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Editorial: Adding *'weight'* to the argument. Adam Hawkey

French may be regarded by many as the language of love, but few may realise it can also be considered the language of science. *Le Système International d'Unités*, or the International System of Units (SI), was established in 1960 by the 11th General Conference on Weights and Measures (CGPM, *Conférence Générale des Poids et Mesures*). The CGPM, created by a diplomatic treaty called the Metre Convention signed in Paris in 1875, ensures wide dissemination and modification of the SI as necessary to reflect the latest advances in science and technology. The SI units consists of units of measurement devised around a number of base units (Table 1) While the physical and life sciences fully embrace this system, other related professions have been slower to fully appreciate it. Even in the clinical setting, using incorrect units to describe quantities is rife: how many of you have equipment, programs, or forms, which require you to enter weight in kilograms or height in centimetres? Using the SI units system, weight is reported in Newton's (N) based on the formula: force (weight) = mass x acceleration (F=ma), while mass (kg) refers to the amount of matter contained in an object or being. An 'out of this world' example clearly illustrates the fundamental difference: a person with a mass of 80kg would weigh ~785N (F=ma [80kg x 9.81m.s-2]) on earth. If this person were on Mars, for example, their mass would remain the same but their weight would now be ~296N (80kg x 3.7-2). While using the SI system is the correct way to present measures, there are occasions when presenting non SI units can also be useful. Representing weight (force) as a percentage of an individual's body weight (BW) enables a better comparison between individuals. For example, if a 50kg female gymnast and a 100kg male boxer both impart 2000N of force then, using the SI system, they would exert the same force. However, their relative forces would be profoundly different: ~4 and ~2 times their BW respectively. I am not suggesting that you should be as pedantic as I am known for being, but the use of the SI system should be encouraged as it allows us all to standardise the way we present data, which can only be advantageous when disseminating important information and knowledge.

Quantity	Base Unit	SI Unit Symbol
Time	Second	s
Length	Metre	m
Mass	Kilogram	kg
Area	Square metre	m^2
Volume	Cubic metre	m^3
Velocity	Metres per second	m/s
Acceleration	Metres per second squared	m/s^2
Force	Newton	N
Pressure	Pascal	N/m^2
Energy	Joule	J
Power	Watt	W

Table 1. SI units system with corresponding symbols

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Welcome to Issue 1 (Vol 4) of the JST

Lecture over; it gives me great pleasure to welcome you to Issue 1 (Vol 4) of the JST. This issue is the largest issue of the JST to date and includes contributions from a range of professionals and academics from the UK, Europe and the United States; continuing the JST's encouragement of inter-professional alliances. The lead article of this issue covers the structure, function and properties of bone; acting as the first part of a feature devoted to the causes, prevention and treatment of osteoporosis. There are two articles concerned with the characteristics and fitness levels of female athletes; one in relation to basketball, the other football (soccer). The acute affects of static and dynamic stretching are discussed, with respect to vertical jumping performance, while a biomechanical analysis of squatting and its implications for ACL injury prevention is also presented. A case study of the application of whole body vibration as an exercise intervention for rheumatoid arthritis continues the recent popularity, in the JST and the wider literature, of vibration research in health and exercise. The final paper assesses the reliability and validity of a new adaptation of agility testing. The diversity of the papers presented in this issue further highlights the inter- and multi- disciplinary aspirations of the journal, while its volume is an indication of the journal's continuing development and popularity. We, as an editorial team, therefore continue to encourage JST readers to contribute to the journal in a number of ways; be this through submitting articles (original research, reviews or case studies), commenting on previous issues, or providing book and product reviews. Inviting scholarly input creates a forum for discussion and a means to connecting with the wider community. For further details or comments, please contact the editor.

Yours in science and health
Adam Hawkey
Editor, Journal of Sports Therapy

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Reviews and invited commentary

Understanding the causes, prevention and treatment of osteoporosis (part 1): the structure of bone and the remodelling proces

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KEY WORDS

bone architecture
bone remodelling cycle
osteoblasts
osteoclasts
osteocytes
osteoporosis

ABSTRACT

Osseous tissue, or bone, is a living tissue, composed of a mixture of organic and non-organic substances. Bone tissue can be described according to its level of structure: macro-, micro-, sub-micro-, nano-, and sub-nano-. At the macroscopic level, bone can be classified as cortical or cancellous, organised microscopically as osteons and trabeculae respectively. At the sub-microstructure level bone can be lamellar or non-lamellar, while at the cellular level, bone consists principally of three main cell types: osteoclasts, osteoblasts, and osteocytes, which interact to continuously regenerate the bone matrix. Bone is continuously modelling/remodelling itself throughout an individual's life, allowing the skeleton to increase in size during growth, respond to physical stresses, and repair structural damage due to fatigue, failure or trauma. Bone homeostasis is only maintained if the processes of resorption and formation are closely coupled. Understanding the micro- and macro-architecture of bone and the processes involved in bone remodelling are crucial in the diagnosis of osteoporosis and the evaluation of the effectiveness of treatments and interventions. The purpose of this article (the first of a three-part feature) is, therefore, to describe the structure and function of bone, the cells involved in bone remodelling, and the process of remodelling itself.

The framework of the human body is provided by the 206 separate bones of the skeleton. Bones provide the structural framework of the body, which supports soft tissues and the surface of which act as points of attachment for tendons and the majority of skeletal muscles. The bones also protect many internal organs, including cranial bones to shield the brain, vertebrae to protect the spinal cord, and the rib cage, which acts as a defensive barrier for the heart and lungs. As well as the bones acting as a protective shield for vital organs, it also acts as a storage facility for a number of minerals, primarily calcium (99% of all body calcium is stored within bone) and phosphorus, which contribute to the overall strength of bone. Bone has the ability to release these minerals into the bloodstream to ensure that critical mineral balances are maintained and to allow the distribution of minerals to other organs. Red bone marrow, which produces red blood cells, white blood cells, and platelets by a process termed hemopoisis, is also contained within certain parts of bones. The skeleton itself can be subdivided into the axial (80 bones) and appendicular (126 bones) components; the axial skeleton forming the axis of the body, supporting and protecting the organs of the head, neck, trunk and spine, while the appendicular skeleton (from the Latin appendic meaning to hang-to) comprises the bones of the upper and lower extremities and the bony girdles that anchor the appendages to the axial skeleton. The bones themselves can be further classified according to their size, shape, function, and the proportion of compact and cancellous bone tissue: long; short; flat; irregular; sesamoid; and sutural.

Organisation of bone

Bone, or osseous tissue, is an extremely complex, organised and specialised connective tissue. It is highly heterogeneous, partially because of its adaptation to resist different, complex and varying stresses (Dudley and Spiro, 1961). Bone is a relatively hard and lightweight composite material, which is strong, but relatively elastic (Nordin and Frankel, 2001). Bone has relatively high compressive strength, of about 170 MPa (1800 kgf/cm^2) (Schmidt-Nielsen, 1984), comparatively poor tensile strength of 104–121 MPa, and very low shear stress strength of 51.6 MPa (Turner et al., 2001). This means it resists pushing forces well, but not pulling or torsional forces. While bone is essentially brittle, it does have a significant degree of elasticity, contributed chiefly by collagen. All bones consist of living and dead cells embedded in the mineralized organic matrix that makes up the osseous tissue. The mechanical behaviour of bone, essentially its behaviour due to forces and moments, according to Frankel and Nordin (2001) is affected by its mechanical properties, its geometric characteristics, the loading mode applied, the direction of the loading, and both the rate and frequency of this loading. Bone exhibits many orders of structures: the macrostructure (cancellous and cortical bone), the microstructure (haversian systems, osteons, single trabeculae - 10 to 500 µm), the sub-microstructure (lamellae - 1 to10 µm), the nanostructure (fibrillar collagen and embedded mineral - ~300 hundred nm to 1 µm), and the sub-nanostructure (mineral, collagen, and non-collagenous organic proteins - <300 nm). Macroscopically, there are two types of osseous tissue (Figure 1): cortical bone (compact), which constitute approximately 80% of the skeleton and are predominantly found in the shafts of the long bones such as the femur and tibia; and cancellous bone (trabecular or spongy), mainly found at the end of long bones and inner parts of flat bones, like the sternum, and irregular bones, such as the vertebrae. Essentially, the tissues are biologically identical; they simply differ in how the microstructure is arranged. The relative proportions of the type of bone vary dramatically depending on the skeletal site; for example the cortical: trabecular ratio at the vertebra is approximately 25:75, while at the head of the femur it is 50:50 (Dempster, 2006). While the diaphysis of a long bone is comprised of layers of cortical bone, the metaphysis and epiphysis are both constructed of cancellous bone, inside a thin layer of cortical bone (Figure 2). The hard outer layer of bones is composed of compact bone tissue, so-called due to its minimal gaps and spaces. Cortical bone is much denser than cancellous bone with a porosity ranging between 5% and 30% (Hall, 2007). In the cortical bone, the periosteum is the outer fibrous structure containing blood vessels, nerve ending and the bone cells. The periosteum is anchored to the bone with Sharpey's fibres, which penetrate into the bone tissue. The endosteum is a membranous sheath, which inhabits the inner surface of cortical bone and is in direct contact with marrow (Brandi, 2009). The basic first level structure, or microstructure, of cortical bone is the osteon or Haversian system (Figure 3a). The osteons are cylinders consisting of four main parts: lamellae, lacunae, canaliculi, and a central canal. The lamellae are essentially rings of matrix, which contain calcium and phosphates, while the lacunae are small cavities housing osteocytes. Canaliculi are spokes that radiate from the lacunae, while the central canal contains blood vessels, nerves and lymphatic vessels (Figure 3b). Cancellous bone does not consist of osteons; the basic first level structure (microstructure) of trabecular bone being trabeculae. It resembles a lattice of thin struts that are constructed of columns of bone (Figure 4) containing osteocytes, lacunae, canaliculi and lamellae. Lighter and less dense than cortical bone, cancellous bone accounts for the remaining 20% of total bone mass but has nearly ten times the surface area of compact bone, with a porosity range of 30–90% (Hall, 2007). Bone marrow can be found in almost any bone that holds cancellous tissue. In newborns, all such bones are filled exclusively with red marrow, but as the child ages it is mostly replaced by yellow, or fatty marrow. In adults, red marrow is mostly found in the marrow bones of the femur, the ribs, the vertebrae and pelvic bones. If, for any reason, there is an alteration in the strain that cancellous bone is subjected to, there is a rearrangement of the trabeculae. So the microscopic difference between compact and cancellous bone is that compact bone consists of Haversian sites and osteons, while cancellous bones do not. Also, bone surrounds blood in compact tissue, while blood surrounds bone in cancellous tissue. In addition to differing in appearance, the two types of bone also differ dramatically in their mechanical properties, particularly in the qualities of strength and elongation. Interestingly the compressive strength of cor-

