, such as mobility and coordination, may have influenced the results. This suggests that, if a subject has poor mobility or coordination, success in the FMS would not be attained despite strong core musculature. An alternative explanation was that only minimum core strength is all that is necessary to successfully complete the FMS. The researchers had difficulty explaining the correlations between core stability and functional movement performance. They suggested that similar body movements, muscle activation, and body coordination patterns are likely responsible for the results of this study. Okado argued that the results support the need for specificity of training. The core assessments were isometric muscle endurance tests, whereas the performance tests of functional movement ability involved dynamic movement. Therefore, it is safe to say that isometric training of the core provided little if any benefit to dynamic performance. Also, the FMS was designed to identify potential injury risks in individuals, and therefore, despite opposition to the argument by Cook (2010), it too may be ineffective in predicting performance.

Unstable surface training, in particular Swiss ball exercises have been promoted as sports specific training by Boyle (2004) and Chek (1999). Few studies have investigated the effectiveness of Swiss ball exercises on performance markers. One significant study by Stanton et al. (2004) examined the effect of a Swiss ball training program on core stability, VO2max, and running economy (Table 8). Subjects were divided into a Swiss ball group and a control group. Both groups continued with their conditioning programme which was primarily running based exercise and skills training. The study demonstrated significant differences favouring resistance exercises on a Swiss ball to improve core stability, but no significant differences were found between groups for VO2max scores and running economy. The study concluded, that the selection of resistance exercises which recruited the core musculature in the manner required for running, may have elicited specific adaptations, resulting in an improved run performance. These were primarily exercises performed in a unilateral, single-leg supported, and vertical position, with a similar arm position to running.

Other studies supported these conclusions, most notable, Carter et al. (2006) and Cosilima (2003) both of whom found that exercises characterized by small loads and long tension times performed using isometric muscle actions, are productive in the development of core endurance. However, Beachle et al. (2004), and an ACSM (2002) report supported earlier findings by Garhamer (1981), that core strength and power might be a greater priority than other fitness components, because of their importance in facilitating the transfer of forces, for significant improvements to occur in sports-related performance markers. Bobbert and Van Zandwijk (1999) found a relationship between core strength and stability and vertical jump height and power, however, the difficulty remains for research as to the level of transferability of core training on different surface type to actual sports performance. The impact on performance markers may be more reasonable to establish. Although a complete transfer is not achievable, the selection of resistance exercises must be considered so as to achieve the maximum transfer to the specific demands of the sport (Willardson, 2004).

The development of sports-specific core stability requires the resistance exercises to be designed with the movement patterns of the sports core stability requirements in mind to achieve optimal transfer (Willardson 2004; Yessis, 2003). However even in sports such as swimming, where there is no base of support, some practitioners such as Gambetta (1999), believe there is a degree of transfer. The core requirements for swimming differ from other ground-based sports as the core is the reference point for all movements. A high degree of core stability should be of positive benefit for swimmers to facilitate the efficient transfer of force between the trunk and the upper and lower extremities to propel the body through the water. This concept was tested by Scibek (2004), who examined the impact of a core stability training programme, utilizing Swiss balls, on dry-land performance markers and swim performance in swimmers. Subjects aged between 18-22 years were randomly divided into a an intervention group and a control group and pre and post-test measures on dry-land performance markers of vertical jump, forward and backwards medicine ball throw, hamstring flexibility, and postural control. Swimming performance was assessed using 100-yard time trials. The study found that Swiss ball exercises executed in a prone position, without foot contact with the ground, appear to be specific to the core stability requirements of swimming but not on swimming performance. There may be a wider range of abilities that influence swimming performance that are of greater significance than core stability. Scibek demonstrated significant differences between the intervention group and control group in the forward medicine ball throw and postural control measures. However, non-significant differences were demonstrated between groups in the backwards medicine ball throw, hamstring flexibility and vertical jump measures. Although there were improvements in two dry-land performance measures, swim time did not improve for the 100 yard time trials for the intervention group. The results indicate that while Swiss ball exercises may have a beneficial and positive effect on some performance markers there was not a transfer to swimming performance.

While the specificity of resistance exercises for core strength and stability having a relationship to improved sports performance, it is agreed by several researchers like Garhamer (1981), Beachle et al. (2004), and Yessis (2003), and in particular by ACSM (2002) report, that there is a transfer from free weight exercises in a standing position on a stable surface to sports performance. Traditional resistance exercises, such as the squat, power clean deadlift, push-press and twisting style rotational exercises, can be modified to put more specific emphasis on core stability. Behm (2005 points out that, the push press and dead-lift can be performed with kettlebells or dumbbells unilaterally and cables or medicine balls can be used in trunk rotation exercises simultaneously enhance movement specific core stability and upper body power ACSM (2002), and Willardson (2007).

2.10.1 Stable and Unstable Surface Training and Athletic Performance

Increasing core stability should be an important priority for all sports conditioning programs however Boyle (2010) points out that in some areas of the body such as the lumbo pelvic hip complex, sufficient mobility must be achieved before developing core stability. This seems to be an important guideline as sports skills are often performed in unstable body positions (e.g., lay-up in basketball, pucking the sliotar in hurling, shooting in soccer or Gaelic football). This requires the prescribing of resistance exercises to develop core stability in unstable positions according to Vera Garcia (2000), who found that traditional resistance exercises can be modified to emphasize core stability by modifying exercises so they could be performed on unstable rather than stable surfaces and while standing rather than seated. Arokoski et al. (2001) found that performing exercises with free weights rather than machines was beneficial to core stability, and Behm (2005) and McCurdy et al. (2005), found performing exercises unilaterally rather than bilaterally had a greater impact on core stability. Sharrock et al. (2011) stated that there appears to be a link between a core stability test and athletic performance tests, however, more research is needed to provide a definitive answer on the nature of this relationship. Ideally, specific performance tests would be better able to examine their relationships to core stability. He also found that it may be necessary to identify specific sub-categories of core stability which best allow for optimal training and performance in individual sports.

However there have been contrary arguments by Buer (2007) who investigated lower body strength training on stable surfaces in elite college soccer players over a 10-week period, and found it produced better improvements in athletic performance markers than unstable training. Unstable training seemed to cause few changes in measures of power that are important in a number of sports. He concluded that the loads in unstable training do not challenge the muscles sufficiently to produce significant improvements in strength, power and in athletic performance tests. He also concluded that unstable training was productive in promoting recovery from injuries, but not in enhancing strength and power for sports. The case for examining the importance of strength in either stable or unstable conditions and it's the relationship to performance markers is established in the work of Nimphius et al. (2010), who stated that relative strength played a crucial role in its impact on speed and agility and its importance was evident over the course of a season.

In a key study, Cressey et al. (2007) investigated the effect of a 10 week lower body unstable surface training programme on performance markers. Two groups of 18-23 years old NCAA division 1 soccer players, with no previous exposure to unstable surface training were pre-tested for speed, agility and power using the counter movement jump, CMJ), bounce depth jump, (BDJ), 10 yard sprint, 40 yard sprint and the agility T-Test. One group acted as a control group and undertook a core stability and lower body strength programme on stable surfaces, while the intervention group undertook a similar programme on unstable surfaces. Results showed that the stable surface group improved significantly more than the unstable surface group in the CMJ and BDJ performance markers and also in the 10 and 40 yard sprints. Though both groups showed significant improvements between pre and post-tests in their T-Test agility times, there was no significant differences between the groups. Cressey concluded that the stable and unstable surface training both made significant improvements in the stretch shortening cycle (SSC) of the jumping performance and the sprints. The unstable surface training underpins the principle of specificity of training and Cressey stated that it was necessary to differentiate between the instability of the foot, which is used on stable surfaces, and the instability of the torso, which experiences instability even when the base is stable. Most athletic actions occur in vertical positions on stable surfaces and Cressey concludes that the instability takes place further up the kinetic chain.

It is also noted that most athletic improvements occur at high velocity and are dependent on the SSC. Since unstable surface training interferes at the amortization (the transition from eccentric to concentric contraction) phase of the SSC movement, Komi (2003) inferred that subsequent force production from the release of stored energy from the eccentric preloading would be significantly compromised by unstable surface training. Cressey supported the views of Behm (2005), and Waller, et, al (2003), who concluded that instability training can be more useful and can be made more sport specific by using unilateral exercises, destabilizing torque above the feet and lifting awkward objects often associated with strongman training. Destabilizing torque can have benefits for improving core stability utilizing unstable surface training and utilizing unilateral exercises, lifting asymmetrical objects, using change of direction activities and utilizing uneven loading.

2.11 Summary

From the review of the research in the area of core training and stable and unstable surface training, it is evident that a great deal more research is needed to assess the effects of different forms of core training on both stable and unstable surfaces. It is also evident that more research is needed to evaluate the effects of such training on athletic performance markers and the transfer of that training to performances on athletic tests. There is no guarantee that improvements in core strength and power will transfer to improvements in sports performance according to Willardson (2005). Although a 100% transfer is impossible to achieve, resistance exercises should be chosen that closely simulate the demands of a sport.

These variables need to be examined on a more extensive region of the core muscles, to give the strength and conditioning field, particularly in the sports of Hurling and Gaelic Football, a greater understanding of the impact and transfer of different forms of core training. Whether this study finds these forms of training to be efficient or inefficient, specific or non-specific, and applicable or non-applicable, it aims to enhance the understanding of core training and athletic performance in Gaelic Games.

Chapter 3

Methodology

Methodology

3. 1 Rationale of the study

It is believed that a strong and stable core allows an athlete to fully transfer any force generated by the lower extremities, through the torso, to the upper extremities, and, when used, to an implement (Behm, 2005; Cissik, 2002). Though traditional core training was performed either in a horizontal position on a stable surface or in a vertical exercise in a stable position, in recent years unstable surface training (UST) has grown in popularity in strength and condition programming. The basis for this development has largely been based around rehabilitation of injuries and the reduction of injury occurrence (Boyle, 2010). Although this has proved valuable especially when proprioceptive deficits have been evident, there has been little evidence to support its use in general exercise scenarios and less still when the aim is to specifically target enhance core stability and endurance, of the core musculature of the body while exercising in an unstable environment, (Cressey, West, & Tiberio, 2007). Schlumberger (2010) has highlighted the importance of the specificity of core training as a means for improved sports performance. The attainment of optimal levels of speed and power are dependent on sports specific movement training that allows force to be transferred through the core, so the optimal level of control to perform with efficiency and effectiveness can be attained in the performance environment. According to Schlumberger, basic postural and movement patterns have to work effectively to avoid compensatory muscle activity. This view is supported by Boyle (2010), Sahrmann (2006), and McGill (2001), who view the core primarily as an anti-rotation, anti-extension mechanism that must operate effectively in both stable and unstable environments. Since most team sports involve performing in a vertical position and often with dynamic movement patterns that are unstable, specific research on the topic is warranted, (Newton, 2006). Hajduk (2008) has shown a significant relationship between core stability training and leg strength in football players and has suggested that vertical core training may bring about a different effect than horizontal core training. The question remains as to the effectiveness of UST to a wider range of athletic performance markers in athletes not involved in rehabilitation training.

The current study seeks to investigate the impact of stable surface training (SST) of the core in vertical and horizontal alignments versus unstable surface training (UST) of the core in vertical and horizontal alignments, on markers of athletic performance relevant to GAA team sports. The performance markers examined are bounce depth jump, countermovement jump, agility (T-test), 10 meter sprint, 30 meter sprints, and 1RM leg strength. Cressey (2007) identified these markers as appropriate markers of athletic performance in male soccer players. The sports teams used in the current study are from elite male Gaelic football and hurling. The teams were divided into five group's i.e., a control group, a stable vertical core group, unstable vertical core group, stable horizontal group, unstable horizontal core group.

3.2 Hypotheses

1. There will be no significant difference in core stability scores pre and post intervention

2. There will be no significant difference in markers of athletic performance pre and post intervention

3. There will be no significant difference in change between participants in different intervention groups and post test

3.3 Participants and Procedures

The subjects were eighty nine players (N=89) from three current senior intercounty hurling and Gaelic football teams. A convenience sampling approach was used with teams who the primary researcher had access too. Players ranged in age from 18-34 years with a mean age of 24.8 years (M=24.8), and a standard deviation of 5.63 years (SD=5.63), and all were selected to take part in the National League and Championship in their respective sports. All players were cleared medically and physically for training and playing purposes and all read and signed the Participant Information Sheet (Appendix 1), and then completed a consent form (Appendix 2) prior to taking part in the study.

Players were pre-tested in mid-March in a series of athletic performance tests (Appendix 4) to establish markers of their athletic ability in acceleration, speed, agility, power, reactive power and leg strength. Cressey et al. (2007) established these components of athleticism as definitive markers of athletic performance. Cressey's view is supported by Alves et al. (2010), who used similar markers in a study on athletic performance in soccer players. The protocols used in this study followed those used in both Cressey and Alves studies. Power and reactive power were tested using the bounce depth jump (BDJ), and countermovement jump (CMJ), both of which were measured using the SmartJump electronic jump mat. Jump height was measured in cm and Peak Power Output (PPO) was measured using Sayers (1999) equation. Sayers, et al. (1999) found the formula to be the most accurate formula for calculation power output from CMJ scores, using a cross-validation of regression equations using PRESS revealed the formula to be both accurate and reliable, (Sayers, et al., 1999).

Agility was measured using the T-test. Pauole et al. (2000) found the T-Test to be a reliable and valid test of agility and compared favourably with other validated tests of agility and in, particular, was highly correlated with the hexagon test. Acceleration and speed were measured by 10 meter and 30 meter sprints, using SmartSpeed electronic gates with HP IPAQ Pocket PC PDA and wireless remote units. Little and Williams (2005), found acceleration and speed were the most significantly correlated tests ($r = 0.623$), and used these measures in a study on acceleration and speed in professional soccer players. Leg strength was measured using a 1RM squat. Seo et al. (2012) found a standardized 1RM testing protocol with a short warm-up and familiarization period was a reliable measurement to assess muscle strength. This supported an earlier study by Levinger et al. (2009), where 1RM's were tested for confidence and reliability and high ICC (ICC > 0.99) and high correlation ($r > 0.9$) were found. Relative strength, which is defined by Jaric (2002), as the maximum force exerted in relation to body weight or muscle size was calculated by dividing the player's 1RM score by their body weight. Weight was measured using a Qualified Digital Weighing Scales.

Core stability was measured using the McGill's (2001) core stability tests, composed of combined time for trunk flexion, trunk extension, lateral right bridge and lateral left bridge. The core stability score for the test was the sum of the four tests in seconds. This test was used as a measure of core stability and for the purpose of selecting the intervention groups. Results from a previous study by McGill, Childs and Liebenson (1999), showed that the 4 trunk isometric muscle endurance tests have excellent reliability coefficients: trunk flexor test had an intraclass correlation coefficient (ICC) = 0.97, the back extensor test had an ICC = 0.97, and right and left lateral trunk musculature tests had an ICC = 0.99 (19).

3.4 Protocols for testing

Detailed explanations of the testing protocols are provided in Appendix 4. The primary researcher underwent a one day workshop provided by IRFU's strength and conditioning education coordinator, on the execution of the testing protocols. The investigator also conducted two pilot tests using a senior club football and hurling team, (n=28), prior to undertaking testing of the subjects for this study. All tests were carried out by the primary researcher. Prior to all testing or exercise training sessions participants performed 5-10 minutes of warm-up activities, consisting of various dynamic stretching and mobility exercises.

Protocol for core testing

McGill et al. (1999) identified a number of tests to determine muscle endurance of the core stabilizing muscles. The four tests, extensor test (back extensor test), flexor test (abdominal flexor test), and side bridge tests were shown to have reliability coefficients of between 0.97 and 0.99, (McGill, 2002)

The isometric muscle endurance.