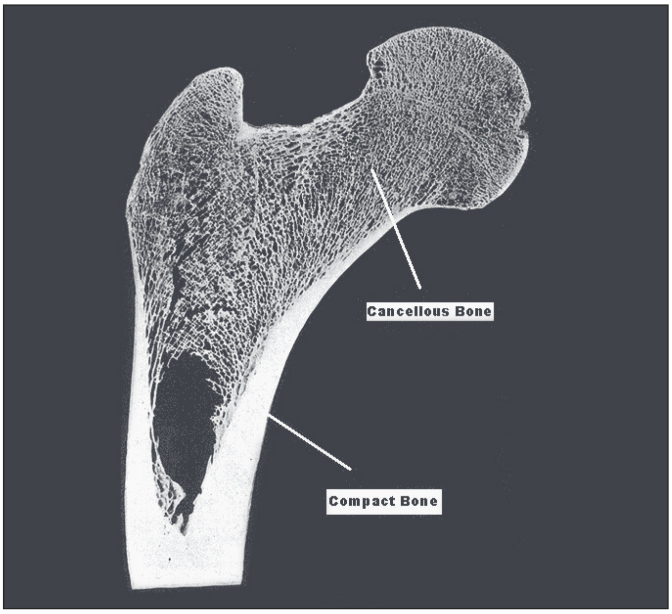

Figure 1. Femur head comprising both compact and cancellous bone (adapted from Henry Gray's *"Gray's Anatomy"*; Lithograph 247 femur)

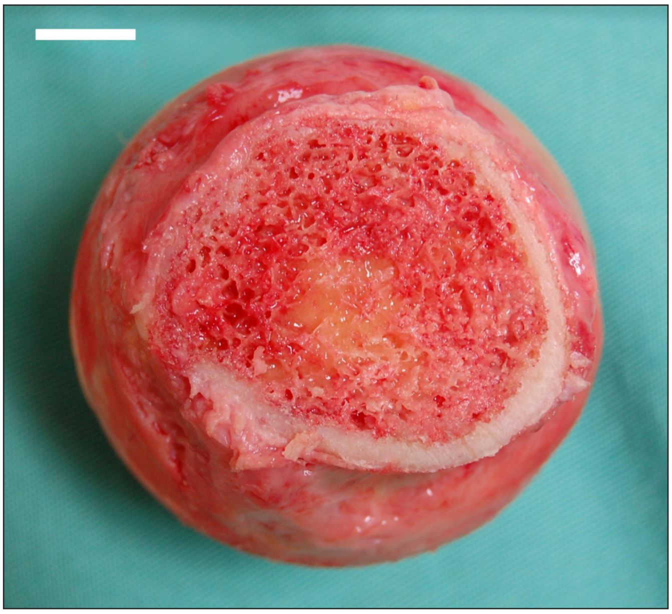

Figure 2. Femur head cut-away to reveal compact and cancellous bone, red and yellow marrow: white bar represents 0.01m (used with permission from Steven Fruitsmaak)

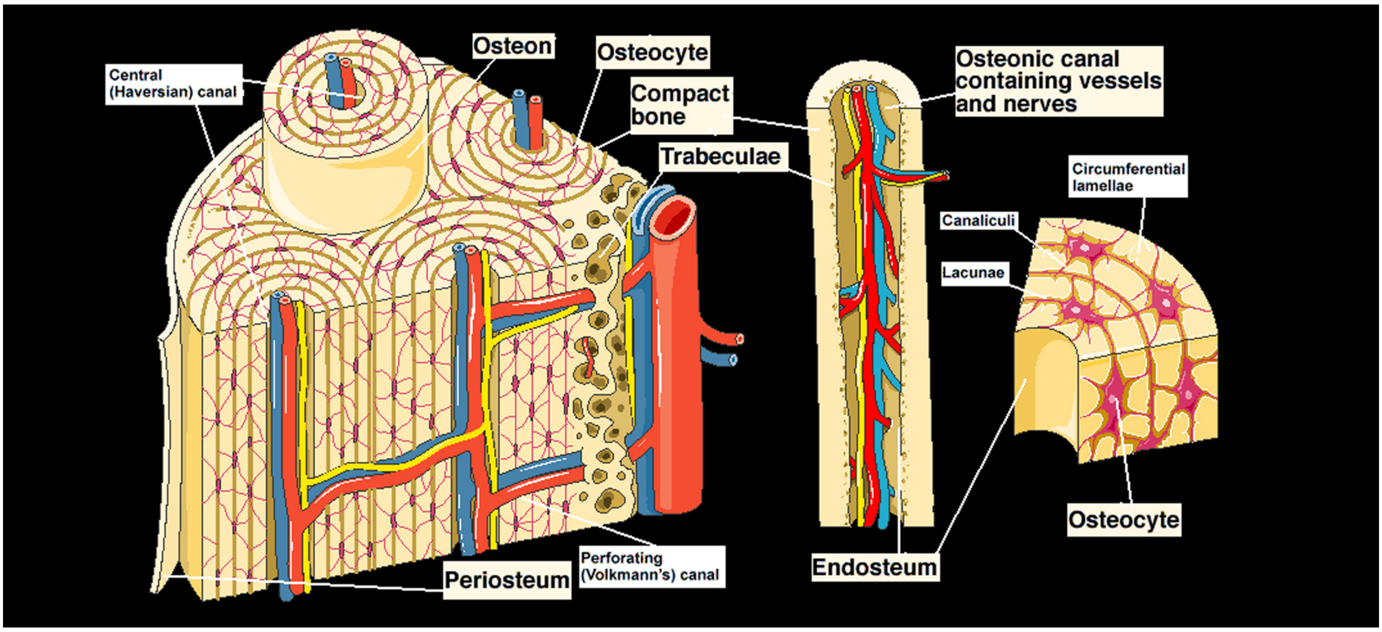

Figure 3a. Bone structure (after Hawkey, 2008; artwork originally adapted and used with permission from Les Laboratoires Servier)

tical bone is, according to Hamill and Knutzen (2009), greater than that of concrete, wood or glass. This can be demonstrated by bone's ability to tolerate large impact loads and resist bending: those experienced during the step and jump phases of the triple jump for example; reported to be as high as 17 times an individual's body weight (BW) in the vertical axis (Hawkey and Scattergood, 2007). While cancellous (trabecular) bone does not have the strength of cortical bone, it is reported to be able to withstand more deformation before failure (Hamill and Knutzen, 2009).

At the sub-microstructure level, bone consists of two main types of tissue, which can be identified microscopically according to the pattern of collagen forming the osteoid (collagenous support tissue of type I collagen embedded in glycosaminoglycan gel): primary (non-lamellar) bone; and secondary (lamellar) bone. Non-lamellar bone, also known as coarse fibred, woven or immature bone is characterised by the presence of randomly oriented coarse collagen fibres (Figure 5). It is mechanically weak and is produced when osteoblasts produce osteoid rapidly, which occurs initially in all fetal bones (later replaced by more resilient lamellar bone). In adults woven bone is created after fractures or in Paget's disease. Lamellar bone tissue, often referred to as mature bone, is identifiable by the presence of collagen fibres arranged in parallel layers or sheets, called lamellae (Figure 6). Lamellar bone, which has a regular parallel alignment of collagen into sheets (lamellae), is mechanically strong. Lamellar bone, which makes its first appearance in the fetus during the third trimester, is mechanically stronger than woven bone

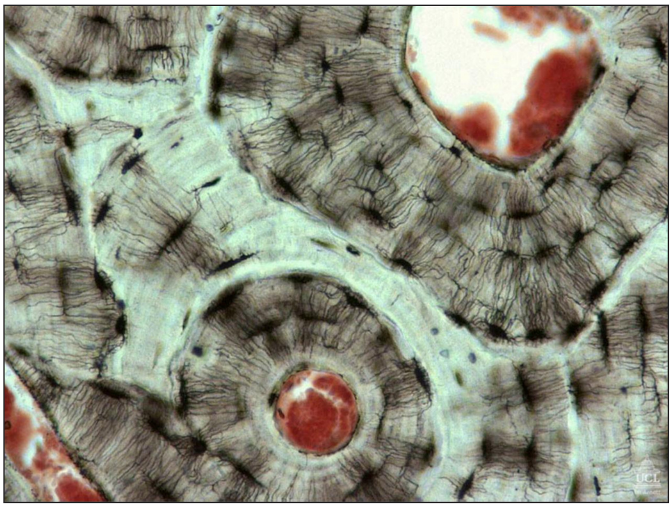

Figure 3b. Compact bone – blood vessels (red) and osteocytes with caneculli (black) clearly visible (used with permission from Tim Arnett/Bone Research Society)

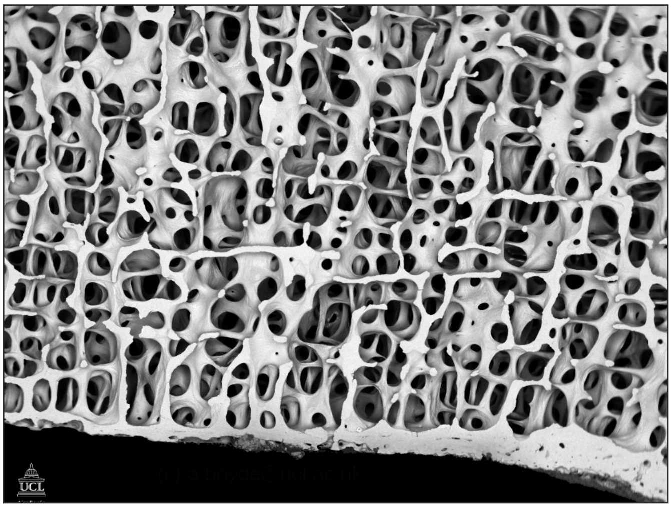

Figure 4. Cancellous bone. Trabecular structure clearly visible (used with permission from Alan Boyde/Bone Research Society)

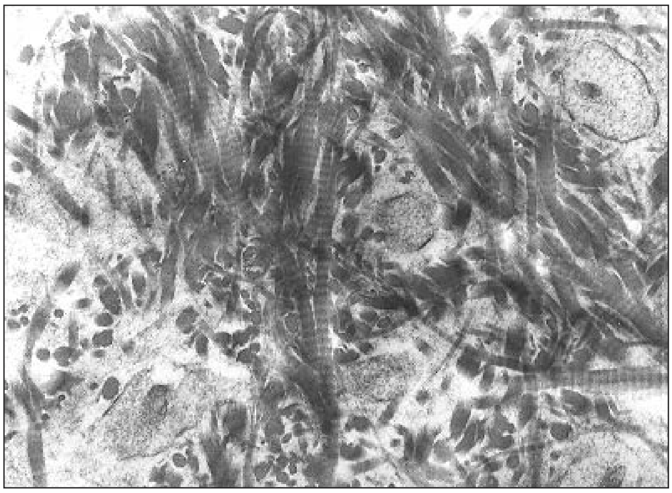

Figure 5. Woven (non-lamellar) bone (used with permission from Robert M. Hunt)

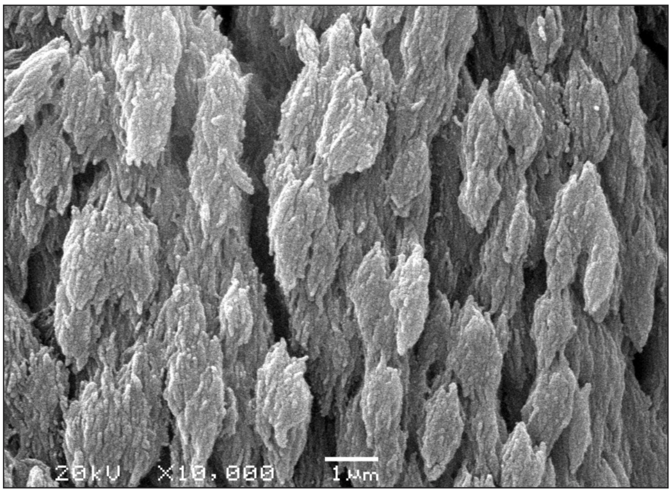

Figure 6. Lamellar bone (used with permission from S. Bertazzo)

and is filled with many collagen fibers parallel to other fibers in the same layer (these parallel columns are called osteons). In cross-section, the fibres run in opposite directions in alternating layers, much like in plywood, assisting in the bone's ability to resist torsion forces. After a fracture, woven bone forms initially and is gradually replaced by lamellar bone during a process known as bony substitution. Compared to woven bone, lamellar bone formation takes place more slowly. The orderly deposition of collagen fibers restricts the formation of osteoid to about 1 to 2 µm per day (Salentijn, 2007).

At the nano- and sub-nanostructure level, bone can be referred to as a two-phase (biphasic) composite material: one phase being mineral (non-organic); the other comprised of collagen and ground substances, known as the organic matter (Figure 7). The organic matter consists of type I collagen fibres embedded in proteoglycans and glycoproteins (Bertazzo and Bertran, 2006; Bertazzo et al., 2006). Collagen molecules secreted by osteoblasts self-assemble into fibrils with a specific tertiary structure having a 67 nm periodicity and 40 nm gaps between the ends of the molecules. The collagen fibres (essentially bundles of fibrils) act as a soft hydrogel template and resist pulling forces. The in-organic matter is made up of stiffening substances to resist bending and compression; the bone mineral is an analogue of crystals of calcium phosphate and hydroxyapatite (HA)Ca10(PO4)6(OH2). Nanocrystalline HA which is typically 20-80nm long and 2-5nm thick comprises 70% of the bone matrix (Bertazzo and Bertran, 2006; Legros et al., 1987; Field et al., 1974). It is this association of hydroxyapatite with collagen fibres which is responsible for the hardness of bone. Bone consists of a dense, layered, regular network of collagen fibres embedded in a hard, solid ground substance (Watkins, 2010). The ground substance is generally referred to as bone salt and consists of a combination of calcium phosphate, calcium carbonate, magnesium, sodium, and chlorine. Non-collagenous organic proteins, including phosphoproteins, such as osteopontin, sialoprotein, osteonectin, and osteocalcin, may function to regulate the size, orientation, and crystal habit of the mineral deposits (Rho et al., 1998). In materials such as bone (and non-biological examples such as fibreglass), where a strong brittle material is embedded in a weaker, but more flexible material, the substances combined are stronger, in relation to their weight, than either substance alone (Bassett, 1965). A number of factors, such as site, age, dietary history and disease have an influence on bone composition (Kaplan et al., 1994). The mineral portion of bone is comprised mainly of calcium and phosphate, giving bone its solid consistency, which accounts for 60-70% of its dry mass. Water is relatively abundant in living bone and accounts for approximately 25% of its total mass: 85% of which is contained in the organic matrix, collagen fibres, ground substance, and hydration shells surrounding bone crystals; the remaining 15% being housed in the canals and cavities

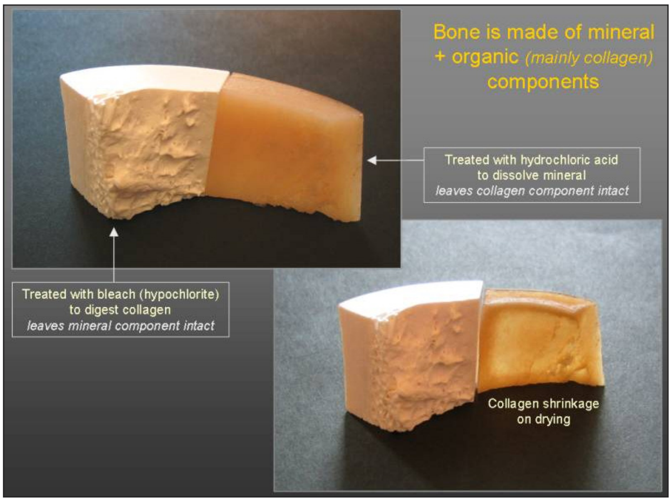

Figure 7. Biphasic bone: mineral and collagen portions (used with permission from Tim Arnett/Bone Research Society)

transporting nutrients to the bone tissue (Frankel and Nordin, 2001).