During protocol described by McGill (1999) consists of four tests that measure all aspects of the core through each of the tests the participants were reminded that these were maximum effort tests and they should maintain each position for as long as possible. Only the subject and tester were present in the testing area. Participants were given no feedback about the duration of their tests or their final scores. Times for each test were recorded separately, in seconds, and were later added together to give a total score in seconds for all four tests combined.

1. Subjects were allowed to practice each position for a maximum hold of five seconds in order to prevent fatigue.
2. A handheld stopwatch was used to measure the length of time subjects were able to hold each isometric position.
3. Subjects were given a minimum of five minutes rest between each test.
4. Each of the individual core tests times was totalled to produce a single "total core" value in seconds.

Trunk flexor test

1. The flexor endurance test starts with the subject in a sit-up position with the back resting against a board angled at 60 degrees from the floor.
2. Both knees and hips are flexed 90 degrees.
3. The arms are folded across the chest with the hands placed on the opposite shoulder, and the feet are secured.
4. The jig is pulled back 10 cm and the person holds the isometric posture as long as possible. Failure is determined when any part of the person's back touches the jig.

Trunk extensor test

1. Subjects start with the upper body cantilevered out over the end of the test bench and with the pelvis, knees, and hips secured.

2. The upper limbs are held across the chest with the hands resting on the opposite shoulders.
3. Failure occurs when the upper body drops below the horizontal position.

Lateral musculature test

1. The subject begins lying in the full side-bridge position (e.g., left and right side individually). Legs are extended, and the top foot is placed in front of the lower foot for support.
2. Subjects support themselves on one forearm and on their feet while lifting their hips off the floor to create a straight line from head to toe.
3. The uninvolved arm is held across the chest with the hand placed on the opposite shoulder. Failure occurs when the person loses the straight-back posture and/or the hip returns to the ground.

Protocols for markers of athletic performance

Tests were conducted in the order of; mass, CMJ, BDJ, acceleration (10m), speed (30m), T-test, core stability and squat 1RM. The order of the tests was designed to eliminate or minimise the impact of fatigue on the subjects, by moving from and followed the sequencing in studies by Cressey (2007), Alves (2010) and Nimphius et al. (2010). Prescribed rest periods were given between tests (Appendix 3). Participants were allowed 30 seconds between each attempt on the CMJ and BDJ and the better of two trials was recorded. The 10m sprint, 30m sprint and the T-test also recorded as the better of two trials, allowing 3 minutes recovery between each trial for the T-test and 1 minute for the 10m and 30m sprints. A 10 minute recovery period was allowed before the four core tests. Subjects were allowed a familiarization attempt for each position (lasting less than 10 seconds). A further 10 minutes was allowed before the 1RM Squat test. Rest periods were in line with protocols used by Cressey (2007), Nimphius et al. (2010) and recommended by Australian Strength and Conditioning Association (ASCA, 2009). Participants were given no feedback about the outcome of their tests or their final scores. Results were recorded on the Performance Marker Record Sheet (Appendix 3) and transferred on to an excel sheet.

3.5 Intervention Groups and Programmes

The McGill (2001) core stability tests are isometric tests with all four positions held until failure which occurs when the subject breaks the form of the prescribed position. There was a minimum of three minutes rest between each of the four tests. Scores from each of the four tests were summed to provide an overall core stability score. This follows the procedure of McGill (2001). Participants were assigned an intervention group based on total core stability score. Labels were

Gambetta (2007), indicated the distribution of core training throughout the season should be based over four periods;

- General preparation; six sessions per microcycle
- Specific preparation; four sessions per microcycle
- Peak competition; three sessions per microcycle
- Transition phase; two sessions per microcycle

The period for this study was the specific preparation period for championship in both hurling and Gaelic football and fell between mid-March and mid-May It occurs after the National League was completed in mid-March (as none of the teams involved were in the play-offs) so all teams in the study were engaged in similar strength and conditioning preparation programmes in terms of capacities, volume and intensity, though uncontrolled difference did exist in the type of exercises and drills used by respective teams. The investigator had access to all training that the teams in the study were involved in.

An eight week core training programme was devised for each group and was divided into two 4 week mesocycles with the second cycle being a progressive development in intensity of the first mesocycle (Appendix 5). Since core training must be adapted to the period of training in the annual cycle and for the purposes of this study that period was the specific preparation period of the season. Therefore each microcycle of core training consisted of four sessions of approximately 20 minutes each, following the recommendations of Szymanski (2010), and Gambetta (2007). Four week mesocycles were recommended increasing either the repetitions or load in a second mesocycle. For inclusion in the study, players were required to complete a minimum of 80% of the core training schedule (25 sessions), between mid-March at the end of the National League and mid-May prior to the start of the Championship. This was a guideline set by the primary researcher to meet the adaptation requirement indicated by Tse (2009). Core training took place, in their intervention groups, after the warm-up for team training, on the playing field or in a sports hall (if the weather was unsuitable) twice a week and individually in a gym prior to the players workout twice a week. The team sessions allowed the investigator to ensure that exercises were performed properly and that players were executing the core programme correctly.

3.6 Programme Design for Core Training

According to Gambetta (2007), core training should be incorporated daily into the training regime of the athlete and volume and intensity should be regulated in coordination with the total load and periodized training period that are required to meet with the objectives of the training cycle. Dynamic postural alignment is controlled by the core so core training programmes were designed so that all movements required the core to work in an integrated and functional manner. Many sport-specific training programmes fail to include low-load motor control training, which has been identified as an essential part of core strength training and improving core stability (Faries, 2007). By neglecting the local muscles, the force produced by the global muscles is too great for the Local muscles to control and leads to greater injury risk. It is believed that high-load training changes the muscle structure, whereas low-load training improves the ability of the CNS to control muscle coordination and the efficiency of movement, (Faries, 2007)] Therefore, by performing a well-structured and functional programme using both low- and high-load training, improvements should be attained in all the processes contributing to core stability and core strength, which, it is reasoned, will in turn, impact on sporting performance.

According to Comerford (2008), if future research can establish (i) reliable exercises that improve the effectiveness of different core exercises; and (ii) the extent to which these muscles need to be activated to bring about sufficient core stability and strength improvements, then core training programmes can be more effective in reducing injuries and enhancing sports performance.

The selection of exercises for core training incorporated the following movements;

- Trunk flexion and extension (sagittal plane)
- Lateral flexion (frontal plane)
- Trunk rotation (transverse plane)
- Combination (triplaner diagonal rotational patterns)

Core training can be carried out in several different formats, such as traditional sets and repetitions or in circuit format. A circuit format was recommended by Bitcon (2009), and Tse (2009), as it provides easier application in team sports settings, and during the specific preparation period, where training may occur in a strength room or on a playing field.

Two workshops were conducted by the primary researcher with each of the four intervention groups. The first workshop was devised to teach the methods of core engagement and to demonstrate and teach the core exercises and parameters. The second workshop was to observe the players performing the core training programme and provide feedback and correction and to answer any questions they had regarding the programme. The control group did not do specific core training during the eight week period but did take part in team training and the team's strength and conditioning programme. Intervention group did not participate in other specific core training other than that prescribed in the programme. Core training sessions on the playing field were supervised by the primary researcher over the first two weeks of the programme to ensure correct technique was being employed. Subjects kept a record sheet (Appendix 6), of their core training over the 2 mesocycles. Intervention programmes began after completion of the second workshop

Three days after completion of the intervention programme, post-tests of the athletic performance markers were conducted by the primary researcher. Teams completed their core training programmes within a week of each other and since the participants in the study were from 3 different teams, this facilitated the post-tests towards the end of the 3rd week of May on 3 separate days (one for each team). Only players who completed the eight week programme were included in the results. A total of eight-nine subjects (N=89) completed pre and post-test, the team's training regime and the eight week intervention. Players from the intervention groups and the control group who had missed training time through injury did not have their results included in the study but were tested to provide feedback to the teams management. A total of 14 subjects (n=14), were discounted from the study for this reason.

3.7 Data Analysis

Test results were recorded on excel and were analysed using SPSS 19. The Komolgorov Smirnoff tests were used to test the data for normality. Leg strength, CMJ power and BDJ power were analysed parametrically as they were found to be normally distributed. Results for acceleration (10M), speed (30M), and agility (T-Test) were analysed non parametrically as they were not normally distributed.

Baseline mean scores were analysed and an ANOVA was used to examine differences at baseline. Tables and graphs showing the percentage change between pre and post test results were also used to demonstrate the magnitude of change that occurred between pre and post test results.

A mixed between – within subject's analysis of variance was conducted to assess the impact of different core stability interventions on markers of sports performance (relative squat, CMJ, BDJ, 10m, 30m, and T test). Participants were tested both pre and post intervention. A series of paired sample t tests were carried out to further explore the differences pre and post intervention within each specific group.

Data was also analysed using Multivariate Analysis of Variance (MANOVA) based on the calculation of the different scores for each variable pre and post intervention, to test for significant changes between the intervention groups. Data was also tested for correlation between core stability and markers of athletic performance at baseline and post intervention. Normally distributed was analysed using Pearson product moment correlations while scales not normally distributed were assessed using Spearman correlations.

Chapter 4

Results

Results

The results chapter includes the following analyses;

1. Tests of normality
2. Analysis of baseline data
3. Change in each group pre to post test
4. Analysis of the changes between groups i.e. is the magnitude of change greater in some groups more than other groups

4.1 Tests of Normality

Preliminary analysis was conducted to screen for potential outliers and to assess if the data was normally distributed. No extreme outliers were found in the data. Normality was assessed using Komolgorov Smirnoff tests and inspection of histograms of the distributions. Results for normality and a non-significant result (P > .05) were taken to indicate normality. The following are considered normal at baseline;

- Pre total
- Pre CMJ power
- Pre BDJ power

Table 9 Tests of Normality

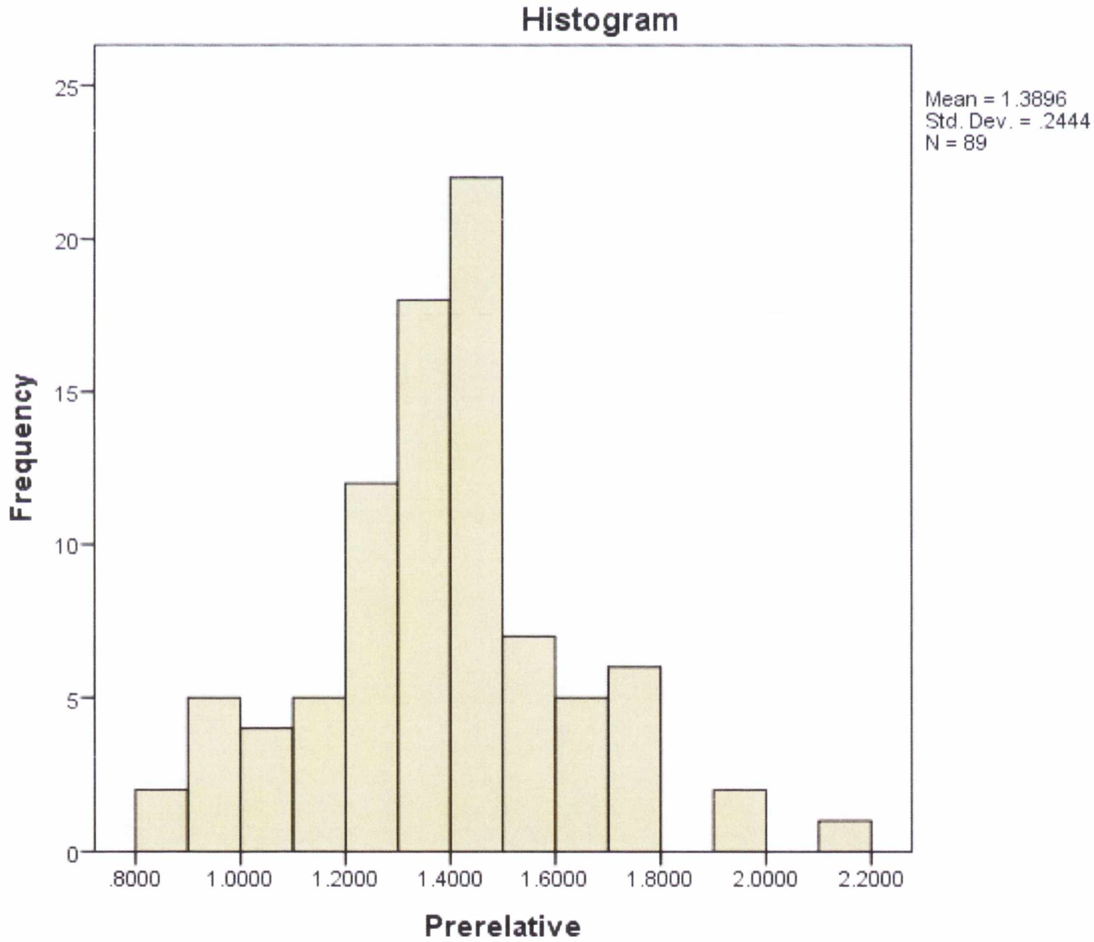
	Kolmogorov-Smirnov		
	Statistic	df	Sig.
Pretotal	0.051	89	.200*
Prerelative	0.104	89	0.02
PreCpower	0.084	89	0.163
PreBpower	0.034	89	0.200*
Pre10m	0.122	89	0.002
Pre30m	0.137	89	0.000
PreT-test	0.213	89	0.000
PreCMJ	0.054	89	0.200*
PreBDJI	0.108	89	0.013*

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

The pre relative squat scores had a reasonably normal bell shape curve and therefore were analysed normally. The 10 m, 30m and T-test were analysed none parametrically as these are not normally distributed.

An inspection of the histogram for the pre relative squat scores (Graph 1) shows a reasonably normal bell shape curve and was therefore analysed normally. The 10 m, 30m and T-test were analysed none parametrically as these are not normally distributed.

Graph 1 Histogram for the pre relative strength



attached to each category of training with the stable surface training method labelled (SST), and the unstable surfacing training method labelled (UST). The intervention groups and their training method were labelled as the stable horizontal core group (SHC), (n=18) and stable vertical core (SVC), (n=18), unstable horizontal core (UHC), (n=21), unstable vertical core (UVC), (n=18), and control group labelled (C), (n=14). Differences in group numbers were due to withdrawals, injuries or removal from the team. Participants who completed the study were ranked from 1-89 based on their total core stability scores and then systematically assigned to the five different groups. Participants ranked 1, 2, 3, 4, and 5, were assigned to groups C, SHC, SVC, UHC and UVC respectively. The reversing the process, participants ranked 6, 7, 8, 9, and 10, were assigned to the groups in reverse order, (UVC, UHC, SVC, SHC, and C). This process continued in this format for all participants, to attain mean scores per group that had the least difference possible between groups.

All four intervention groups received a core training programme, developed by the primary researcher based on the previous recommendations of Szymanski (2010) and Gambetta (2007), which advised that 4 core training sessions a week each consisting of approximately 20-30 minutes each, to include spinal mobility exercises, and to work for sets of between 12-15 reps per exercise. They also recommended exercises to be performed, consecutively in circuit format with rest periods of maximum of 30 seconds. Participants were taught how to effectively activate the transverse abdominus and multifidus muscles, which have been shown to be important muscles for stabilizing the trunk, in both the prone, seated and vertical positions and was deemed a necessary skill for core training, (Panjabi, 1992). Core training cycles were found by Tse (2009), to require an 8-week period for an effective impact with a recommendation that subjects need to complete close to 32 sessions for significant adaptation to occur.
Core training programmes for all groups had to meet the criteria of involving transverse, frontal and sagittal planes of motion, involve all twenty nine core muscles, and comply with the parameters for stability and strength as identified by Clark (2007). The intervention programmes were carried out under either a stable or unstable conditions and in either horizontal or vertical body positions. The fifth group was a control group (CT) and did not receive an intervention. Each training programme was explained and practiced with each intervention group. This training took approximately 20-30 minutes and was administered during the preparation period between the end of the National League and the beginning of the Championship

4.2 Baseline Data

Baseline data was assessed to see if there were differences between groups. Table 10 presents mean and standard deviation scores. A series of one way ANOVA's were conducted to explore the differences between groups at baseline in the following tests: core stability, relative strength, etc. A Kruskall Wallis test was used to assess differences between these groups for the 10 metre, 30 metre & T-test as these were not normally distributed. The only measurement which was found to be different at baseline was the Relative Squat, p=.016. A post hoc Tukey analysis indicated that the mean score for the SVC group differed from the UVC. Therefore, there is strong evidence that groups were similar at baseline.