Bone modelling and remodelling

Bone has the ability to adapt its size and shape in response to mechanical loads (Brandi, 2009). This ability can be described through two similar, but distinct, processes: bone modelling and bone remodelling. The bone modelling process occurs not only during the growth period, but also during adulthood. It can be viewed as the bone directly responding to mechanical loading by initiating bone formation, without prior bone resorption. This process can be seen in tennis players, where the radius of the playing arm shows larger external diameter and a thicker cortex than the non-playing arm (Brandi, 2009). The converse is evident in those who are confined to long-term bed-rest, or astronauts in spaceflight, where significant bone loss is experienced (Hawkey, 2003a; 2003b). The process of bone remodelling is a surface-based phenomenon involving the removal of bone matrix (resorption) and the deposition of new bone (inversion). There are three principal cells that are active in this process within the bone matrix: osteoclasts, osteoblasts, and osteocytes. Osteoclasts are large multinucleate cells, which resorb bone and remove degraded material (Figure 8a). They are located on bone surfaces in what are called Howship's lacunae or resorption pits. These resorption pits are left behind after the breakdown of the bone surface. Osteoclasts are derived from a monocyte stem-cell lineage, and are equipped with phagocytic-like mechanisms similar to circulating macrophages. Osteoclasts mature and/or migrate to discrete bone surfaces. Upon arrival, active enzymes, such as tartrate resistant acid phosphatase, are secreted against the mineral substrate (Figure 8b). This creates an acidic environment on the surface of bone, which dissolves the bone's mineral content. Once the mineral content of the bone has been dissolved, enzymes released from osteoclasts remove the remaining collagenous bone matrix to complete the process of resorption. The rate at which osteoclasts resorb bone is inhibited by calcitonin and osteoprotegerin. Calcitonin is produced by parafollicular cells in the thyroid gland, and can bind to receptors on osteoclasts to directly inhibit osteoclast activity. Osteoprotegerin is secreted by osteoblasts and is able to bind RANK-L, inhibiting osteoclast stimulation (Boulpaep et al., 2005). Following resorption, osteoblasts (Figure 9) are then attracted to the resorption cavity and start to produce and deposit organic matrix called osteoid, primarily composed of Type I collagen. Minerals start to crystalise around the collagen scaffold to form hydroxiapetite, the primary in-organic constituent of bone, which contains calcium phosphate. The product of this process is new bone matrix being deposited and mineralised (Helfich, 2003; Phan et al., 2004; Hawkey, 2007). As osteoblasts form new bone tissue many of them become embedded into the matrix they create; causing them to differentiate into osteocytes (Figure 10), while other, non-active osteoblasts called bone lining cells, cover all of the available bone surface and function as a barrier for certain ions. Osteocytes are, therefore, essentially mature osteoblasts trapped within calcified bone, and are believed to transmit information about mechanical forces in response to deformations of bone caused by muscular activity; which then directs bone remodelling to accommodate these forces (You et al., 2000; Ehrlich and Lanyon, 2002). Bone remodelling differs from modelling in that it is initiated by a period of resorption lasting approximately two weeks, while osteoclasts erode an area of bone. The duration of this remodelling process is approximately three to six months; the majority of this period being taken up with bone formation (Manolagas, 2000). This remodelling process (often termed the bone remodelling cycle) can be clearly identified into four distinct phases: quiescence/activation; resorption, reversal, and formation (Figure 11). It has been estimated that this bone remodelling process, which is essentially the interaction of osteoclasts and osteoblasts, is in action, at any one time, in approximately 500,000 sites throughout the body, which equates to approximately 10% of the bone surfaces in the adult skeleton (Marx, 2004).

The process of bone responding to changing loads is known as Wolff's Law, which describes the remodelling of bone and is influenced and modulated by mechanical stresses (Buckwater et al., 1995). Specifically, Wolff's law states that "every change in the form and function of a bone or of their function alone is followed by certain definitive changes in their internal architecture and equally definite secondary alteration in their external conformation, in accordance with mathematical laws" (Keller and Spengler, 1989). Repeated stress, such as weight-bearing exercise or bone healing, results in the bone thickening at the points of maximum stress (Wolff's law). It has been hypothesized that this is a result of bone's piezoelectric properties, which cause bone to generate small electrical potentials under stress. (Netter, 1987). All of the bone in an adult's skeleton is replaced every ten years (Marx, 2004), with approximately 10% renewed by remodelling every year (Manolagas, 2000). Due to this remodelling process, bone mass is continually changing throughout life, during skeletal growth, consolidation and involution. In healthy young adults, total bone mass remains relatively constant, indicating equal rates of bone depositing and resorption. However, the remodelling process is not uniform, with some bones, or areas of bone, experiencing very different levels of remodelling. A good example of this is the distal portion of the femur, which is fully replaced approximately every six months; the shaft of the femur, however, is remodelled much more slowly. Although the exact processes are not yet known, it is believed that the interaction between osteoclasts and osteoblasts changes throughout life. During the younger years bone goes through a growth period, during which approximately 90% of peak bone mass is deposited. During this period the osteoblast cells are more prevalent than osteoclast cells, meaning more bone is laid down. A consolidation period of approximately 15 years then follows, which increases bone mass further until peak bone mass is reached in the mid-twenties. Involution, a stage where bone resorption begins to supersede bone deposition, then typically starts between the ages of 35 and 40 with cortical and trabecular bone being lost with advancing age in both sexes according to bone type and anatomical site. Generally, women lose 35-50% of trabecular and 25-30% of cortical bone, while men lose 15-45% and 5-10% of trabecular and cortical bone respectively, over their lifetime (Riggs and Melton, 1986). Bone loss starts initially on the surfaces of bone, so any alterations in bone mass are seen earlier, and to a greater extent in areas with a higher percentage of trabecular bone as opposed to those consisting principally of cortical bone (Brandi, 2009); the head of the femur and the vertebrae for example. Bone homeostasis is only maintained if the opposing (or complimentary) actions of osteoclasts and osteoblasts are balanced, meaning resorption and formation are closely coupled. A defect in either process can result in increased bone accumulation (osteopetrosis), or in increased bone turnover (osteoporosis). In the second part of this feature, the mechanisms and risk factors of osteoporosis will be discussed as will the efficacy of various techniques employed to quantify bone health.

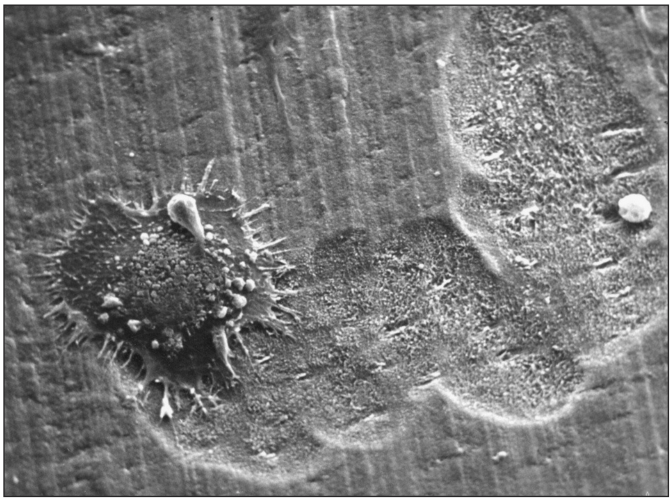

Figure 8a. Osteoclast Cell (used with permission from Alan Boyde/Bone Research Society)

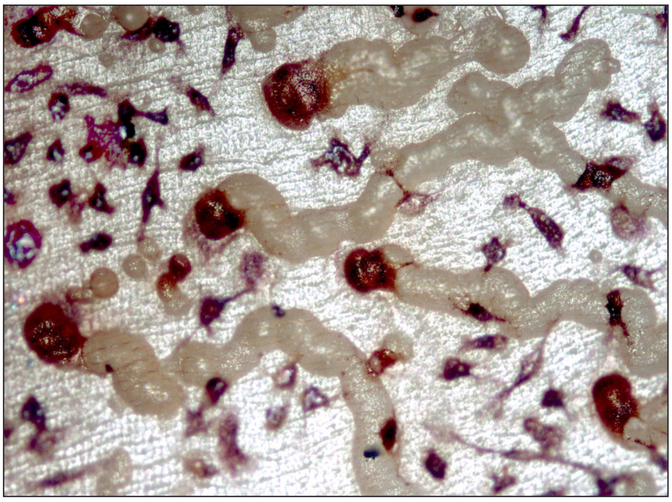

Figure 8b. Osteoclast Cells resorbing bone (used with permission from Tim Arnett/Bone Research Society)

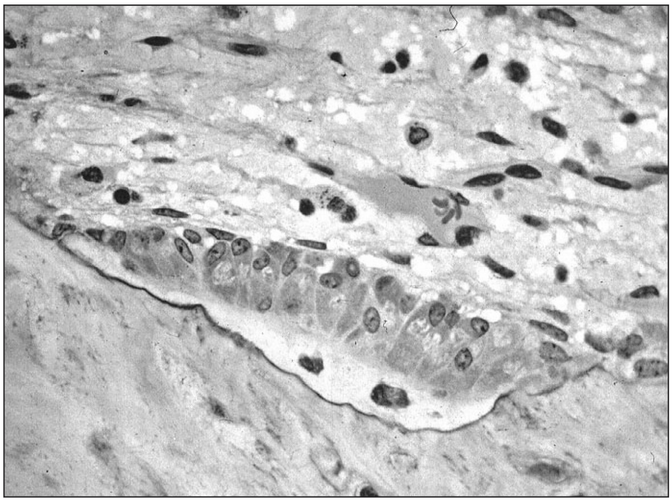

Figure 9. Osteoblast Cell (used with permission from Robert M. Hunt)

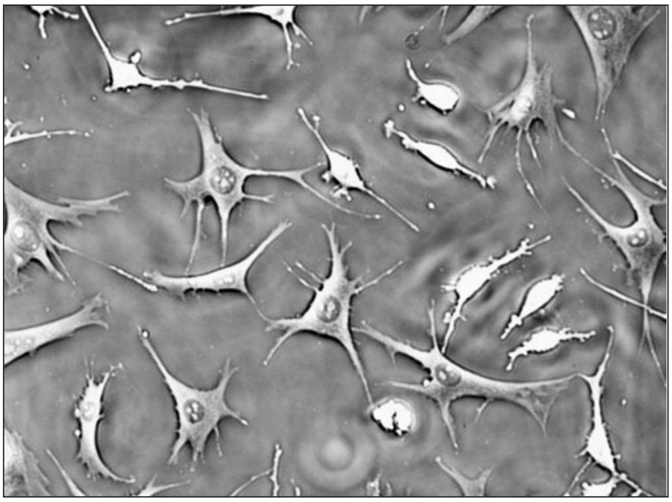

Figure 10. Osteocyte Cells (used with permission from the Southwest Research Institute funded by NIH grant AR046798)

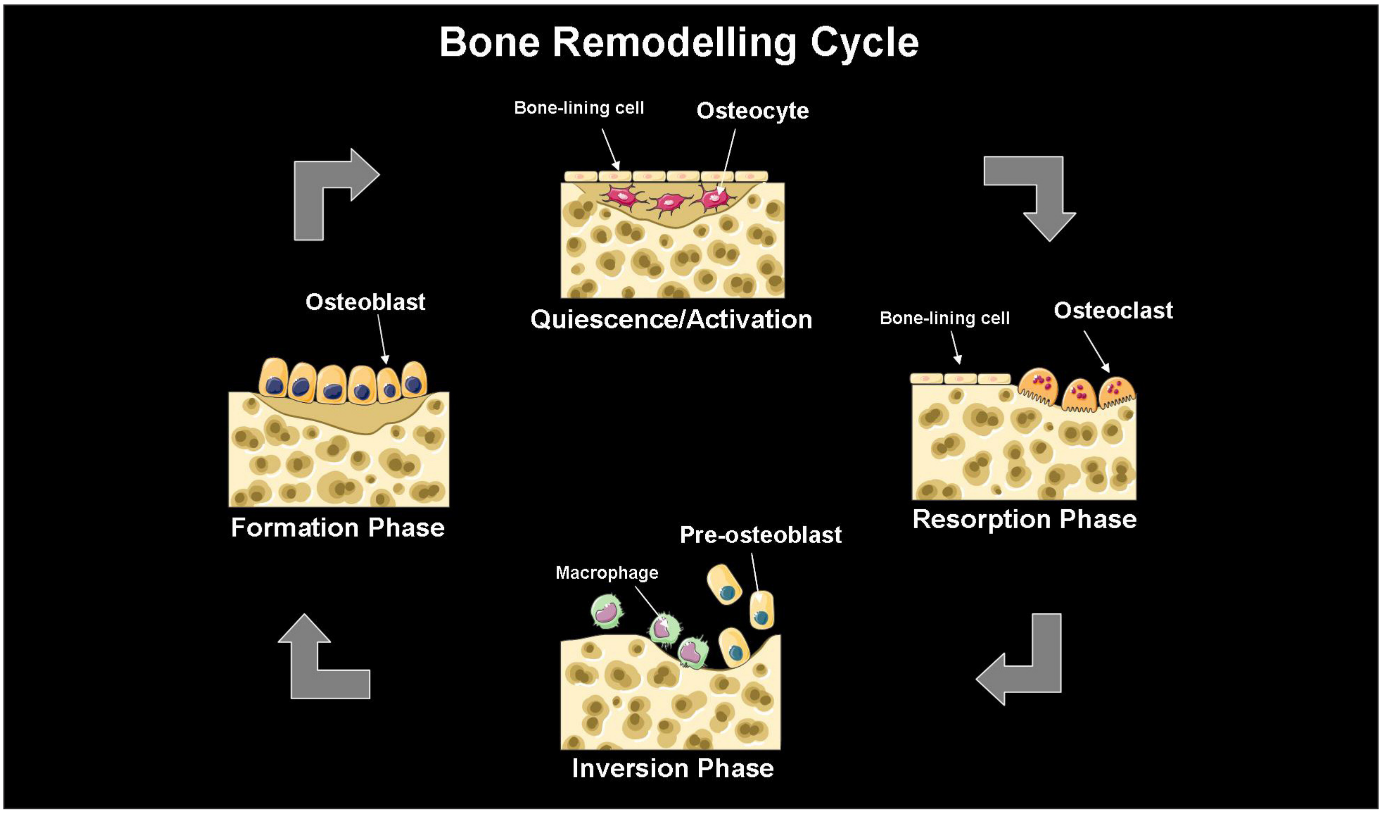

Figure 11. Simulated representation of the Bone Remodelling Cycle (after Hawkey, 2008; artwork originally adapted and used with permission from Les Laboratoires Servier)

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Original Research

Anthropometric and fitness development of British elite female basketball players: from grassroots to high level

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KEY WORDS

BMI
Arm span
Flexibility
Agility
Speed
Endurance.

ABSTRACT

Basketball is one of the most practised sports in the world. There is a large amount of articles analysing and studying the basketball player's anthropometry, the basketball parameters, the physiological demands, and the fitness level of the team. However, the vast majority of these studies have focused on male basketball, as opposed to female. There are only a few studies working on British high level female basketball teams. To compare and evaluate the body composition and fitness characteristics of British female basketball players from grassroots to high level against the studies which are available in the literature. Seventy eight (n = 78) female basketball players from the English Basketball League and the Great Britain National Team participated in the current study. The anthropometry tests were: weight, height, arm span, and BMI; and the fitness tests were: Flexibility (sit and reach), Agility (4x10-meter shuttle run), Lower Body Power (Standing Broad Jump), and 20-meter shuttle run Tests. Statistical differences were found between groups in the Agility and Standing Broad Jump Tests. Cardiorespiratory fitness showed a slight tendency to improve as the team's level increased, although statistical differences were not observed. British female basketball players had fitness level and body composition values lower than high-level female basketball teams from countries where basketball is more popular and better developed. The S&C coach role within the technical staff is necessary and highly recommended to achieve high level competition.

Sport science now plays an important contribution to the study and analysis of talent identification processes in sport (Williams and Reilly, 2000). Basketball is one of most practised sport in the world. Having said this, this sport is not too popular in England and in the United Kingdom. Team sports such as football, cricket, rugby union and rugby league have much more participation (i.e. there are 900 basketball teams (39,312 players) versus 51,966 football teams (4,850,569 players) (FIBA and FIFA, 2011) in the United Kingdom. Still, thanks to the London 2012 Olympic and Paralympics Games, basketball has been further developed during the last decade (i.e. the Great Britain team was formed at the end of 2005 to be competitive and their qualification for the 2009 European Basketball Championship, after 28 years of absence from any major international basketball event, has marked Great Britain as one of the uprising basketball nations in Europe). Therefore, studies of the actual English Basketball situation will help optimise talent identification, as well as develop English and British basketball players in the future. The knowledge of body composition and fitness level of the players and their evolution through the season is very helpful for the Head Coach, as well as for the Strength & Conditioning Coach (Drinkwater et al, 2008; Ziv and Lidor, 2009). Both of them can use these values to coach and train the team in relation to certain particular aspects that need to be improved in order to achieve the elite or better performances (Hoffman et al., 1996; Ziv and Lidor, 2009). Therefore, assessing player fitness and body composition is important so coaches are aware of the fitness changes and limitations of different levels, ages and between the genders of their different teams. These measurements also allow a coach to monitor the effectiveness of their training programme over the season, or over the several years (Drinkwater et al., 2008). The aim of this study, therefore, was twofold: a) to study the anthropometric and fitness level development of English female basketball players from grassroots to high level and b) to compare and evaluate the resulting values with the few studies available in the literature.

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Methods

Participants

78 female basketball players from top-4 teams that compete in the England Basketball League Division I and II and 1 Great Britain National Team volunteered to participate in this study after having signed the corresponding informed consent. The distribution of the players was as follows: 17 players from an Under 17 Regional Squad Performance Team (U17) which were the National Champion; 13 players were playing in a 2 top Under 18 England National League Team (U18); 19 players belonged to a 4 top senior England National League Division II Team (Senior II); 14 players played for a 4 top senior England National League Division I Team (Senior I); and finally 15 players made up the Under 20 Great Britain National Team (U20 GB) that participated in the European Championship. Their anthropometric characteristics are indicated in Table 1

Fitness Tests

The fitness tests were selected based on validated batteries commonly used in sport in different cross-sectional and longitudinal studies. These tests are described in detail in a specific article (Ruiz et al., 2006). Each subject performed all tests on two separate and non-consecutive days in December.

First day's Tests:

Flexibility (sit and reach). This test is part of the FITNESSGRAM battery (Welk and Meredith, 2008). The subjects attempted to reach forward as far as possible from a seated position with both legs straight and without bending the knees. Two alternative repetitions were carried out and the best attempt was recorded.

Table 1. Anthropometric characteristics of each group

Team	n	Age (years)	Age Range (yrs)	Height (m)	Mass (kg)	BMI (m/kg^2)	Arm span (m)	Training /Week (days)*
U20 GB	15	18 ± 1	3.00 ± 0.74	1.79 ± 0.06	80.42 ± 11.94	24.88 ± 2.60	-	3.80 ± 1.90
Senior I	14	21 ± 2	7.00 ± 2.31	1.74 ± 0.04	75.21 ± 15.38	24.67 ± 4.25	1.77 ± 0.08	3.50 ± 0.76
Senior II	19	18 ± 3	5.00 ± 2.94	1.70 ± 0.08	64.32 ± 7.14	22.38 ± 2.15	1.69 ± 0.07	3.00 ± 0.00
U18	13	16	3.00 ± 0.00	1.67 ± 0.06	63.69 ± 7.59	22.60 ± 2.41	1.67 ± 0.08	3.00 ± 0.00
U17	17	15 ± 1	3.00 ± 0.87	1.74 ± 0.1	65.54 ± 11.21	21.59 ± 2.32	-	2.47 ± 0.51
Mean	**78**	**18**	**4**	**1.73**	**69.84**	**23.22**	**1.71**	**3.15**
SD		**2**	**2**	**0.04**	**7.54**	**1.46**	**0.05**	**0.51**

* A training session is two hours of practice. The weekly game is not included in these data.