Table 10 Baseline analysis

Measures N=	**Control** **14**	**SHC** **18**	**SVC** **18**	**UHC** **21**	**UVC** **18**	**Sig**
Core Stability	345.7 ± 104.9	370 ± 109.4	381.7 ± 102.0	349.0 ± 104.6	386.2 ± 81.8	.674
Relative Strength	1.33 ± 0.2	1.37 ± 0.2	1.27 ± 0.2	1.4 ± 0.3	1.5 ± 0.2	.016*
CMJ power	3650.9 ± 374.6	3461 ± 440.9	3600.8 ± 574.7	3556.8 ± 547.5	3600.2 ± 371.1	.826
BDJ power	3567.4 ± 430.8	3224.0 ± 475.0	3409.9 ± 717.5	3407.0 ± 656.0	3470.9 ± 442.4	.523
10 metre **	1.88 ± 0.25	1.93 ± 0.31	1.83 ± 0.26	1.82 ± 0.2	1.77 ± 0.3	.370
30 metre**	4.52 ± 0.5	4.30 ± 0.3	4.25 ± 0.2	4.3 ± 0.3	4.3 ± 0.3	.228
T test**	9.93 ± 0.78	9.57 ± 0.8	9.42 ± 0.8	10.0 ± 1.0	9.43 ± 0.7	.155

*Sig P<.05 ** Analysed non parametrically using Kruskall Wallis tests

4.3 Pre to Post Intervention Changes

4.3.1 Percentage Change pre and Post Intervention

Table 11 shows the percentage change that occurred between the pre and post tests for each variable in each group. Percentage change was calculated by subtracting the post test scores from the pre-test scores, dividing the result by the pre-test score and multiplying by 100. All scores changed in the expected direction i.e. core stability totals increased after the intervention; the scores on the sprinting tests and the agility test decreased indicating faster times. Scores for tests of power and leg strength all increased indicating improvements from the pre-tests. The control group showed the highest percentage change in relative strength at 15.85%, reactive power at 5.24%, acceleration at 2.55%, and speed at 3.12%. The UVC group had the highest percentage change in core stability at 20.12% and CMJ power at 5.19%. The UHC group had the highest percentage change in agility at 5.17%.

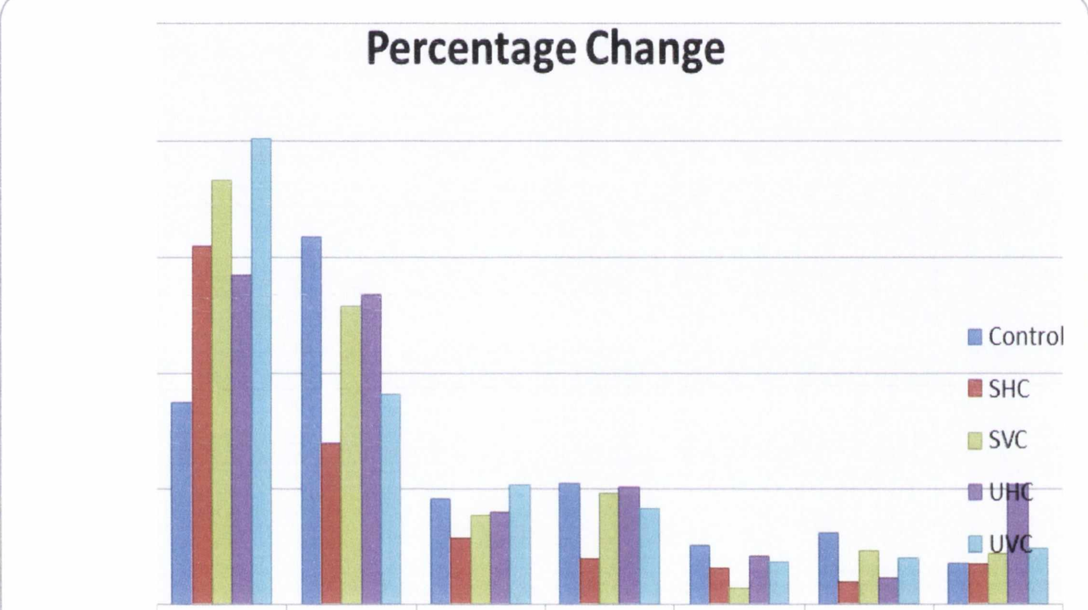
Table 11 Percentage change pre and post intervention

Measures **N=**	**Control** **14**	**SHC** **18**	**SVC** **18**	**UHC** **21**	**UVC** **18**
Core Stability	8.75%	15.49%	18.31%	14.21%	20.12%
Relative Strength	15.85%	6.97%	12.93%	13.4%	9.13%
CMJ power	4.6%	2.86%	3.89%	4.01%	5.19%
BDJ power	5.24%	2.00%	4.85%	5.1%	4.18%
10 metre	-2.55%	-1.55%	-0.73%	-2.08%	-1.88%
30 metre	-3.12%	-0.95%	-2.34%	-1.18%	-2.03%
T test	-1.78%	-1.72%	-2.22%	-5.17%	-2.46%

% change = (pre – post/ Pre score) *100

Minus score indicate % change improved by reduced times

The percentage change from pre-test to post test for each group for each measure (Graph 2) demonstrates that all groups improved in core stability and all performance markers throughout the study with core stability and relative strength demonstrating the highest percentage change over all the variables. It must be noted however that not all variables would be subject to change at the same rate or to the same degree. Some markers of performance are subject to small margins of change due to the nature of the difficulty in impacting change on those abilities (i.e. acceleration and speed).

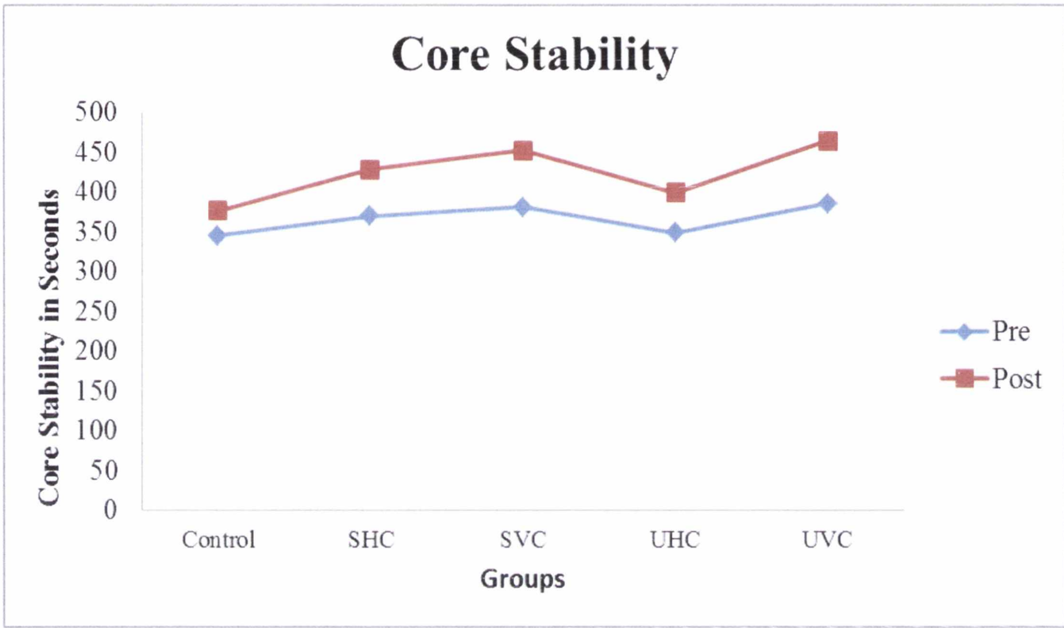


	Core	Rel SQ	CMJ	BDJ	10m	30m	Ttest
Control	8.75%	15.85%	4.60%	5.24%	2.55%	3.12%	1.78%
SHC	15.49%	6.97%	2.86%	2.00%	1.55%	0.95%	1.72%
SVC	18.31%	12.93%	3.89%	4.85%	0.73%	2.34%	2.22%
UHC	14.21%	13.40%	4.01%	5.10%	2.08%	1.18%	5.17%
UVC	20.12%	9.13%	5.19%	4.18%	1.88%	2.03%	2.46%

Graph 2 Percentage change from pre to post for each group for each measure

4.3.2 Changes in Core Stability

There were changes in mean scores from baseline to post intervention for all groups for core stability. These changes are displayed in the table 10.



Graph 3 Differences in mean scores for stability from pre-test to post-test for all groups

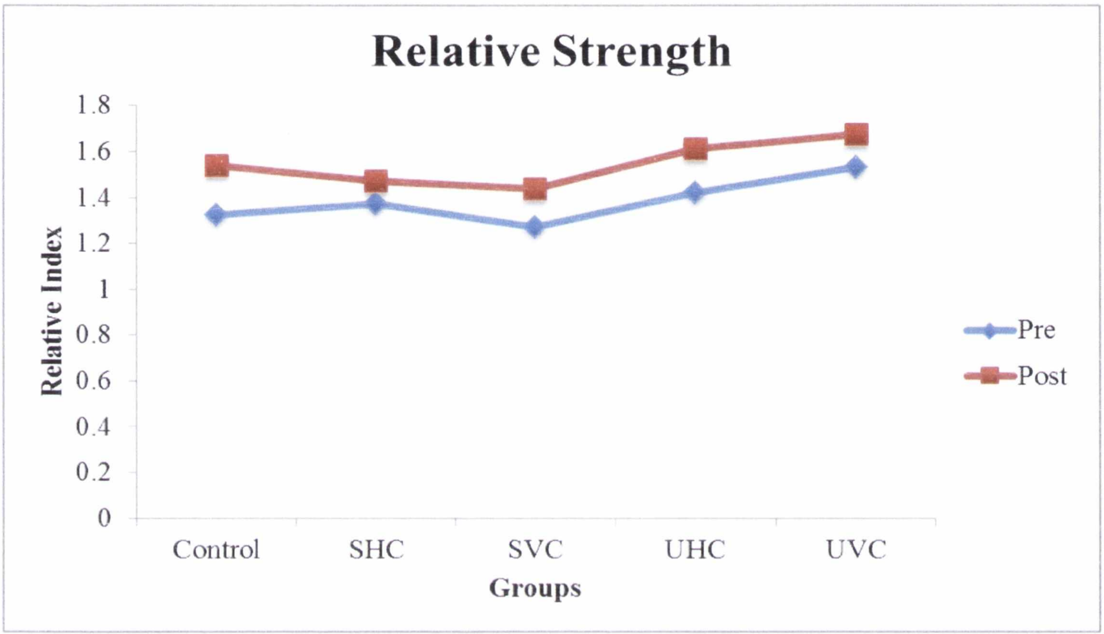
A paired sample t test was conducted to evaluate the impact of each intervention on participant's core stability scores. There was a statistically significant increase in core stability mean scores in each of the subgroups P< .05. The eta squared statistic ranged from .38 to .81 indicating a large effect size (Table 12).

Table 12 T-Test results of impact of intervention on mean core stability scores

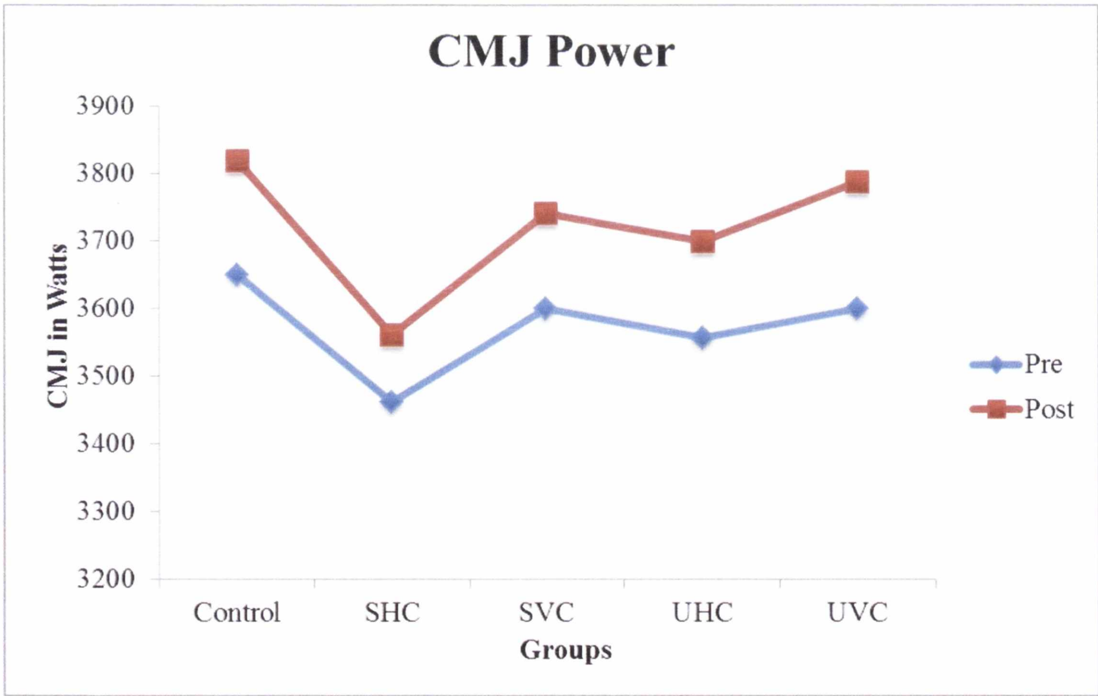
	Control	SHC	SVC	UHC	UVC
Core stability mean change	30.25 ± 35.08	57.3 ± 55.8	69.8 ± 45.3	49.6 ± 41.5	77.7 ± 38.2
Significant	.007	.000	.000	.000	.000
Eta squared	0.38	0.53	0.72	0.60	0.81

4.3.3 Changes in markers of athletic performance

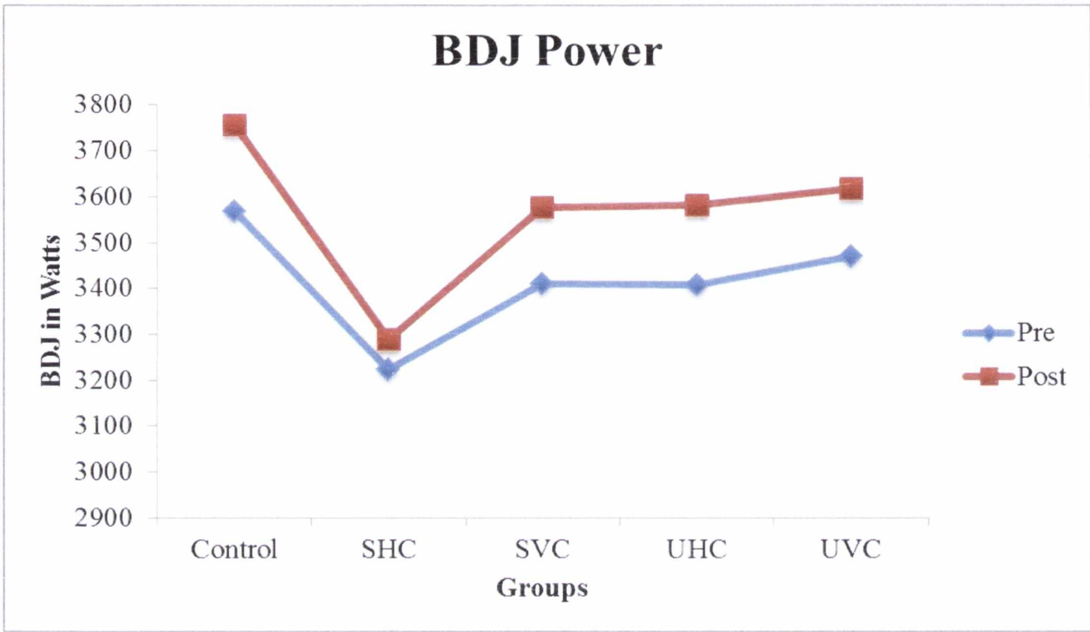
Graphs 4-9 below, display the changes in relative strength, CMJ, etc., from baseline to post intervention. Changes for the control group and intervention each group are presented.