Anthropometric Tests

Anthropometric measures were taken, following the Lohmann et al. (1988) instruction. Standing height and arm span were measured with precision of 0.1 cm with a stadiometer and a tape measure, respectively (SECA Ltd, model 220, Germany). Body mass (kg) was recorded with a scale SECA (SECA Ltd, Germany) to the nearest 100 g, the subjects wearing light, indoor clothing and no shoes. The Body Mass Index (BMI) was calculated using the Quetelec formula: BMI = weight (kg) / height (m2).

Speed of Movement-Agility (using shuttle run 4 x 10-meter). This test is a variation of the shuttle run (10 x 5-m) test included in the EUROFIT battery (1993). The subjects had to run back and forth four times along a 10 m track at the highest speed possible. At the end of each track section, they had to step on the floor line. This allows measurement of not only speed of displacement, but also of agility and change of direction (COD). Two non-consecutive repetitions were carried out and the best attempt was recorded.

Lower body power (using standing broad jump). In the standing broad jump test, the subject had to push off vigorously and jump as far as possible trying to land with both feet together. The score is the distance from take-off line to the point where the back of the heel which is nearest to the land is. Two non-consecutive repetitions were carried out and the best attempt was recorded.

Sprints (5 and 10-meter sprint): Players have to run as fast as possible in both the 5 meter-sprint and the 10 meter-sprint, starting in a stationary position. Three attempts of each test were performed and the best of them was recorded. Two photoelectric cells Eleiko Sport MAT RS 232 (United Kingdom) were used to record the times of the 5 and 10-meter sprint tests.

Second day's Tests:

Cardiorespiratory fitness (20-meter shuttle run test or Bleep test) (Léger et al. 1984). In this test, the initial speed is 8.5 km/h, which is increased by 0.5 km/h per min (1 min equals one stage). The subjects run in a straight line, to pivot upon completing a shuttle, and to pace themselves in accordance to audio signals given. The test is finished when the subject stops or fails to reach the end lines concurrent with the audio signals on two consecutive occasions. The equation of Léger and Gadoury (1989) was used to estimate the maximum oxygen uptake (VO2max):

VO2max = 20.6 + Last stage completed x 3

Furthermore, the equation of Léger et al. (1984) was used to estimate the maximum oxygen uptake (VO2max) considering the player's age:

VO2max = 31.025 + 3.238S – 3.248A + 0.1536SA

where A is the age (years) and S refers to the final speed (S = 8 + 0.5 x Last stage completed).

Statistical Analyses

Descriptive statistics were performed for all the variables in order to check for the assumptions of normality. Mean ± standard deviation of the data was calculated. Normal distribution and homogeneity of the parameters were checked with Shapiro–Wilk, and Levene's test. The statistical differences were assessed using Student's t test. A P value of 0.05 or lower was considered as being statistically significant. An analysis was performed using SPSS version 16.0 (Chicago, IL, USA).

Results

All the variables were normally distributed. Levene's test showed no violation of homogeneity of variance. The general group characteristics were the following: they were aged 18 ± 2, had a Body Mass Index (BMI) of 23.22 ± 1.46, a mass of 69.84 ± 7.54 kg, and a height of 1.73 ± 00.4m. The anthropometric results for each female basketball team participating in this study are presented in Table 1. Height, weight, BMI, and arm span became higher as the level of the teams increased. Consequently, the higher the level of the team is, the higher the value of those variables is for their players. The same is true for the age values, which experienced a similar progression, with the exception of the U20 GB Team, obviously due to the competition rules. Table 2 shows all the fitness test results. Flexibility tended to decrease as the team's level increased, although statistical differences were not found. The players improved their performance in the Agility and Standing Broad Jump as the team's level increased. Statistical differences were found between groups (Table 3). Finally, cardiorespiratory fitness showed a slight tendency to improve as the team's level became higher, but statistical differences were not observed.

Table 2. Fitness test results of each group of female elite basketball players (n= 79).

Team	Flexibility (m)	Agility (s)	10m Sprint (s)	5m Sprint (s)	S.B. Jump (m)	Bleep Test (stages)	VO2max ($ml.kg.min^{-1}$)	VO2max ($ml.kg.min^{-1}$)*
U20 GB	-	10.28 ± 0.40	-	-	-	7.92 ± 1.12	44.37 ± 3.35	43.61 ± 3.41
Senior I	0.06 ± 0.07	10.18 ± 0.50	2.23 ± 0.13	1.31 ± 0.08	1.96 ± 0.2	8.19 ± 1.39	45.18 ± 4.17	42.01 ± 4.46
Senior II	0.08 ± 0.08	10.55 ± 0.44	-	-	191 ± 0.21	7.53 ± 1.27	43.18 ± 4.04	43.17± 6.06
U18	0.09 ± 0.07	10.63 ± 0.45	-	-	1.90 ± 0.21	7.35 ± 1.36	42.64 ± 4.60	45.13 ± 4.49
U17	0.07± 0.06	11.68 ± 0.70	2.67 ± 0.1	1.47 ± 0.07	1.71 ± 0.22	7.54 ± 1.64	43.22 ± 4.91	46.73 ± 5.19

* This value has been calculated using an equation which considers the basketball player's age.

Table 3. Statistical differences between teams in the Agility and Standing Broad Jump (Student's *t* test)

Agility	U17	U18	Senior II	Senior I	U 20GB
U17	-	0.000	0.000	0.000	0.000
U18	-	-	0.352	0.024	0.041
Senior II	-	-	-	0.025	0.057
Senior I	-	-	-	-	0.253
U 20GB	-	-	-	-	-
S. B. Jump	U17	U18	Senior II	Senior I	
U17	-	0.025	0.005	0.002	
U18	-	-	0.318	0.146	
Senior II	-	-	-	0.250	
Senior I	-	-	-	-	

Discussion

Anthropometric variables

All the anthropometric variables (age, height, weight, BMI, and arm span) showed a tendency to go up as the team's level increased. After having analysed each group, U17 obtained a similar age and slight higher values of height, weight and BMI than those found by Bale (1991) in the U17 England Team. With regard to the U18 Team, their values were similar than those given by Greene et al. (1998) (166.19 cm) and Tsunawake et al. (2003) (166.5 cm) for high school players aged 16.02, and 17.06 years old, respectively, and higher than those observed by Koley and Singh (2003) (160.32 cm) in inter-university Indian basketball players. The Senior II Team had values (1.7m) higher than the U18 Team, but lower than those of the Senior I Team (1.74m). However, these results were lower than the values given by Salgado-Sánchez et al. (2009) regarding Spanish first (1.83m) and second (1.80m) division players and in the same line as third division (1.75m) players. Basinac et al., (2009) also showed higher heights in players from Bosnian first league teams (1.78m). On the contrary, the values of the Senior I Team were similar to Greek elite basketball players from second division (1.75m) (Bayios et al., 2006) and to those found in 4 top-ranking teams of the England National League Division II (1.75m) (Delextrat and Cohen, 2009). Also, Fernández-Río et al. (2000) obtained similar values in second division Spanish players (1.74m), and so did Narazaki et al. (2009) in NCAA division II players. Lastly, Hopper (1997) and Drinkwater et al. (2007) observed similar values in Australian netball players (1.74m) and state basketball players (1.74m), respectively. Finally, the U20 GB Team had values lower than those found by Nunes et al. (2008) in the Brazilian National Team that participated in the 2004 Olympic Games (1.83m), and similar values to those found by Carter et al. (2005) in 14 teams in the Women's World Basketball Championships, Australia 1994 (1.8m). Cook et al. (2004) and Drinkwater et al. (2007) also obtained lower heights in Australian elite or national junior basketball players (1.78m and 1.78m, respectively) with the same age than our players. Similarly, Payne et al. (1997) showed lower values (1.77m) in college varsity players.

Regarding weight, the U17 Team showed a slightly higher weight than the values of the U17 England Team, according to Bale (1991). The U18 and Senior II Teams obtained very low values, compared with other European Leagues (due to the former's low height). The Senior I and the U20 GB Teams showed the highest weight. Only Salgado-Sánchez et al. (2009) obtained higher values, although that was just in Spanish second division players. Besides, taking into account the players' BMI value (21.59, 22.60, 22.38, 24.67 and 24.88), some Teams (Senior I and U20 GB) were very close to the overweight zone (25), and the other teams (U17, U18 and Senior II) had values too elevated and not recommended to play basketball at high level. The arm span is a very important parameter for basketball players. Most of the coaches want to have players with a large arm span, since it is an advantage when it comes to stealing the ball, catching a rebound or doing a deflection. Nevertheless, there are not many studies (Ackland et al., 1996 and 1997) that show a benchmark for this parameter in spite of the great importance that it bears for the basketball. In this study, it can be seen that the arm span, like the height, the weight and the BMI, increases as the team's level goes up due to the growing effect. The values found (1.67, 1.69, 1.77m respectively) in the different teams in this study regarding the arm span values are lower than the values observed by Ackland et al. (1996 and 1997) before the Women's World Basketball Championships that was held in Australia in 1994. This, together with the low height and the elevated weight, and BMI, shows that these players did not possess the most appropriate body composition factors for the practice of high level basketball (Ziv and Lidor, 2009) in the future (i.e. World Championships, Olympic Games, European Championships or first division teams in countries such as U.S.A, Australia, Russia, Spain, or France where female basketball has a very good level).