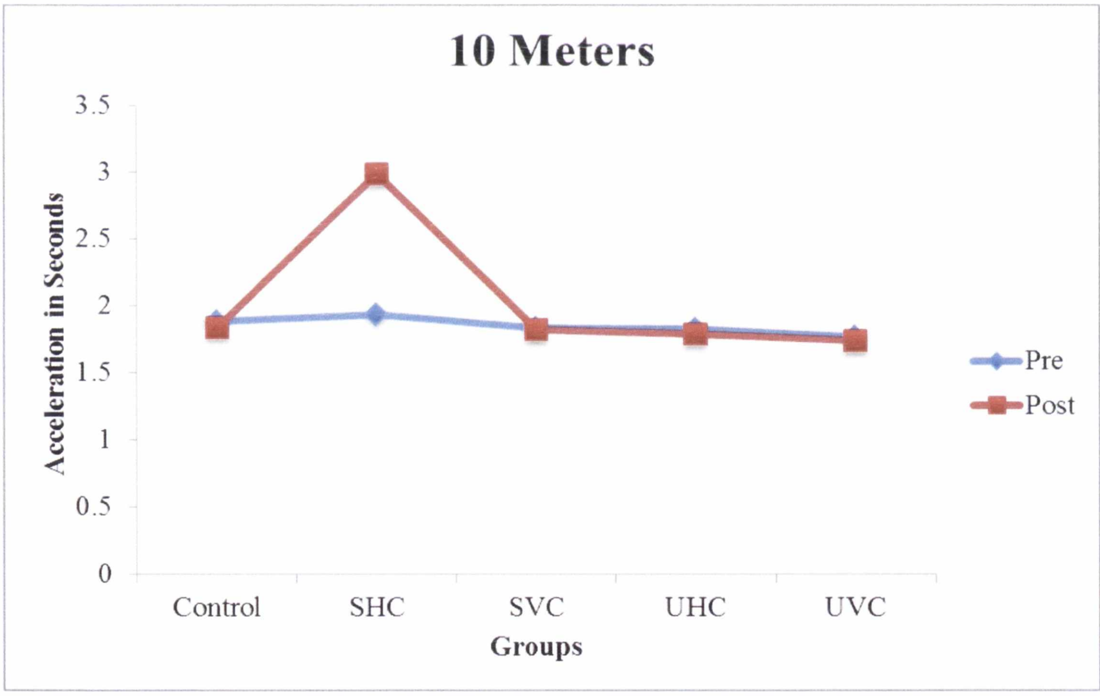
Graph 4 Differences in mean score for relative strength from pre-test to post test for all groups



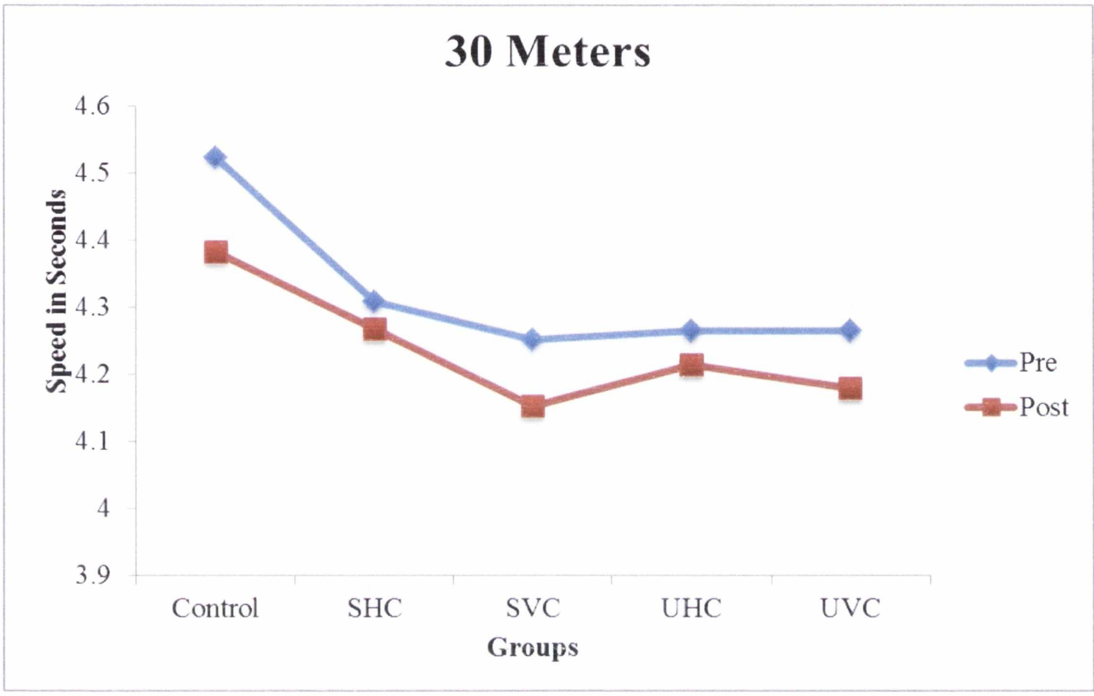
Graph 5 Difference in mean scores for CMJ from pre-test to post test for all groups



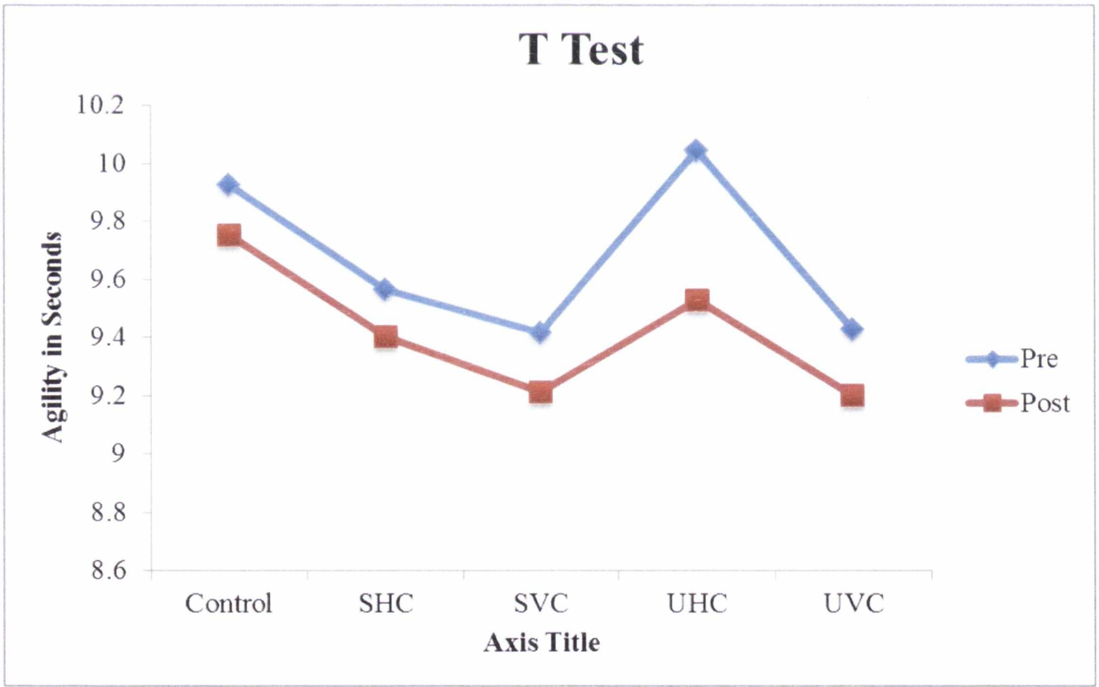
Graph 6 Differences in mean scores for BDJ from pre-test to post test for all groups



Graph 7 Differences in mean score for acceleration from pre-test to post test for all groups



Graph 8 Difference in mean scores for speed from pre-test to post test for all groups



Graph 9 Differences in mean scores for agility from pre-test to post test for all groups

A series of paired sample t tests were carried out to explore the differences in markers of athletic performance pre and post intervention within each specific group. The mean change results of these tests are presented in Table 13. Each group made significant improvements over time and the control group also made these improvements. All changes were in the expected directions i.e.

strength increased while speed tests scores decreased from pre to post intervention. The greatest changes for relative strength occurred in the UVC (eta squared =0.62), for BDJ, the UVC group also had the greatest change, (eta squared =0.7), as they also did for the T-Test, (eta squared =0.6). For the CMJ, the SVC and UVC groups improved the most, (eta squared =0.39, and 0.35 respectively). The UVC group therefore emerged as the group who experienced the greatest magnitude of change across the most markers of performance. This may suggest important information for the design of core training programmes that require a transfer of core stability and strength, into athletic performance. The greatest change for the 10 meter acceleration was for the control group (eta squared =0.45), and for the 30 meter sprint the greatest changes, though relatively small, were for the control group and the SVC group, (eta squared =0.27, and 0.29 respectively).

Table 13 Paired sample t test with eta squared indicating pre to post intervention mean changes

Measures **N=**	**Pre – Post** **Control** **14**	**Pre – Post** **SHC** **18**	**Pre – Post** **SVC** **18**	**Pre – Post** **UHC** **21**	**Pre – Post** **UVC** **18**
Relative Strength P= Eta squared =	0.21 ± 0.19 .001 0.50	0.1 ± 0.1 .002 0.44	0.16 ± 0.15 .000 0.54	0.19 ± 0.17 .000 0.54	0.14 ± 0.11 .000 0.62
CMJ power P= Eta squared =	168.07 ±215.9 .012 0.33	99.0 ± 206.4 .058 0.20	139.9 ± 182.5 .005 0.39	142.9 ± 287.1 .034 0.21	187.0 ± 258.1 .007 0.35
BDJ power P= Eta squared =	186.9 ± 281.8 .027 0.27	64.4 ± 211.2 .213 0.09	165.4 ± 167.9 .001 0.51	173.0 ± 207.9 .001 0.42	145.1 ± 231.5 .017 0.7
10 metre ** P= Eta squared =	-0.05 ± 0.05 .006 0.45	-0.03 ± 0.1 .72 0.08	-0.01 ± 0.15 .70 0.01	-0.04 ± 0.15 .38 0.06	-0.03 ± 0.22 .91 0.02
30 metre** P= Eta squared =	-0.14 ± 0.21 .03 0.27	-0.04 ± 0.08 .06 0.23	-0.10 ± 0.16 .02 0.29	-0.05 ± 0.16 .13 0.09	-0.08 ± 0.22 .18 0.14
T test** P= Eta squared =	-0.18 ± 0.44 .18 0.11	-0.16 ± 0.33 .04 0.20	-0.21 ± 0.32 .015 0.30	-0.52 ± 0.65 .001 0.40	-0.23 ± 0.19 .001 0.60

** analysed non parametrically using Wilcoxan Signed Rank Test

Eta squared gives an indication of the magnitude of change. Guidelines proposed by Cohen for interpreting these are as follows .01 small effect size; .06 moderate effects; .14 large effects.

4.4 Comparison of Changes between Different Intervention Groups

4.4.1 Comparison of Core Stability Scores between Different Intervention Groups

A one way between groups analysis of variance was conducted to explore changes in core stability scores across different intervention groups. For this analysis the difference between each participant's pre and post core stability scores were calculated. There was a significant difference at the P <0.05 level in the core stability scores across the groups indicating that some groups changed significantly more than other groups: F (4.84) = 2.8, P = 0.031. The effect size calculated eta squared, was 0.12. This is considered a medium effect size using the criteria of Cohen (1988). Post hoc comparisons using the Tukey HSD test indicated the mean change for the UVC group (mean change 77.7 ± 38.2) was significantly different from the control group (mean change 30.2 ± 35.0). No other significant difference was found between the groups, (Table 14). It should be noted that while not significant, greater improvements in mean core stability scores were found in intervention compared to control groups (see table 13).

Table 14 Mean change, standard deviation, F value, effect sizes and univerate analysis for core stability

Measure	Control 1	SHC 2	SVC 3	UHC 4	UVC 5	F	Eta squared	Pairwise Comparison
Core	30.25 ± 35.08	57.3 ± 55.8	69.8 ± 45.3	49.6 ± 41.5	77.7 ± 38.2	4.84*	.12	5>1

4.4.2 Comparison of Markers of Athletic Performance between Groups

A mixed between – within subject's analysis of variance was conducted to assess the impact of different core stability interventions on markers of sports performance (relative squat, CMJ, BDJ, 10m, 30m, and T test). Participants were tested both pre and post intervention. There was a substantial main effect for time, Wilks Lambda = .32, F (6, 79) = 28.15, P <.000, partial eta squared = .68. Using guidelines proposed by Cohen this would suggest a very large effect size. All groups were found to improve in markers of sports performance post intervention (see Table 13). There was no significant interaction between group and time, F (24, 276) = 0.744, p = .44, partial eta squared = .07 indicating similar changes over time for participants in each of the separate groups. The main effect for group was also found to be not significant Wilks Lambda = .65, F (24,

276) = 1.54, p = .054. This suggests no overall significant difference in markers of sport performance scores between each of the groups.

An analysis of the data was conducted using Multivariate Analysis of Variance (MANOVA) based on the calculation of the difference scores for each variable pre and post intervention. As this analysis does not take into account the effect of time the Mixed between – within subjects analysis of variance are presented. The findings of the MANOVA confirm the findings from the Mixed between within subject's analysis of variance.

Both the mixed between within analysis of variance and MANOVA assess the markers of athletic performance as a combined dependent variable. Further analysis was carried out to assess changes in each of the individual markers of athletic performance. Scores that were normally distributed were assessed using one way between groups analysis of variance. Non normal scores were evaluated using Kruskall Wallis tests. For each analysis the difference in scores from pre to post intervention was calculated. There was no significant difference in relative squat $F(4,84) = 1.47$, $p = 0.22$, counter movement jump $F(4, 84) = 0.35$, $p = 0.84$ and bounce depth jump $F(4,84) = 0.86$, $p = 0.49$ using one way between groups analysis of variance. Kruskall Wallis tests revealed no significant difference in the magnitude of change in 10 metre $\chi2 = 4.3$, $p = 0.36$; 30 metre $\chi2 = 3.8$, $p = 0.43$ and t tests $\chi2 = 5.1$, $p = 0.27$ scores between different intervention groups. Therefore, changes in each of the markers of athletic performance are similar across groups with all groups displaying similar magnitude of improvements.

4.5 Relationship between core stability and markers of athletic performance

The relationship between core stability and markers of athletic performance were analysed. Markers of athletic performance that were normally distributed were analysed using Pearson product moment correlation while scales not normally distributed were assessed using Spearman correlations. The correlations between core stability and markers of athletic performance at baseline are presented in T**able** 15. The correlations between core stability and markers of athletic performance post intervention are presented in **Table**16.

Table 15 Correlation between core stability and markers of athletic performance at baseline

Measures	Core stability	Squat	Relative Strength	CMJ power	BDJ power	10 metre**	30 metre**	T test**
Core stability P =	1.00	0.18 .09	.15 .15	-.13 .21	-.07 .53	-.45 .000*	-.50 .000*	-.67 .000*

*Sig P<.05

**Analysed non parametrically using Spearman correlations

Table 16 Correlation between core stability and markers of athletic performance post intervention

Measures	Core stability	Squat	Relative Strength	CMJ power	BDJ power	10 metre**	30 metre**	T test**
Core stability P =	1.00	.32 .002*	.28 .008*	-.05 .63	-.03 .78	-.41 .000*	-.57 .000*	-.67 .000*

*Sig P<.05

**Analysed non parametrically using Spearman correlations

At baseline and follow up there is a clear consistent relationship between 10 metre, 30 metre and t test and levels of core stability. Therefore, those that were found to score highest in core stability tests were more likely to have better speed and agility scores. A relationship was evident between core stability scores and scores on the squat and relative strength post intervention. There was no relationship between core stability and the CMJ and BDJ at baseline and post intervention.

4.6 Summary

The results indicate that significant changes occurred in core stability, post intervention across all groups with the greatest magnitude of change in the intervention groups. Therefore, the hypothesis that stated that there would be no significant difference in core stability scores pre and post intervention was rejected. The hypothesis that examined if there would be significant difference in markers of athletic performance pre and post intervention was also accepted, as no significant difference across groups on the combined dependent variables, (F24, 276) = 1.02, p = .44; Wilks Lambda = .74, partial eta squared = .07. Data from a mixed between-within subject's analysis of variance revealed significant improvements in markers of athletic performance over time. The percentage change for all markers of athletic performance showed improvement, with the UVC group showing the greatest percentage change at 20.12%. Significant change was found in markers of athletic performance across each of the participating groups and consequently the hypothesis that stated that here would be no significant difference in change between participants in different intervention groups and post-test was rejected. Although no group improved significantly more than any other group there was an exception with the SVC and UVC groups, who improved significantly in relative leg strength with the UVC group improving significantly more than the SVC group. Finally, Spearman correlations demonstrated a clear relationship between acceleration, speed and agility and levels of core stability and a clear relationship also exist between core stability and leg strength post intervention.

Chapter 5

Discussion

Discussion

It has been stated by Cholewicki and McGill (1996), that the benefits of a strong core leads to an increase in power transfer involved in throwing, jumping, running, lifting, striking, and many sports specific movement patterns. Cholewicki and McGill (1996) and Crisco & Panjabi (1991), all found evidence to show that an under developed lumbo pelvic hip complex can impede movement ability and can also be correlated with low back pain. As the spine is essentially unstable, an important role of the musculature system is to tighten the spine during movements that cause instability (McGill, Grenier, Kavcic, & Cholewicki, 2003).

It was the purpose of the study to investigate the effect of different core training programmes in both stable and unstable environments on markers of athletic performance among intercounty GAA players. Behm (2005), and Cissik (2002) both believe that a strong and stable core allows an athlete to fully transfer any force generated to the lower and upper extremities. Traditional core training has been performed either in a horizontal position on a stable surface or in a vertical exercise in a stable position. In recent years unstable surface training (UST) has grown in popularity in strength and conditioning programming. The impact of core training on athletic performance has not been clearly established. The basis for the increased emphasis on core training has largely been based around the rehabilitation of injuries, and the reduction of injury occurrence (Boyle, 2010). As of yet there has been little evidence to support the use of core training in general exercise scenario's and less still when specifically aimed at improving athletic performance, (Cressey, West, & Tiberio, 2007). Schlumberger (2010) has highlighted the importance of developing the specificity of core training as a means for enhanced sports performance. He contends that the attainment of optimal levels of speed and power are dependent on sports specific movement training that transfer to the necessary level of optimal control required to perform with efficiency and effectiveness in a competitive environment. Boyle (2010) and Cook (2010) stress the importance of optimal core stability and strength in facilitating efficient hip and thoracic mobility in movements associated with generating speed and power and further support for this concept is offered by Sharrock et al. (2011) who indicated that more research was required into the relationship between the specificity of core training and specific performance tests of speed and power.

This chapter discusses the results of the eight week intervention which was performed in two, four week mesocycles, utilizing a vertical core training programme under stable and unstable conditions and a horizontal core training programme also under stable and unstable conditions to measure the impact on acceleration, speed, vertical jump, reactive jump and leg strength on male, senior intercounty Hurlers and Gaelic footballers. The results of the pre-test for core stability showed that there was no significant difference at the outset of the study, between the intervention groups in measures of core stability. It was also established that there were no significant differences between the intervention groups and the control group at baseline in measures of acceleration (10 meter sprint), speed (30 meter sprint), lower body power (countermovement jump), reactive power (bounce depth jump), agility (T-test), and relative leg strength (1RM/weight). A Kruskall Wallis test indicated that baseline mean scores were similar with the exception of relative leg strength (p=0.016). This test was a measure of maximum leg strength in relation to body mass, and it was outside the parameters of the study to control body weight during the intervention. A post hoc Tukey analysis indicated that there was a strong similarity between the groups with only the mean scores for the SVC and UVC showing a significant difference. It would anticipate that there would be slight differences between groups at baseline due to the relatively small numbers in each group. A greater number of subjects would possible reduce these differences.

All subjects in the study were actively engaged in their respective team's physical preparation during the study. This was the period between the end of the National League and the beginning of the Championship; therefore it is not surprising that all scores changed in the expected direction as a result of the team's training programme. Principles of training such as specificity, overload, etc. were applied to the core training intervention programmes. The core stability scores and all performance marker scores, increased after the intervention; the scores on the sprinting tests and the agility test decreased indicating faster times. Scores for tests of power and leg strength all increased indicating improvements from the pre-tests.

The focus of the study was on the level of improvement in the performance markers as a result of the different core strength and stability intervention. Therefore it was hypothesised that core stability training would impact significantly on markers of athletic performance. A mixed between – within subject's analysis of variance assessed the impact of different core stability interventions on markers of athletic performance to see if the individual intervention groups changed pre and post intervention. Difference in pre scores on markers of physical performance (Relative squat, CMJ, BDJ, 10m, 30m, and T-test) and post scores of physical performance were calculated using a one way between groups multivariate analysis of variance to investigate changes in these scores across each of the five groups. Though all groups improved, no group improved significantly more than any other group. The changes in core stability and markers of athletic performance are discussed in detail in the following sections. Data was also tested for correlation between core stability and markers of athletic performance at baseline and post intervention.

5.1 Core Stability

A one way between groups analysis of variance was conducted to explore changes in core stability scores across different groups. Difference between pre and post core stability scores indicated a significant difference in the core stability scores across the groups ($P = 0.031$). Post hoc comparisons were used to identify where these differences occurred and the only significant difference was between the UVC group (mean change 77.7 ± 38.2) and the control group (mean change 30.2 ± 35.0). No other significant difference was found between the groups. It should be noted that while no significantly greater improvements in mean core scores were found in, intervention compared to control groups., there is a strong indication that core training in an unstable environment and performed in a vertical position has a greater impact on core stability and strength. From these findings it appears that core training in unstable vertical positions, provides greatest gains in core stability scores. This may occur because the core is challenged in a pattern of movement that has greater transfer to athletic movements. This finding was supported by Ruiz and Richardson (2005) and Schibek et al. (2001) who found unstable surface training significantly improved static balance and postural control measures through greater control of the core musculature. They found that sports skills, because of the nature of the competitive environment in which they are performed, are often executed off balance or out of postural alignment, and consequently, greater core strength and stability provide an enhanced foundation for greater force production in the upper and lower extremities of the body. This view is shared by the finding of further studies by Cosilima et al. (2003), and Santana (2001). Studies by Marshall and Murphy (2006), Behm et al. (2005), and Norwood et al. (2007) also concluded that exercising under unstable conditions increased core muscle activity more than exercising in stable conditions. It should be noted that in the current study that the stable and unstable training groups all improved indicating the positive effects of core training on core stability and endurance when carried out in stable and unstable environments and in horizontal and vertical positions. However, Norwood (2007) specifically observed that the relationship between the level of instability of an exercise and muscle activation levels is linear, with the level of activation increasing as instability increases. This would seem to support the findings of this study where the most unstable intervention group (UVC) showed the greatest level of improvement in core stability and significantly better than the control group who undertook no specific core training.

The findings in the current research are also in agreement with Hedrick (2000), who contends that the forces from ground reaction combined with the forces generated by the lower body muscles, transfer up the to the upper body extremities via the lumbo pelvic hip complex during the course of physical activity, suggesting that unstable vertical core training facilitates more effectively, this transfer of forces through the LPHC and should therefore facilitate athletic performances that takes place in the vertical position. Sato and Mokha's (2009) study on core stabilization and ground reaction forces and Sharrock et al, (2011) study on core stabilization and athletic performance both demonstrated a link between the core strength and stability tests and athletic performance tests with subject who performed best on core tests also performing above the norm on performance tests. They indicated the need for more research to provide a definitive answer on the nature of the relationship indicating which specific performance tests would better define their relationships to core stability.

The findings in the current research attempted to address that issue and concluded that relative leg strength was significantly related to core training in vertical, unstable conditions though the relationship to other markers of athletic performance is still inconclusive. Cressey et al. (2007) reported unstable surface training significantly improves markers of athletic performance. In the current study all groups were found to improve in markers of athletic performance, post intervention. A mixed between within analysis of variance showed no significant interaction between group and time, $F(24, 276) = 0.744$, $p = .44$, partial eta squared = .07 indicating similar changes over time for participants in each of the separate groups. While there was no difference between the different groups, as all groups improved in the same direction, there was a significant difference in each group pre and post intervention. The control group, however also improved, so the findings cannot differentiate between the participants in the intervention and control groups. These finding have similarities to studies by Nesser et al. (2008), Scibek et al. (2001), Tse et al. (2005) and Stanton et al. (2004), who found that there was a lack of evidence that demonstrated the importance of core strength in terms of its impact on sports performance. Studies that have examined core strength and sport-specific performance markers have often failed to find a relationship between these variables despite core training of different types improving core strength and stability,

5.2 Relative strength

With regard to athletic performance markers and in particular relative strength, the analysis of variance (ANOVA) in this study demonstrated that all groups had a significant difference between pre and post-test but the multivariate analysis of variance (MANOVA) found that the SVC and UVC differed significantly in relative strength p=.010. This finding is consistent with that of Hedrick (2000) and D. Brittenham and G.Brittenham (1997), who found core stabilization and strength to be a crucial component in facilitating efficiency of force output, and according to Hedrick, (2000), a critical factor in improving leg strength. Strength forms the foundation on which speed, power and agility are built and maintained, (Boyle, 2010), and if strength is maintained over the course of a season, then speed, power and agility level have a greater potential to be maintained at their optimum levels. The role of core strength and stability in enhancing relative leg strength would seem to be an important factor as evidenced by Spinks (2007), and Cressey (2007), who found lower body leg power, which significantly improved from pre to post test, did so by much larger proportions in athletes with great core stability and strength. The current study further supports this view with a Pearson product moment correlation showing that some relationship was evident between core stability scores and scores on the squat and relative strength post intervention.

Anderson and Behm (2004) suggested that increased instability may help achieve a threshold point for the abdominal stabilizers to increase in activation levels. Beyond that threshold there is a limited understanding on the impact of both instability and multi-joint exercises and the amount of resistance created by instability during the movements. Anderson and Behm (2004) investigated the effects of squatting under three conditions of varying stability and found the greatest degree of core activity occurred in the condition of greatest instability, (performed on balance disc). This could account for the significant difference between the stable and unstable surface groups in this study, as training in a vertical and unstable position would seem to enhance the ability to generate force with greater control. Unstable vertical core training directly challenges postural control and would account for significant improvements over stable surface training. Moreover Behm, Anderson, and Curnew (2002), concluded that the neuromuscular adaptation acquired from unstable surface training is associated with increases in strength, brought about additional stimuli that cause a greater training adaptation. These findings were further supported by Ruiz and Richardson (2005) and Schibek et al. (2001). In the current study, the UVC group had the highest percentage increase in core stability at 20.12% which would be supported by the above research in explaining the significant improvement in relative strength. It is widely believed in strength and conditioning literature that higher strength levels are a pre-requisite for enhanced performance in tests of speed, acceleration and power, (Nimphius, et al., 2010).

5.3 Counter Movement Jump

All groups with the exception of the SHC group significantly improved their counter movement jump scores between pre and post-test ($P<.0.05$). The SHC eta squared value indicates a large effect though not significant at the 0.05 level. This result is in keeping with the findings of Clark (2008), who refers to the core as an integrated unit, where muscle activation must operate synergistically to produce force, as each of the structural components must operate at maximum effeciency to allow for the transfer of ground reaction forces further up the kinet chain. However despite improvements in pre to post tests CMJ scores and dispite research by Bobbert and Van Zandwijk (1999), which found a relationship between core strength and stability and vertical jump height and power, there was no relationship in the current study between core stability and the CMJ at baseline and post intervention. Research by both Willardson (2004), and Yessis (2003), agree that there is a relationship between core stability and the effective transfer of power, the findings of this study could not establish that relationship, possible due to the smaller number of subjects and the timing of the intervention during a period when field based training was also occurring. This lack of relationship can also be explained by Nessar (2008), who contends that core stability has little impact of power output. He concluded that increases in core stability contribute to improved strength but may not contribute to increased power output unless core training is the movement specific focus of power training. This finding was supported by Nimphius (2010) who found no significant relationships between countermovement jump height and any other measure of athletic performance inclusive of core strength. In the current study, it may be that core stability results in improvements in linear movements (sprinting & agility) and that leg strength is more important for vertical power jumps. There is some evidence to support this with clear correlations evident between squat and CMJ ($r=0.37$, $P<.01$) at baseline and post intervention ($r =.43$, $P<.01$. The training principle of specificity would support this conclusion. The strength and conditioning programme that all groups undertook as part of the championship preparation also seemed to have a positive impact in their CMJ with both vertical groups in the study performing better. The control group did not improve as much as other groups in core tests but made similar gains to other groups in CMJ.

5.4 Bounce Depth Jump

The reactive ability of the body to produce force quickly was measured using the bounce depth jump. Cressy (2007) had found that unstable training attenuated improvements in BDJ and in 10 and 40 meter sprint times. This study found that all intervention groups increased their BDJ from pre to post-test with the exception of the SHC group. This group's eta squared score, did however indicate a moderate effect by the intervention. Pearson product moment correlation found there was no relationship between core stability and BDJ at baseline and post intervention in this study. Core stability may result in improvements in leg strength which is important for vertical power jumps, there is some evidence to support this with clear correlations evident between squat and CMJ ($r=0.37$, $P<.01$) and BDJ ($r = .35$, $P <.01$) at baseline and post intervention ($r =.43$, $P<.01$; $r = .48$, $P <.01$).

The role of relative strength may be a factor in the relationship between core strength and reactive power as indicated by Nimphius (2010) whose study on the relationship between performance components found relative leg strength to be a significant factor influencing speed, agility and power. However, Nesser and Lee (2009) did not find a relationship so the issue is still unclear. It would seem that enhanced core strength and stability can allow for a more effective rate of force development, (Hakkinen, 2003), and for the enhancement of the stretch shortening cycle in producing explosive power (Hennessy, 2001), but there is little evidence from the current study, to support a relationship between core stability and BDJ.

5.5. 10 meter Sprint

Only the control group had a significant difference between the pre and the post test and the effect on all other groups was small (eta squared = .06). The explosive nature of the 10 meter may not be enhanced by unstable surface training as the transition from eccentric to concentric contraction in unstable conditions does not facilitate the power generation required in the explosive start in the 10m sprint, (Komi, 2003; Cressey, 2007). This may account for the lack of significant differences in the UVC and UHC groups. Although Sharrock (2011) found core stability to be important though not conclusive in enhancing speed and power, he found correlations between core stability tests and sprinting and agility performance tests. He indicated the need for more specific performance tests to provide more conclusive relationships. Buer (2007) found stable surface training produced better improvements in athletic performance markers than unstable training which seemed to cause few changes in measures of power. He concluded that the loads in unstable training do not challenge the muscles sufficiently to produce significant improvements in strength, power and in athletic performance tests. This could also be true of core training in both stable and unstable surfaces and may warrant further investigation into the intensity levels required to bring about changes in performance. This study, using Spearman correlations did find at baseline and follow up that there is a clear consistent relationship between 10 metre and levels of core stability. Therefore, those that were found to score highest in core tests were more likely to have better acceleration scores.