Fitness level

Flexibility showed a tendency to decrease as the teams' age became higher. The inverse development of flexibility as we grow older is widely known (Delgado-Fernández et al., 1997; Alter, 1998; Ruiz Pérez, 2004; Berdejo-del-Fresno and González-Ravé, 2010), and is the only physiological capacity that shows regression as physical development progresses. Despite being a positive number, the flexibility value obtained in the players that participated in the present study (0.07, 0.9, 0.08, 0.06m respectively) does not show an outstanding result, and could perfectly be classified as normal (Merino et al. 2011) and lower than the result obtained by Cook et al. (2004) (12.33 cm) in Australian elite junior players. Special attention should therefore be paid to the flexibility training with the aim to improve performance in the long term (Berdejo-del-Fresno, 2008). The application of a static stretching protocol in the warm-ups and cool-downs during a whole season has proved to result in long-term significant improvements of flexibility without worsening the improvements obtained in speed of movement-agility and lower body power (Berdejo-del-Fresno, 2009). Regarding the speed of movement-agility test, there have not been found any other studies that involve basketball players and make use the same test (4x10 m shuttle run) to measure the speed of movement and the coordination in an integrated way (Ruiz et al., 2006). However, this test is a good way to measure the basketball player's ability to make changes of CODs similar to those performed in a basketball game. The results in this study showed a clear improvement of the performance as the teams' level and age increased. The two best results obtained (10.18 – 10.28 s) (Senior I and U20 GB Teams) in this study were similar with to the value obtained by Berdejo-del-Fresno (2008) in relation to Spanish male junior basketball players at the beginning of the season (10.13 s). Jones et al. (2009), in the same line than Graham-Smith and Pearson (2005), suggested that, for basic improvements in COD and speed, athletes should seek to maximise their sprinting ability and enhance their eccentric knee flexor strength to allow effective neuromuscular control of the contact phase of the COD and speed task. Finally, Graham-Smith et al., (2009) added that the penultimate contact plays a significant role in deceleration when changing direction, i.e. greater braking forces in the penultimate contact are associated with faster agility times. Therefore, if basketball players wish to improve their agility capacity, they will have to work on their sprinting ability, eccentric knee flexor strength, and their body position before turning.

The speed tests (5 and 10-meter sprint) could only be performed in two teams: the U17 and the Senior I. The results have shown that the basketball players in this study are slower than those participating in other studies studies. Mikolajec et al. (2003) analysed the Under 17 Women Polish Basketball Team and found times in the 5-meter sprint of 1.26 s in the 5-meter sprint at the beginning of the camp and a time of 1.18 s six weeks after, compared with 1.47 s in the U17 Team (same age) and 1.31 s in the Senior I team. Jones et al. (2009) also obtained better times in 33 university student physically actives with a background in several sport (1.08 s). In relation to the other speed test (10-meter sprint), Vaquera et al. (2000) analysed a male junior team with a 10-meter sprint test and a 10-meter sprint test integrated in a court training. The results that they obtained were 1.9 and 1.96 s, respectively. Vaquera et al. (2003) reported values of Spanish first and second division basketball players in the 10-meter sprint. First division players (1.70 s) were slower than second division basketball players (1.66 s). In the same study (Vaquera et al., 2003); guards and forwards were quicker (1.66 s) than centres (1.72 s). Also, guards were found quicker than centres in both teams (Senior I and U17) in this study (Table 4). Finally, Cook et al. (2004) found in Australian elite junior players times of 1.91 s for women and 1.76 for men. Despite the fact that some of the above mentioned studies showed values corresponding to young or male sportsmen, the difference between their and the values in this study is considerable. Thus, it is clear evidence that the basketball players that took part in the present study need to work harder on their speed.

Table 4. Positional differences in the speed tests.

TESTS	Senior I		U17	
	Guards	Forwards/Centres	Guards	Forwards/Centres
n	7	7	9	8
5m Sprint (s)	1.27 ± 0.07	1.35 ± 0.07	1.44 ± 0.07	1.50 ± 0.08
10m Sprint (s)	2.15 ± 0.08	2.30± 0.12	2.61 ± 0.09	2.73 ± 0.08

In relation to lower body power, the standing broad jump test showed a clear performance improvement as the teams' level and age increased. However, the best value obtained in the Senior I Team (1.96cm) was a poor performance similar to that of Indian boys aged 13-14 years (1.88 - 2m) (Singh et al., 1987) and obviously lower than that observed in male sportsmen (Silla and Rodríguez, 2005; Dood and Alvar, 2007). Even the value performed by the U17 Team 1.71m was lower than that found by Berdejo-del-Fresno (2010) and Berdejo-del-

Fresno et al. (2010) in Spanish highly trained female young tennis players (aged 11 years old) (1.74m). Thus, despite the fact that agility, speed and lower body power progressively improved from U17 to Senior level, those improvements may have not been caused by the effect of training (see Training Sessions/Week in Table 1). They were basically produced by the maturation effect, since the best explosive strength performance is caused by two fundamental factors: first, the inter- and intra-muscular coordination developed with the training; and second and most importantly, the hormonal increase that is produced during the puberty, which provokes an increase in strength due to higher muscular hypertrophy (Delgado-Fernández et al., 1997). This means that, with the final aim of developing explosivity and power jump, plyometrics training and coordination training should be applied, for it has been proved that there is an important relationship between leg strength, jump capacity, speed and agility on playing time at elite level (Hoffman et al., 1996; Taylor, 2004; Ziv and Lidor, 2009). The values of maximum oxygen uptake (VO2max) obtained through the different formulas (Table 2) for the different teams were lower than those indicated by other authors: Vaccaro et al. (1979): 49.6 ml/min/kg; Riezebos et al. (1983): 50.1 ml/kg/min; Dal Monte et al. (1987): 49.6 ml/kg/min; Joussellin et al. (1990): 51.1 ml/kg/min; Smith and Thomas (1991): 51.3 ml/kg/min; Hakkinen (1993): 48 and 47 ml/kg/min; Franco (1998): 50.36 ml/kg/min; Fernández-Río et al. (2000): 46.6 ml/kg/min; Tsunawake et al. (2003): 56.7 ml/kg/min; Koley and Singh (2010): 46.54 ml/kg/min. The VO2max values that were obtained from the different formulas showed statistical differences between the VO2max calculated with the equation that considers age and that which does not consider this parameter. This is the reason why new specific tests have been developed for their use in each of the sport. TIVRE-Basket (Morante et al., 2003) is a specific test which has been designed to be used in basketball and has proved a useful way to measure the aerobic capacity and recovery capacity of the basketball player (Vaquera et al., 2007). Given that non-specific tests like the Bleep test and the Yo-Yo test have showed similar results, it is highly recommended to make use of a specific test in order to measure VO2max and aerobic endurance.

To sum up, if British basketball wishes to reach an international level it is recommended that a higher number of training sessions is performed during the week, as well as specific fitness, tactical and technical sessions, since some of the teams (e.g. U17) have players who only practise once a week (mean: 2.47 days per week plus game), and none of the teams perform fitness sessions during the season despite their proved benefits (Javorek, 1995; Jukic et al., 1999; Marlow, 2001; Trninic et al., 2001; Jukic et al., 2005; Drinkwater et al., 2005; Berdejo-del-Fresno et al., 2008).

Conclusions

In the present study it has been demonstrated that British basketball players have fitness level and body composition values lower than other high level teams from countries where basketball is more popular and better developed. With regards to body composition, the players participated of this study were smaller and heavier than those of first division teams, and similar to those of second division. They showed the highest values of BMI and Body Fat (%), these being counter-productive in the high level. As for the fitness level, the players in this study showed a low flexibility, speed, power and maximum oxygen uptake (VO2max) values, but average agility (except U17 Team) results. Finally, it must be said that the role of an S&C coach as part of the technical staff is essential and highly recommended if the aim of a team is to reach high level competition.

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Original research

The impact of playing position and level on the fitness characteristics of female soccer players

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KEY WORDS

Soccer
Playing position
Playing level

ABSTRACT

Football can be classified as an aerobic or endurance sport encompassing short periods of intense anaerobic activity throughout the ninety minutes of a game. The demands placed on a player during a game therefore require them to be proficient in a range of fitness components such as aerobic and anaerobic power, speed and agility, and a these demands may vary between different playing positions and levels. The purpose of the current study was to examine the effect of playing position and level on the fitness levels of female soccer players. Thirty two open age (16+) professional and semi-professional female soccer players completed tests for aerobic endurance, speed, and agility. Two factor ANOVA indicated an effect for differences in playing level for the Yo-Yo Intermittent Endurance Test (YIET) ($F = 22.52$, $P < 0.01$) and the Balsom Run ($F = 5.7$, $P < 0.05$). No effects for differences in playing position were found, and there were also no interaction effects between playing level and position. Bonferroni Post-Hoc follow up tests indicated significant differences between the National and Regional ($P < 0.05$), and National and County ($P < 0.01$) playing levels for the YIET. These differences were due to the better performance of the National level players in comparison with both the Regional and County level players. For the Balsom Run, a significant difference ($P < 0.05$) was found between National and County playing levels, with the National level players performing better than the County level players. The results of the current study suggest that playing position has no effect on aerobic endurance, speed and agility for female soccer players. However higher levels of aerobic endurance and greater agility may be required to perform at the National playing level.