5.6. 30 meter Sprint

Only the control group and the SVC group had a significant difference between pre and post-test. The effect for all other groups (with the exception of the UHC group) was large (eta squared greater than 0.14). Nesser (2008) had concluded that core strength and stability training only contribute moderately to speed and power performances and this would hold true for the finding relating to the 30 meter sprint. Sharrock (2011) found core stability to be related to improvements in 40 yard dash times and this study, using Spearman correlations found at baseline and follow up that there is a clear and consistent relationship between 30 metre speed and levels of core stability. This was supported by Spinks (2007), who, found significant improvements from pre-training to post-training in sprint velocities although the margins of improvements in times were relatively small due to the small scope for improvement in relatively short periods of training. Therefore, those that were found to score highest in core tests were more likely to have better speed scores. It has been suggested by Cressey (2007) that unstable surface training undermines the specificity of training and is less likely to produce significant improvements in performance. This could explain why only the SVC had a significant improvement in the 30 meter sprint time, as there may be little transfer from unstable surface training and according to Hibbs (2008), there may not be a transfer from core training where the load and movement patterns are not specific to the athletic demand. This again highlights the need for specificity in core training to facilitate improvements in running speed.

5.7 Agility

All groups with the exception of the control group had a significant difference between pre and post-test at $p<0.05$. The control group's eta squared score indicates a large effect though not significant at the 0.05 level. The change of direction at speed requires a rapid transfer of ground forces to maintain speed. Core strength and stability should be an important factor in facilitating this transfer, and research by Behm (2005), and Cissik (2002) support this view. There is, however still a lack of evidence indicating the relationship between core strength and stability and performance in agility tasks. The results of this research do indicate that development of the core does seem to lead to enhanced agility performance. Spearman correlations found at baseline and follow up that there is a clear consistent relationship between agility and levels of core stability. Therefore, those that were found to score highest in core stability tests were more likely to have better agility scores.

Cressey (2007) had found no significant difference between stable and unstable surface training on agility. However Cressey did not include core training as part of his intervention, so there exists, the possibility that further research could greatly enhance our understanding of this area. There is also a lack of evidence to indicate at what speed angles the level of core stability has the most effect. The only study to examine factors that directly impact on agility was carried out by Galpin (2008), who found foot speed and its development to be a key factor in improving agility performance. The relationship between core stability and foot speed was not established in that study but Sharrock (2011) reported a relationship between core stability and agility but indicated the importance of investigating the relationship of different sub-categories of core strength stability to athletic performance. This was attempted in this study and there seems to be sufficient evidence to warrant further investigation.

5.8 Limitations

There were certain limitations in the study that were outside the control of the research

- All the teams in the study were in competitive environments as the study was conducted during the course of a regular season so programmes designed to improve speed, agility and power were on-going and the extent to which impacted on the post-test results was outside the control of the study, although every effort was made to harmonise the programmes across all 3 teams. However all teams had two strength and conditioning sessions a week, all aimed at the same capacities and the time allocated to those sessions was similar but the degree to which the implementation of these sessions was conducted was outside the control of the study.

- The training history of players would have been different across all teams. Since the study was conducted with adult senior teams it was not possible to control for age related advantages or disadvantages associated with training history.
- Number of subjects was determined by the number of teams who were willing to have the study conducted during a competitive season.
- Subject numbers were also limited by the exclusion of injured players and players who failed to complete a minimum of 80% of the core training schedule (25 sessions) over the course of the intervention.

Chapter 6

Conclusions

Conclusions

The outcome of the research intervention indicated core training in stable and unstable environments and in the horizontal and vertical positions does not significantly impact on markers of athletic performance. The indications are that substantial improvements may occur in athletic performance as a result of core training and the range of improvement may vary according to the type of core training used by the athlete. Several factors may have contributed to the lack of significant difference being found. The load required to enhance athletic performance may need to be greater than the loads used in conventional core training and certainly when unstable surfaces are involved, (Buer, 2007). The specificity of movements required for most athletic performances may not be sufficiently targeted or met by core training where there is a degree of isolation of muscle groups that facilitates enhanced muscle efficiency but does not transfer directly to the movement patterns of sports.

The hypothesis that stated there would be no significant difference in core stability scores pre and post intervention was rejected with significant difference between pre and post testing found. This difference was found to be greater than in the control group – therefore the core training intervention was effective at improving scores on core test

The hypothesis that stated that there would be no significant difference in markers of athletic performance pre and post intervention was accepted and though there was no significant difference at post-test there was evidence of improvement in markers of athletic performance over time.

The hypothesis that stated that there would be no significant difference in change between participants in different intervention groups at post-test was accepted. Though all groups improved more than the control group, the improvements were not significant. The results of the MANOVA showed that no group improved significantly more than any other group with the exception of the SVC and UVC groups who improved significantly in relative leg strength. The UVC group improved significantly more than the SVC group and these findings is supported by the findings of by Hedrick (2000) and have important implications for strength and conditioning programme for Hurling and Gaelic Football.

Recommendations

Recommendations for further studies in the area of stable and unstable core training and its impact on athletic performance are;

- Establish a clear differentiation between core stability and core strength as a means for examining its role in athletic performance. The distinction between the two are blurred in current research and this can lead to a lack of clarity when it comes to assessing their impact on overall strength and conditioning programmes and indeed on their transfer to improved athletic performance.
- There is a need to examine in more detail the type of core exercise that elicits the highest levels of both peak and mean muscle activation, so they can be effectively integrated into training programmes for different level athletes.
- There is a need for similar research which targets other sports specifically. Some sports such as Hurling may require greater levels of core stability in the fundamental skills of the game than Gaelic football because of the levels of torque involved in the fundamental skills of the sport.
- It may be worth examining athletic performance markers in clusters that have a high degree of dependence. It would seem that reactive power and acceleration are more closely link and may help establish some clarity in the role of core stabilization when it comes to performance in those markers.
- Further studies could examine the differences between sub categories of core training on performance markers and to also examine relationship between mobility and stability as they impact on athletic performance.
- The relationship between unstable core stability training and leg strength needs further investigation to understand the mechanisms that allow the impact to occur.
- Further studies could examine core training intervention in off season where findings are not influenced by field training. It may be worth examining if core training intervention was beneficial in reducing injury.
- A longer intervention may be required to see greater improvements

REFERENCES

Abt, J., Smoliga, J., Brick, M., Jolly, J., Leephart, S., & Fu, F. (2007). The relationship between cycling mechanics and core stability. *Journal of Strength and Conditioning Research, 21*(4), 1300–1304.

Alves, M, Rebelo, J., Abrantes, J., & Sampaio, J. (2010). Short-term effects of complex and contrast training in soccer players' vertical jump, sprint, and agility abilities. *Journal of Strength Conditioning Research, 24*(4):936-41

American College of Sports Medicine. (2002). Progression models in resistance training for healthy adults. *Medical. Science, Sports and Exercise. 34*:364-380

Anderson, K.G., & Behm, D, G. (2004). Maintenance of EMG activity and loss
Of force output with instability. *Journal of Strength and Conditioning Research, 18*:637-640.

Anderson, K., & Behm, G. D. (2005). Trunk muscle activity increases with unstable
squat movements. *Canadian Journal of Applied Physiology, 30*, 33-45.

Arokoski, JP., Kankaanpää, M., Valta, T., Juvone, I., Partenen, J., Taimela, S., Lindgren,
KA., & Airaksinen, O. (1999). Back and hip extensor muscle function during therapeutic
exercises. *Archive of Physical Medicine and Rehabilitation, 80*:842-50.

Arokoski JP, Valta T, Airaksinen O, Kankaanpää M. (2001). Back and abdominal muscle
function during stabilization exercises. *Archive of Physical Medicine and Rehabilitation, 82*:1089-98.

ASCA, (2009). *Bridging the gap between sport science and practical application*. Australian Strength & Conditioning Conference, ASCA, Brisbane, Australia.

Baechle, T.R., Earle, R., & Wathen, D. (2000). *Resistance Training. In: Essentials of Strength Training and Conditioning*. T.R. Beachle and R.W. Earle, eds. Champaign, IL: Human Kinetics, pp. 395-425.

Baker, D. (2000). Overuse of Swiss ball training to develop core stability or improve sports performance. *Strength and Conditioning Coach 8*: 5–9.

Barry, D.R., & Lawrence, R. (2005). Principles of core stabilization for athletic populations. *Athletic Therapy Today 10*: 13–18,

Behm, D. (1995). Neuromuscular implications and applications of resistance training.
Journal of Strength and Conditioning Research, 9, 264-274.

Behm, G. D., Leonard, M. A., Young, B. W., Bonsey, C. A., & MacKinnon, N. S. (2005).
Trunk muscle electromyographic activity with unstable and unilateral exercises. *Journal of Strength and Conditioning Research, 19,* 193-201.

Behm, G. D., Anderson, K., & Curnew, S. R., (2002). Muscle force and activation under
stable and unstable conditions. *Journal of Strength and Conditioning Research, 16*, 416-422.

Bergmark, A. (1989). Stability of the lumbar spine. A study in mechanical engineering. *Acta Orthopaedica Scandinavica Supplamentum, 230*:1-54.

Biering-Sorensen, F. (1984). Physical measurements as risk indicators for low-back trouble over a one-year period. *The Spine Journal, 9*, 106-117.

Bobbert, M., & Van Zandwijk, J. (1999). Dynamics of force and muscle stimulation in human vertical jumping. *Medicine and Science in Sports and Exercise, 31*(2), 303-310.

Bompa, T., & Haff, G. (2009). *Periodization Theory and Methodology of Training*. Human Kinetics, Champaign, Ill, USA.

Borghuis, J., Hof, AL, & Lemmink, K. (2008). The importance of sensory-motor control in providing core stability. Implications for measurement and training. *Sports Medicine. 38* (11): 893-916.

Boyle, M. (2004). *Functional training for sports*. Human Kinetics, Champaign, IL, pp. 53-73.

Boyle, M. (2010). *Advances in functional training techniques for coaches, personal trainers and athletes.* Target Publications. CA

Briggs, A. M., Greig, A. M., Wark, J. D., Fazzalari, N. L., & Bennell, K. L. (2004). A review of anatomical and mechanical factors affecting vertebral body integrity. *International Journal of Medicine and Science, 1,* 170-180.

Brittenham, D., & Brittenham, G. (1997). *Stronger abs and back*. Human Kinetics, Champaign, IL.

Butcher, S.J., Craven, B.R., Chilibeck, P.D, Spink, K.S, Grona, S.L, & Sprigings, E.J. (2007). The effect of trunk stability training on vertical take-off velocity. *Journal of Orthopaedic Sports and Physical Therapy, 37*:223-31.

Carter, J., Beam, W., McMahon, S., Barr, M., & Brown, M. (2006). The effects of stability ball training on spinal stability in sedentary individuals. *Journal of Strength and Conditioning Research, 20*:429-435.

Chek P. (1999). *Swiss ball exercises for swimming, soccer and basketball.* Sports Coach, 21:12-3.

Cholewicki, J., & McGill, S.M. (1996). Stability of the in-vivo lumbar spine: implications for injury and chronic low back pain. *Clinical Biomechanics, 11*:1-15.

Cholewicki, J., & McGill, S. M. (1996). Mechanical stability of the in vivo lumbar spine: implications for injury and chronic low back pain. *Clinical Biomechanics, 11*, 1- 15.

Cholewicki, J., Simons, A.P., Radebold, A. (2000). Effects of external trunk loads on lumbar spine stability. *Journal of Biomechanics. 33*:1377-85.

Cholewicki, J., & VanVliet, J. J. (2002). Relative contribution of trunk muscles to the stability of the lumbar spine during isometric exertions. *Clinical Biomechanics, 17*, 99-105.

Cholewicki, J., Simons, P. A., & Radebold, A. (2000). Effects of external trunk loads on lumbar spine stability. *Journal of Biomechanics, 33*, 1377-1385.

Clark, M. (2008). *NASM Essentials of Personal Fitness Training*. Lippincott, Williams & Wilkins, Baltimore MD.

Comerford, M., & Mottram, S. (2001). Functional stability re-training: principles and strategies for managing mechanical dysfunction. *Manual Therapy Journal, 6*:3-14.

Cook, G. (2002). Weak links: screening an athlete's movement patterns for weak links can boost your rehab and training effects. *Training and Conditioning 12:* 29–37.

Cook, G. (2010). *Movement: Functional Movement Systems: Screening, Assessment, Corrective Strategies*. On Target Publications, CA, USA

Cosio-Lima, L.M., Reynolds, K.L., Winter, C., Paolone, V., Jones, M.T. (2003). Effects of physioball and conventional floor exercises on early phase adaptations in back and abdominal core stability and balance in women. *Journal of Strength and Conditioning Research, 17*:721-5.

Cowley, P., & Swensen, T. (2008). Development and reliability of two core stability field tests. *Journal of Strength and Conditioning Research. 22*(2):619-624.

Cowley, P.M., Fitzgerald, S., Sottung, K., & Swensen, T. (2009). Age, weight, and the front abdominal power test as predictors of isokinetic trunk strength and work in young men and women. *Journal of Strength and Conditioning Research, 23*(3):915-925.

Cram, J. R., & Kasman, G. S. (1998). *Introduction to surface electromyography.* Gaithersburg: Aspen Publication.

Cresswell, A.G., Grundstrom, A., & Thorstensson, A. (1992). Observations on intra-abdominal pressure and patterns of abdominal intra-muscular activity in man. *Acta Physiologica Scandinavica. 144*:409-18.

Cressey, M. E., West, A. C., Tiberio, P. D., Kraemer, J. W., & Maresh, M. C. (2007). The effects of ten weeks of lower-body unstable surface training on markers of athletic performance. *Journal of Strength and Conditioning Research, 21,* 561-567.

Crisco, J. J., & Panjabi, M. (1991). The intersegmental and multisegmental muscles of the spine: A biomechanical model comparing lateral stabilizing potential. *The Spine Journal, 7,* 793-799.

Seo, D., Kim, E., & Fahs, C. (2012). Reliability of the one-repetition maximum test based on muscle group and gender. *Journal of Sports Science and Medicine, 11*, 221-225

DiStefano, L.J., Clark, MA., & Padua, D.A. (2009). Evidence supporting balance training in healthy individuals: a brief review. *Journal of Strength and Conditioning. Research. 23*(9): 2718–2731.

Elphinston, J., & Pook, P. (1999). *The Core Workout*. Rugby Science. Cardiff.

Ellenbecker, T.S., & Davies, G.J. (2001). *Closed Kinetic Chain Exercise: A Comprehensive Guide to Multiple Joint Exercises*, (1st Ed.). Champaign, Ill.: Human Kinetics.

Faries, M., & Greenwood M. (2007). Core training: stabilizing the confusion. *Strength & Conditioning Journal,* 29(2):1025.

Fredericson, M., & Moore, T. (2005). Core stabilization training for middle and long distance runners. *New Studies in Athletics, 20*, 25-37.

Gajda, R.S., & Dominquez, R.H. (1982). *Total Body Training*. Warner, New York.

Galpin. A.J., Li, Y., Lohnes, C.A, & Schilling, B.K. (2008). A four week choice foot speed and choice reaction training programme improves agility in previously non-agility trained, but active men and women. *Journal of Strength & Conditioning Research. 22*(6):1901-1907.

Gambetta, V. (2007). Athletic development. *The art and science of functional sports conditioning.* Human Kinetics, Champaign, IL.

Gambetta, V., & Clark, M. (1999). Hard core training. *Training and Conditioning Journal, 10*, 34-40.

Gambetta, V. (1999). Let's get physiotherapy for swim-specific weight training. *Rodale's Fitness Swimmer 8*(3):30-33.

Garhammer, J. (1981). Free weight equipment for the development of athletic strength and power. *National Strength Coaches Associations. Journal. 3*(6):24-26.

Grieve G.P. (1982). Lumbar instability. *Physiotherapy; 68*(1):2–9.

Hamlyn, N., Behm, G. D., & Young, B. W. (2007). Trunk muscle activation during dynamic weight-training movements and isometric instability activities. *Journal of Strength and Conditioning Research, 21*, 1108-1112.

Hakkinen, K., Allen. M., Kraemer. W., Groostiaga. E., Izquierdo. M., Rusko. H., Mikkola. J., Hakkinen. A., Volkeinen. H., Kaorahainen. E., Rema. S., Erola. V. Ahtiainen. J. & Pravolainen, L. (2003). Neuromuscular adaptations during concurrent strength and endurance training versus strength training. *European Journal of Applied Physiology. 89*:42-52.

Hedrick, A. (2000). Training the trunk for improved athletic performance. *Strength and Conditioning Journal, 22,* 50-61.

Hennessey. L., & Kielty. J. (2001). The relationship between the stretch shortening cycle and sprint performance in trained female athletes. *Journal of Strength and Conditioning Research. 15:* 326-331.

Herrington, L. (2009). A comparison of Star Excursion Balance Test reach distances between ACL deficient patients and asymptomatic controls. *Physical Therapy.16* (2):149–152.

Hibbs, A., Thompson, K., French, D., Wrigley, A., & Spears, I. (2008). Optimizing Performance by Improving Core Stability and Core Strength. *Sports Medicine, 38*(12), 995-1008

Hodges, P. W., & Richardson, C. A. (1996). Inefficient muscular stabilization of the lumbar spine associated with low back pain: A motor control evaluation of the transversus abdominis. *The Spine Journal, 21*, 2640-2650.

Hodges, P. W., & Richardson, C. A. (1997). Contraction of the abdominal muscles associated with movement of the lower limb. *Physical Therapy 77*:132-144.

Hodges, P. W., & Richardson, C. A. (1999). Altered trunk muscle recruitment in people with low back pain with upper limb movement at different speeds. *Archives of Physical Medicine and Rehabilitation, 80,* 1005-1012.

Houglum, P. (2005). Therapeutic Exercise for Musculoskeletal Injuries, *Physiotherapy Canada, 58*(3), 239.

Hubbard, L. (2010). The effect of ankle taping on mechanical laxity in chronic ankle instability. *Foot Ankle International. 31*(6):499-504.

Jaric, S. Ugarkovic, D. & M. Kukolj, M. (2002). Evaluation of methods for normalizing strength in elite and young athletes. *Journal of. Sports Medicine and Physical. Fitness 42*:141–151.

Johnson, P. (2002). Training the trunk of the athlete. *Strength and Conditioning Journal, 24,* 52-59.

Jones. M.T. (2003). Effects of physioball and conventional floor exercise on early phase adaptations in back and abdominal core stability and balance in women. *Journal of Strength and Conditioning Research, 17:*721-725

Kaltenborn, F.M. (1989). *Manual Mobilization of the Extremity Joints* (4th Ed.). Minneapolis: OPTP

Kavcic, N., Grenier, S., & McGill, S.M. (2004). Determining the stabilizing role of individual torso muscles during rehabilitation exercises. *Journal of Spine Therapy, 29*:1254-65.

Khuman, R., Chavda, D., Surbala, L., Chaudhary, E., Bhatt, U., & Nambi, G. (2013). Physical Therapy in Temporomandibular Dysfunction Following Maxillo–Mandibular Fixation in Sub-Condylar Mandibular Fracture - A Single Case Study. *Internation Journal of Health, Sport, and Recreation. 3*(9): 45-55

Kibler, W.B., Press J., & Sciascia, A. (2006). The role of core stability in athletic function. *Sports Medicine. 36*(3): 189-98.

Kisner, C. & Colby, L.A. (2002). *Therapeutic Exercise: Foundations & Techniques.* Philadelphia, Pa: FA Davis Co; 4th Ed.

Kohle, J.M,. Flanagan, S. P., & Whiting, W. C. (2010). Muscle activation patterns while lifting stable and unstable loads on stable and unstable surfaces. *The Journal of Strength and Conditioning Research. 24* (2) 313-321.

Levinger, I., Craig, G., Hare, D., Jerums, G., Toia, D., & Selig, S. (2009). The reliability of the 1RM strength test for untrained middle-aged individuals. *Journal of Science and Medicine in Sport, 12*, 310—316

Liemohn, P. W., Baumgartner, A. T., & Gagnon, H. C. (2005). Measuring core stability. *The Journal of Strength and Conditioning Research, 19,* 583-586.

Little, T., & Williams, A. (2005). Specificity of acceleration, maximum speed, and agility in professional soccer players. *Journal of Strength and Conditioning Research 19*(1):76-78.

Luoto, S., Helioraara, M., Hurri, H., & Alaranta, M. (1995). Static back endurance and the risk of low back pain. Clinical Biomechanics, 10, 323-324.

Magnusson, M. L., Aleksiev, A., Wilder, D. G., Pope, M. H., Spratt, K., & Lee, S. H. (1996). Unexpected load and asymmetric posture as etiologic factors in low back pain. *European Spine Journal, 5*, 23-35.

Marshall, P. W., & Murphy, B. A. (2005). Core stability exercises on and off a Swiss ball. *Archives of Physical Medicine and Rehabilitation, 86*, 242-249.

Marshall, P. W., & Murphy, B. A. (2006). Increased deltoid and abdominal muscle activity during Swiss ball bench press. *Journal of Strength and Conditioning Research, 20,* 745-750.

McCurdy, K.W., Langford, G.A., Doscher, M., Wiley, L,. & Mallard. K.G. (2005). The effects of short-term unilateral and bilateral lower-body resistance training on measures of strength and power. *Journal of Strength and Conditioning Research, 19*:9-15..

McDonagh, J. M., & Davies, T. C. (1984). Adaptive response of mammalian skeletal muscle to exercise with high loads. *European Journal of Applied Physiology and Occupational Physiology, 52,* 139-155.

McGill, S.M. (2001). Low back stability: from formal description to issues for performance and rehabilitation. *Exercise and Sport Sciences Reviews, 29*, 26-31.

McGill, S. M. (2002). *Low back disorders. Evidence based prevention and rehabilitation*.. Human Kinetics, Champaign, IL.

McGill, S.M., Grenier, S., Kavcic, N., & Cholewicki, J. (2003). Coordination patterns of muscle activity to assure stability of the lumbar spine. *Journal of Electromyography and Kinesiology, 13,* 353-359.

MCGill, S.M. (2001). Low back stability: From formal description to issues for performance and rehabilitation. *Exercise, Sport Science. Review. 29*(1):26-31.

McGill, S.M., Grenier, S., Kavci, N., Cholewicki, J. (2003). Coordination of muscle activity to assure stability of the lumbar spine. *Journal of Electromyography and Kinesiology 13*:353-359.

McGill, S.M., Childs, A., & Liebenson, C. (1999). Endurance times for low back stabilization exercises: Clinical targets for testing and training from a normal database. *Archive Physical Medicine and Rehabilitation. 80*: 941-4.

McGuine, T.A., & Keene, J.S. (2006). The effect of a balance training program on the risk of ankle sprains in high school athletes. *American Journal of Sports Medicine, 34:* 1103–1111.

Morris M., & Morris, S. (2001). *Resistaball C.O.R.E. Instructor Certification*. Destin, FL: Resistaball, Inc.

Nadler, S. F., Malanga, G. A., Bartoli, L. A., Feinberg, J. H., Prybicien, M., & Deprince, M. (2002). Hip muscle imbalance and low back pain in athletes: influence of core strengthening. *Medicine and Science in Sports and Exercise, 34*, 9-16.

Nesser, T., Huxel, K., Tincher, J., & Okada, T. (2008). The relationship between core stability and performance in division I football players. *Journal of Strength and Conditioning Research. 22*(6):1750-1754.

Nesser, T., Lee, W. (2009). The relationship between core strength and performance in division 1 female soccer players. *Journal of Exercise Physiology. 12*(2):21-28.

Newton, H. (2006). *Explosive Lifting for Sport*. Human Kinetics, Champaign, IL.

Nichols, T.R. (1994). A biomechanical perspective on spinal mechanisms of coordinated muscle activation. *Acta Anatomica, 15*:1–13.

Nimphius, S., McGuigan, M., & Newton R. (2010). Relationship between strength, power, speed, and change of direction performance of female softball players. *Journal of Strength and Conditioning Research. 24*(4):885-95.

Nitz, A.J., Peck, D. (1986). Comparison of muscle spindle concentrations in large and small human epaxial muscles acting in parallel combinations. *American Journal of Surgery, 52*:273-7.

Norwood, T. J., Anderson, S. G., Gaetz, B. M., & Twist, W. P. (2007). Electromyographic activity of the trunk stabilizers during stable and unstable bench press. *Journal of Strength and Conditioning Research, 21*, 343-347.

Okado, T., Huxel, K., & Nesser, T. (2011). Relationship between Core Stability, Functional Movement, and performance. *Journal of Strength and Conditioning Research 25*: 1: 252-261

Panjabi, M.M. (1991). The stabilizing system of the spine. Part I. Function, dysfunction, adaptation and enhancement. *Journal of Spinal Disorders, 5*:383-9.150.

Panjabi, M.M. (1992). The stabilizing system of the spine. Part II. Neutral zone and stability Hypothesis, *Journal of Spinal Disorders, 1992; 5*:390-7.

Pauole, K., Madole, K., Garhammer, J. (2000). Reliability and validity of the T-test as a measure of agility, leg power, and leg speed in college-aged men and women. *Journal of Strength Conditioning Research, 14*(4):443-450.

Plisky, P.J., Rauh, M.J., Kaminski, T.W., & Underwood F.B. (2006) Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball players. *Journal of Orthopaedic Sports Physical Therapy. 36*(12):911–919.

Pope, M.H., & Panjabi, M.M. (1985). Biomechanical definitions of spinal instability *Journal of Spinal Disorders, 10*: 255–256,

Prentice, W.E. (2004). *Rehabilitation Techniques for Sports Medicine & Athletic Training, Exercise: Foundations & Techniques*, Philadelphia, Pa: FA Davis Co; .4th Ed.

Reed, C.A., Ford, K.R., Myer, G.D., & Hewett, T.E. (2012). The effects of isolated and integrated 'core stability' training on athletic performance measures: a systematic review. *Sports Medicine. International; 42*(8):697-706.

Reiman, M., Krier, A., Nelson, J., Rodgers, M., Stuke, Z., & Smith, B. (2010). Testing procedures using clinical stabilization vs. traditional methods. *Journal of Strength and Conditioning Research,* 24(3), 730-736.

Richardson, C. A., & Jull. G, A. (1995). Muscle control-pain control. What exercises would you prescribe? *Manual Therapy, 1*(1):2–10.

Richardson, C., Jull, G., Toppenber, R., & Comerford, M. (1992). Techniques for active lumbar stabilization for spinal protection. *Australian Journal of Physiotherapy, 38:*105-12.

Roetert, E., McCormick, T., Brown, S., & Ellen-Becker T. (1996). Relationship between isokinetic and functional trunk strength in elite junior tennis players. *Isokinetic and Exercise Science. 6*:15-20.

Ruiz, R., & Richardson, M. (2005). Functional balance training using a domed device. *Journal of Strength and Conditioning, 27*(l):50-55.

Saal, J. A. (1990). Dynamic muscular stabilization in the nonoperative treatment of lumbar pain syndromes. *Orthopaedic Review, 19*, 691-700.

Sahrmann, S. (2006). Trunk Rotation-Related Impairments in People With Low Back Pain Who Participated in 2 Different Types of Leisure Activities: A Secondary Analysis. *Journal of Orthopaedic & Sports Physical Therapy, 36*(2):58-71.

Sale, D. (1988). Neural adaptation to resistance training. *Medicine and Science in Sports and Exercise, 20,* S135-S145.

Santana, J.C., Hamstrings of steel: Preventing the pull. (2001). Part IL Training the triple threat. *Journal of Strength and Conditioning, 23* (l):18-20.

Sato, K., & Mokha, M. (2009). Does core strength training influence running kinetics, lower-extremity stability and 5000-m performance in runners? *Journal of Strength and Conditioning Research. 23(*1):133-140.

Sayers, S., Harackiewicz, V., Harman, E., Frykman, C. &Rosenstein, N, (1999). Cross-validation of three jump power equations. *Medical Science in Sports Exercise. 31*(4):572-7.

Scheibek, J.S., Guskiewicz, K.M. Prentice, W.E. Mays, S. &. Davis. J.M. (2001). *The effect of core stabilization training on functional performance in swimming.* University of North Carolina, Chapel Hill,

Sharrock, C., Cropper, J., Mossad, J., Johnson, M., & Malone, P. (2011). A pilot study of core stability and athletic performance. Is there a relationship? *International Journal Sports Physical Therapy. 6*(2): 63–74.

Spinks, C. (2007). The effects of resisted sprint training on acceleration performance and kinematics in soccer, rugby union, and Australian football players. *Journal of Strength Conditioning Research, 21*(1): 77-85.

Stanton, R., Raeburn P.R, & Humphries B. (2004). The effect of short-term Swiss ball training on core stability and running economy. *Journal of Strength and Conditioning Research. 18*(3):522-528.

Stockbrugger, B.A., & Haennel, R.G. (2001). Validity and reliability of a medicine ball explosive power test. *Journal of Strength and Conditioning Research, 15*: 431–438.

Szymanski, D. J. (2010). General, Special, and Specific Core Training for Baseball Players *Performance Training Journal, 9*, 5, 16-21.

Tse, M.A., McManus, A.M., Masters, R.W. (2005). Development and validation of a core endurance intervention program: implications for performance in college-age rowers. *Journal of Strength and Conditioning Research, 19*:547-52.

Vera-Garcia, F.J., Grenier, S.G. & McGill. S.M. (2000). Abdominal muscle response during curl-ups on both stable and labile surfaces. *Physical Therapy, 80*:564-569.

Verstegen, M, & Williams P. (2004). *Core performance.* New York: Rodale.

Wedderkopp, N., Katoft, M., Holm, R., & Froberg, K. (2003). Comparison of two intervention programmes in young female players in European handball, with and without ankle discs. *Scandinavian Journal of Medical Science in Sports 13*: 371–375.

Willardson, J.M. (2005). Response: Letter to the editor regarding "The effectiveness of resistance exercises performed on unstable equipment." *Strength and Conditioning. Journal, 27*(4):11-13.

Willardson, J.M. (2004). The effectiveness of resistance exercises performed on unstable equipment. *Strength and Conditioning Journal, 26* (3):70-74.

Willardson, J.M. (2005). Core stability training: applications to sports conditioning programs. *Journal of Strength and Conditioning Research, 21*:979-85.

Yaggie, J.A., & Campbell. B.M. (2007). Effects of balance training on selected skills. *Journal of Strength and Conditioning Research, 20:*422-428. 2006.

Verstegen, M., & Williams P. (2008). *Core Performance Golf: The Revolutionary Training and Nutrition Program for Success on and off the Course*. Rodale USA

Yessis, M. (2003). Using free weights for stability training. *Fitness Management, 4*, 26-28.

APPENDICES

Appendix 1

Participant Information

This study is being undertaken as part of a Master's Degree in Strength and Conditioning at Cork Institute of Technology. The study seeks to examine the impact of 4 different types of core training on markers of athletic performance in senior intercounty level GAA players. The study involves participants undergoing a series of tests for acceleration over 10 meters, speed over 30 meters, a countermovement jump, a bounce depth jump from a 30cm box, a test of agility (T-Test), a 1 repetition maximum squat, and a core stability test (the McGill test). Each participant's weight will also be taken.

Following testing, the participants will be divided into 5 groups. One group, a control group will not take part in the core training intervention but will continue normal training with their inter-county teams. The other groups will take part in an 8 week intervention of core training carried on either a stable or unstable surface and in a horizontal or vertical position. These 4 groups will continue normal training with their inter-county teams. The core training commitment is 4 times a week for 20 minutes a session over an 8 week period. At the end of this period, the participants will be re-tested on the same tests prior to the intervention.

All results will be available to the participants on completion of the study. Participants must complete 80% of the workouts for their data to be included in the study. Participants will be asked to sign an informed consent form (Appendix 2) and to be declared medical fit to take part by their team medical staff.

I have read and understood the participant information for this study.

Signed:

Date:

Appendix 2

Informed Consent Form

Name of participant: ___________________________ Team: ___________________

A study of the impact of core training on markers of athletic performance

I have read the participant information sheet for this study and understand what is involved in taking part. Any questions I have about the study and my participation in it have been answered to my satisfaction. I understand that I do not have to take part and that I may decide to withdraw at any time without giving a reason. It has been made clear to me that if I feel my rights are being infringed or that my interests are being ignored, neglected or denied, I should inform Cork Institute of Technology. I have been cleared medically and physically to train and to play with my team and subsequently am able to take part in this study. Any concerns I have that may arise during the time of the study or any concerns that may arise will be addressed by the investigator. I therefore agree to take part in the study.

Signed:

Date:

Appendix 3

Performance Markers Testing

Name: ________________________ Team: __________________ Test date: ________

Performance Marker	Test Result				
Counter Movement Jump (CMJ)					
Bounce Depth Jump (BDJ)					
10 M Sprint					
30 M Sprint					
T-Test					
Squat 1RM/Weight					
Core Test	Trunk flexion	Trunk extension	Lateral right	Lateral left	**Total (sec)**

Performance Markers Testing

Name: __________________________ Team: __________________ Test date: ________

Performance Marker	Test Result				
Counter Movement Jump (CMJ)					
Bounce Depth Jump (BDJ)					
10 M Sprint					
30 M Sprint					
T-Test					
Squat 1RM/Weight					
Core Test	Trunk flexion	Trunk extension	Lateral right	Lateral left	**Total (sec)**

Appendix 4

Testing Protocols

Acceleration and Speed Tests (10M and 30M tests)

Purpose

The purpose of the 10M and 30M tests is to test the subjects acceleration (10m), in which they need power to initiate movement and accelerate quickly towards top speed, and in the case of speed (30M), to attain maximum speed as quickly as possible, (Little, 2005).

Procedure

1. SmartSpeed timing gate system are set at start, 10M and 30 metre distances
2. Stands have legs opened out to the maximum and the first level pulled to the max height, approx. 3 foot.
3. The RFID reader is connected to starting line timing gate
4. A place line is drawn to indicate start position
5. Laser and mirror were checked for alignment
6. Switch on the hand held device and enter smart speed
7. Push the start a session icon
8. Switch on lights and then press the scan icon and click next.
9. Click on track timing and 3 gate system.
10. Issues subjects with wrist band containing sensor.
11. Test system by tester walking through the start, 10 metre and 30 metre gates.
12. Click next
13. Ensure RFID is enabled
14. Instruct each subject to scan in prior to commencing sprint and tester ensures this number has registered correctly.
15. Subjects will be given 2 trials, with 3 minutes rest between trials and with the best score being recorded.
16. Subjects will be asked to place toe of lead foot at the start line.
17. They will then be told to commence the sprint at their own initiative with no countermovement.
18. The system will allow for the recording of both sprint times simultaneously which makes fluency of testing easier.

Counter Movement Jump (CMJ)

Purpose

The test aims to determine the explosive leg power of the subject from a dynamic counter movement jump. Athletes need explosive lower extremity power in order to get off the ground and reach a maximum jump height.

Procedure

1. Subjects stand on the SmartJump mat.
2. Subjects are instructed to bend their knees and then jump as high as possible with hands placed and remaining on hips.
3. Subjects are instructed to achieve a straight leg position during the jump (no flicking of heels).
4. The SmartJump system then calculates individuals vertical jump height in cm.
5. Subjects are given two trials with 3 minutes rest between trials and with the best score recorded.
6. The system used the Sawyer's Formula to calculate a power score in watts.

Figure 1:

Bounce Depth Jump (BDJ)

Purpose

The test aims to determine the explosive leg power of the subject from a drop height of 30cm and a reactive vertical jump. This measures the reactive ability of the stretch shortening cycle in the athletes jump.

Procedure

1. Subjects step off a box, 30cm in height and land on two feet on the SmartJump mat.
2. Subject are instructed to land then jump as high as possible and as quickly as possible with hands placed and remaining on hips.
3. Subjects are instructed to achieve a straight leg position during the jump (no flicking of heels).
4. The SmartJump system then calculates individuals jump height in cm.
5. Subjects are given two trials with 3 minutes rest between trials and with the best score recorded.
6. The system used the Sayer's Formula to calculate a power score in watts.

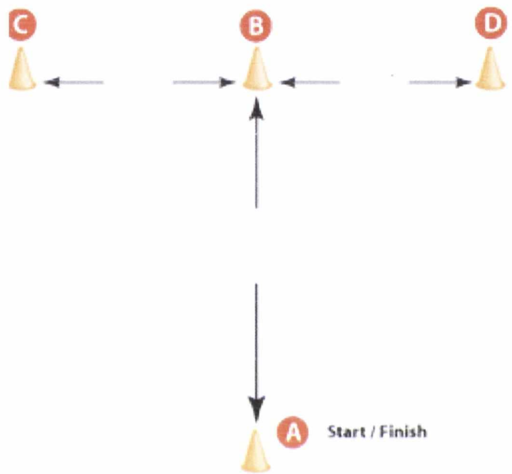
T-Test (Agility)

Purpose

The primary purpose of the T-Test is to test the subject's agility. The T-test is a measure of leg power, speed, and agility, (Little, 2005). In order to produce what is perceived as a quality performance or good time in the T-test an athlete must have explosive power during direction changes, speed to cover the course, and agility to maneuver the course.

Procedure

1. Set out 4 cones in the shape of a T as in the diagram below.



2. There is a 10 metres from start (A) to top (B), 5 metres either side from top (B) to each end cone (C) and (D).
3. Time is recorded using a handheld stopwatch.
4. The tester gives a "ready" and "go" signal and subject sprints from cone A-B.
5. Turn left and sprint to cone C touching the base with their left hand.
6. Turn right and sprint to cone D touching base with right hand.
7. Turn left and sprint to cone B Touching base with left hand and sprint to cone A
8. Subjects are given two trials with a 3 minute recovery and the best score is recorded.

Leg Strength

Purpose

The purpose of the strength testing is to establish subject's base line strength by establishing their 1 rep max for the Squat.

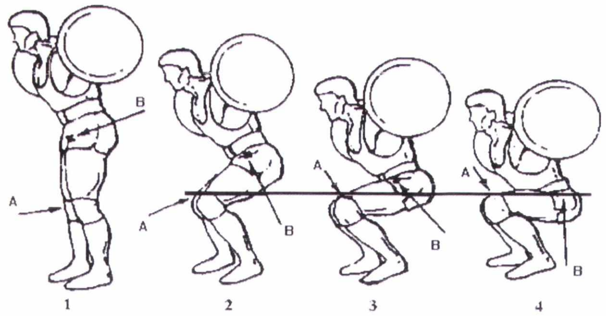
Procedure

Prior to beginning the back squat strength test, the subjects performs a full body joint mobility routine to prepare the body for movement under stress. Following this activity they perform a warm-up set with a bodyweight only followed by a set with an unloaded barbell.

1. Then add enough weight to allow 5-6 comfortable repetitions. Rest for 2-4 minute.
2. Estimate a warm-up load that will allow 3-5 repetitions, without coming close to maximum failure. Rest for 2 minutes.
3. The next set will be 2-3 repetitions with a weight that you can lift 3-4 times. Rest for 3-4 minutes.
4. Make a 10-20% load increase and try for your one rep max. If the subjects succeed,
5. Next, increase the weight again slightly and retry after 2-4 minutes of rest. If they fail, then decrease the load by 5-10% and retry after 2-4 minutes.
6. Once the subjects get to step 5, they get three attempts for the 1RM test, in which they can adjust the load up or down.

The test stops if;

- The athlete does not achieve full parallel depth (1 warning – next rep fail)
- Their back does not remain flat / becomes rounded
- Their knees buckle together excessively during a rep
- The athlete does not appear competent for any other reason


A
B
1
A
B
2
A
B
3
A
B
4

Core Testing

Purpose

McGill et al. (1999) identified a number of tests to determine muscle endurance of the core stabilizing muscles. The four tests, extensor test (back extensor test), flexor test (abdominal flexor test), and side bridge tests were shown to have reliability coefficients of between 0.97 and 0.99, (McGill, 2002)

Protocol

The isometric muscle endurance.

During protocol described by McGill (1999) consists of four tests that measure all aspects of the core through each of the tests the participants were reminded that these were maximum effort tests and they should maintain each position for as long as possible. Only the subject and tester were present in the testing area. Participants were given no feedback about the duration of their tests or their final scores. Times for each test were recorded separately, in seconds, and were later added together to give a total score in seconds for all four tests combined.

1. Subjects were allowed to practice each position for a maximum hold of five seconds in order to prevent fatigue.
2. A handheld stopwatch was used to measure the length of time subjects were able to hold each isometric position.
3. Subjects were given a minimum of five minutes rest between each test.
4. Each of the individual core tests times was totalled to produce a single “total core” value in seconds.

Trunk flexor test

1. The flexor endurance test starts with the subject in a sit-up position with the back resting against a board angled at 60 degrees from the floor.
2. Both knees and hips are flexed 90 degrees.
3. The arms are folded across the chest with the hands placed on the opposite shoulder, and the feet are secured.
4. The jig is pulled back 10 cm and the person holds the isometric posture as long as possible. Failure is determined when any part of the person’s back touches the jig.

Trunk extensor test

1. Subjects start with the upper body cantilevered out over the end of the test bench and with the pelvis, knees, and hips secured.
2. The upper limbs are held across the chest with the hands resting on the opposite shoulders.
3. Failure occurs when the upper body drops below the horizontal position.

Lateral musculature test

1. The subject begins lying in the full side-bridge position (e.g., left and right side individually). Legs are extended, and the top foot is placed in front of the lower foot for support.
2. Subjects support themselves on one forearm and on their feet while lifting their hips off the floor to create a straight line from head to toe.
3. The uninvolved arm is held across the chest with the hand placed on the opposite shoulder. Failure occurs when the person loses the straight-back posture and/or the hip returns to the ground.

Appendix 5

Core Training Programmes

Stable Horizontal Core Training (SHC) Cycle 1

2 Rounds– 2 Minutes rest between rounds

4 times a week X 4 weeks

Exercise	Reps/Time	Load	Rest
Plank 4 point	60 sec	BW	30 sec
Alternate leg/arm cycle	15 each side	BW	30 sec
Kneeling Superman w/ rotation	15 each side	BW	30 sec
Side plank	45 sec each side	BW	30 sec
Oblique Crunches	20 each side	BW	30 sec
Bridge 2 legs	15 X 5 sec	BW	30 sec
Bent Knee Reverse Crunches	20	BW	30 sec
Side Raises	12 each side	BW	30 sec

Stable Horizontal Core Training (SHC) Cycle 2

3 Rounds– 1 Minutes rest between rounds

4 times a week X 4 weeks

Exercise	Reps/Time	Load	Rest
Plank 3 point	60 sec	BW	30 sec
Hyperextension (full)	15 each side	BW	30 sec
Single leg V sit-ups	15 each side	BW	30 sec
Side plank on hand with leg raise	12 each side	BW	30 sec
Single leg Bridge	10 X 5 sec each side	BW	30 sec
Russian Twist	15 each side	5%BW	30 sec
Side Raises	15 each side	BW	30 sec

Unstable Horizontal Core Training (UHC) Cycle 1

2 Rounds– 2 Minutes rest between rounds

4 times a week X 4 weeks

Exercise	Reps/Time	Load	Rest
Swiss ball plank 4 point(feet on ball)	60 sec	BW	30 sec
Single leg crunch on Swiss ball	15 each leg	BW	30 sec
Swiss ball hyperextension	15	BW	30 sec
Forearm Side plank w/ Dumbbell raise	10 each side	5% BW	30 sec
Seated Swiss Ball Twist	15 each side	BW	30 sec
Swiss ball bridge on 2 legs	12 X 5	BW	30 sec
Swiss Ball leg raise	12	BW	30 sec
Swiss Ball arm windmill	15 each side	BW	30 sec

Unstable Horizontal Core Training (UHC) Cycle 2

3 Rounds– 1 Minutes rest between rounds

4 times a week X 4 weeks

Exercise	Reps/Time	Load	Rest
Swiss ball plank 3 point(foot on ball)	60 sec	BW	30 sec
Straight Single leg crunch on Swiss ball	15 each leg	5%%BW	30 sec
Swiss ball hyperextension	15	5% BW	30 sec
Forearm Side plank w/ Dumbbell and leg raise	10 each side	5% BW	30 sec
Swiss ball single leg bridge	10 X 5 sec each side	BW	30 sec
Swiss Ball arm windmill	15 each side	5%BW	30 sec

Stable Vertical Core Training (SVC) Cycle 1

2 Rounds– 2 Minutes rest between rounds

4 times a week X 4 weeks

Exercise	Reps/Time	Load	Rest
Overhead Squat	15	5%BW	30 sec
Woodchop	12 each side	5% BW	30 sec
Frontal Raise w/Disc	15	10%BW	30 sec
Kneeling Med ball throw	15	5%RM	30 sec
Hanging Knee Raise	10	BW	30 Sec
Side Lunge extended resistance	15 each side	5%BW	30 sec
Kettle Bell Swing	15 each side	5%BW	30 sec
Medicine Ball Slams	15	5%BW	30 sec

Stable Vertical Core Training (SVC) Cycle 2

3 Rounds– 1 Minutes rest between rounds

4 times a week X 4 weeks

Exercise	Reps/Time	Load	Rest
Overhead Squat	15	10%BW	30 sec
Woodchop	12 each side	10% BW	30 sec
Hanging Knee Raise	20	BW	30 Sec
Kneeling Med ball throw	15	10%RM	30 sec
Side Lunge extended resistance	15 each side	10%BW	30 sec
Kettle Bell Swing	15 each side	10%BW	30 sec
Medicine Ball Slams	15	10%BW	30 sec

Unstable Vertical Core Training (UVC) Cycle 1

2 Rounds– 2 Minutes rest between rounds

4 times a week X 4 weeks

Exercise	Reps/Time	Load	Rest
Single leg Squat	12 each side	BW	30 sec
Single Leg Frontal Raise w/Disc	10 each side	10%BW	30 sec
Single leg straight leg deadlift	10 each side	10%BW	30 sec
Single Leg Kettle Bell Swing	10 each side	5%BW	30 sec
Lunge with Medicine Ball Rotation	10 each side	5%BW	30 sec
Single Leg Medicine Ball Slams	10 each side	5%BW	30 sec
Swiss ball Kneeling	30 sec	BW	30 sec

Unstable Vertical Core Training (UVC) Cycle 2

3 Rounds– 1 Minutes rest between rounds

4 times a week X 4 weeks

Exercise	Reps/Time	Load	Rest
Single leg Squat	10 each side	10%BW	30 sec
Single Leg Frontal Raise w/Disc	15 each side	15%BW	30 sec
Single leg straight leg deadlift	12 each side	15%BW	30 sec
Overhead Lunge with knee lift	10 each side	10%BW	30 sec
Single Leg Medicine Ball Slams	15 each side	5%BW	30 sec
Single leg reverse overhead throw	10 each side	5%BW	30 sec

Appendix 6

Core Training Record Sheet

Name: ______________________________ Team: ______________________

Core session No.	Date	Completion time (mins)	Rate satisfaction with session (1-5) (1=Poor; 5= Excellent
1			
2			
3			
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