Football can be classified as an aerobic or endurance sport encompassing short periods of intense anaerobic activity throughout the ninety minutes of a game (Svensson & Drust, 2005). The majority (85%) of a game involves low intensity activity (60% walking, 25% jogging), 10% of a game involves high intensity activity (6.5% running, 2.0% high speed running and 0.5% sprinting), whilst approximately 5% of time is spent standing still (Bradley et al., 2009). The duration of each sprint tends to be short, with approximately 50% of sprints being shorter than 10m and approximately 95% of sprints being less than 30m (Stolen et al., 2005). It has also been reported that there are approximately 1,400 changes of activity and direction during the course of a game (Krustrup et al, 2005). The demands placed on a player during a game therefore require them to be proficient in a range of fitness components such as aerobic and anaerobic power, speed and agility, and a these demands may vary between different playing positions and levels (Svensson and Drust, 2005). The current study examined the effect of playing position and level on the fitness levels of female soccer players. Differences in the demands placed on different playing positions and levels have been reported in relation to several aspects of the game. For example, the average distance covered by male Premier League players during a game is approximately 11km (Rienzi et al., 2000; Bradley et al., 2009), but significant differences between playing positions have been reported. Wide midfielders and central midfielders may cover greater distances (11.5km) than central defenders (10km), full backs (10,7km) and forwards (10.3km). Wide midfielders also cover a significantly greater distance during high intensity and very high intensity running than all other positions (Bradley et al, 2009). Similar average distances covered during a game (10.5km) have been reported for elite professional female players (Mohr et al., 2008), with the same trends for differences between playing positions also observed in the female game (Mohr et al., 2008). These differences in the distances covered by players in different positions may result in these players exhibiting differences in physiological characteristics, with full backs and wide midfielders performing significantly better on tests of intermittent endurance performance such as the Yo-Yo Intermittent Endurance Test (YIET) (Carvalho et al., 2004).

In terms of the speed and agility of different playing positions there is contradictory evidence in the literature. Forwards may be required to cover a greater distance (520m) in high intensity running than both midfielders (430m) and defenders (330m) (Mohr et al, 2008). Perhaps unsurprisingly, it has

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therefore been suggested that male forwards are significantly faster than defenders and goalkeepers (Gil et al., 2007), with the same trend reported in female players (Vescovi et al., 2006). This trend has not always been reported however, with several studies with observing no difference in 30m sprint performance of male and female players of different playing positions (Coelho et al., 2007; Wells and Reilly, 2002; Todd et al., 2002). Forwards have been found to be significantly more agile than other playing positions (Gil et al., 2007), and a similar trend was found by Vescovi et al. (2006) who reported that goalkeepers and defenders had lower performance levels on two measures of agility than both midfielders and forwards. In addition to the differences reported between playing positions, the Characteristics of football players have been shown to differ depending on their playing level. For example, elite players may demonstrate significantly better aerobic and anaerobic endurance in comparison with sub-elite players (Metaxas et al., 2000; Dunbar and Treasure, 2005), and this results in elite players covering greater distances at a greater intensity during match play (Mohr et al., 2003). This ability to cover greater distances at a higher intensity is important for football performance and may be the most notable difference between elite and non-elite players (Bangsbo et al, 2006). This is because, although most game time is spent in low intensity activity, it is the high intensity activity that occurs at crucial times during the game (Carvalho, 2004). This has been illustrated by Mohr et al., (2003) who reported that International level players cover a 28% greater distance in high intensity running than lower level professionals (2.43km and 1.9km respectively) and a 58% greater distance sprinting (650m and 410m respectively). It has also been suggested that agility performance can differentiate between elite and non-elite players, and may be the most important factor in distinguishing between selected and non-selected midfielders and forwards (Gil et al., 2007).

Methods

Participants

Thirty two (n=32) open age (16+) female soccer players with a mean age of 21 ± 5 years volunteered for this study. All participants played for one of three teams at the same club. Team one (N) (N = 15, age 25 ± 4yrs), is entered in the FA Women's Premier League Southern Division, team two (R) (N = 5, age 22 ± 6yrs) plays in the South West Regional Premier Division and the third team (C) (N = 12, age 17 ± 2yrs) plays in the Somerset FA Division 2 County league. These Leagues are ranked at steps 2 (National), 4 (Regional) and 6 (County) respectively on the on the Football Association Women's Football Pyramid. Players were also divided into five groups based on playing position; full-backs (N = 6), central defenders (N = 7), wide midfielders (N = 7), central midfielders (N = 7), and forwards (N = 5).

Procedures

Aerobic endurance (Yo-Yo Intermittent Endurance Test), speed (30m sprint test), and agility (Balsom Agility Run) were assessed during two testing sessions. Prior to testing, all participants completed a 15 minute standardised warm up consisting of gentle jogging, changes in pace and direction and a variety of dynamic stretches. All sprint and agility times were recorded using Brower PhotoGate infrared timing gates.

Yo-Yo Intermittent Endurance Test (YIET) - Level Two

Marker discs were positioned 20 metres apart, with additional markers 2.5m behind the 20m markers. Participants were required to run back and forth (2 x 20m) in time with an audible "beep". At the end of the 40m run (1 'shuttle'), participants either walked or jogged slowly 2.5m around the additional markers back to the start point within 5 seconds. At this point the participants stopped and waited for the signal for the start of the next shuttle. The speed of the shuttle runs progressively increased throughout the test, starting at 11.5 km/h, and participants were given a warning if they did not reach any line of markers on time. The test was terminated when a participant could not follow the set pace of the "beeps" on two separate occasions and/or stopped voluntarily. The total distance covered (i.e. 40m x number of completed shuttles) was reported as the subject's performance measure in the YIET.
(Bangsbo, 1994).

30m Sprint Test

Marker disks were positioned 30m apart, with a 'run-off' zone at the end of the 30m. Participants were instructed to start two paces behind the disks at the start line, and to sprint at full speed through the finish line. Participants completed three trials with two minutes between trials, and the average time was recorded.

Balsom Agility Run

The agility test followed the protocol outlined by Balsom (1990). Participants completed three trials with two minutes between trials, and the average time was recorded. It should be acknowledged that the Balsom Run requires participants to follow a pre-defined course, and does not include a decision making, cognitive component. The protocol therefore assesses the change of direction speed component of agility

Statistical Analysis

The Statistical Package for Social Sciences (v16.0; SPSS, inc., Chicago, IL, USA) was used for statistical analysis. Mean and

SD were calculated for each of the tests. Two-factor ANOVA and Bonferroni Post-Hoc follow-up tests were used to examine the differences in the characteristics of the paying positions and levels

Results

Two factor ANOVA indicated an effect for differences in playing level for the YIET ($F = 22.52$, $P < 0.01$) and the Balsom Run ($F = 5.7$, $P < 0.05$). No effects for differences in playing position were found, and there were also no interaction effects between playing level and position. Descriptive statistics for the fitness test results of the different playing positions and levels are shown in Table 1. Bonferroni Post-Hoc follow up tests indicated significant differences between the National and Regional ($P < 0.05$), and National and County ($P < 0.01$) playing levels for the YIET. These differences were due to the better performance of the National level players in comparison with both the Regional and County level players. For the Balsom Run, a significant difference ($P < 0.05$) was found between National and County playing levels, with the National level players performing better than the County level players.

Table 1. Descriptive statistics for the battery of fitness tests for the professional and semi-professional players

	National	Regional	County	Full Backs	Central Defenders	Wide Midfield	Central Midfield	Forwards
YIET(m)	3405 ± 735*+	2280 ± 778*	1630 ± 671+	2653 ± 1322	2240 ± 928	2370 ± 905	2982 ± 1379	2650 ± 1006
30m Sprint(s)	4.59 ± 0.32	4.61 ± 0.36	4.79 ± 0.29	4.6 ± 0.32	4.82 ± 0.31	4.62 ± 0.2	4.64 ± 0.35	4.58 ± 0.51
Balsom Run(s)	11.03 ± 0.6#	11.55 ± 0.59	11.81 ± 0.68#	11.44 ± 0.7	11.52 ± 0.71	11.58 ± 0.52	11.21 ± 0.81	11.55 ± 1.68

* Significant difference between National and Regional ($P < 0.05$)
+ Significant difference between National and County ($P < 0.01$)
# Significant difference between National and County ($P < 0.05$)

Discussion

This study examined the effect of playing position and level on the fitness levels of female soccer players. Significant differences between playing levels were observed for the aerobic endurance and agility, but not for 30m sprint speed. In terms of aerobic endurance this was due to the better performance of the National level players in comparison with both the Regional and County level players, whilst for agility this was due to the better performance of the National players in comparison with the County players. The greater aerobic endurance exhibited by the National level players was in line with the trend reported by Metaxas et al. (2000) and Dunbar and Treasure (2005), and may be a result of the greater distances covered at higher intensity by the elite players (Mohr et al., 2003). These results may suggest that a higher level of aerobic endurance is required to perform at the National level of the Football Association Women's Football Pyramid, and that the YIET is able to differentiate players from different levels in the Women's Football Pyramid. The higher levels of agility of the elite players observed in this study has also been reported by Power et al. (2005), and suggests that agility performance may be a predictor of selection (Gill et al., 2007) at the National level of the Football Association Women's Football Pyramid. These results also suggest that the Balsom Run is able to differentiate players from different levels in the Women's Football Pyramid. No significant differences in 30m sprint time were found between the playing levels, and similar results were reported by Todd et al. (2002). These results suggest that 30m sprint time is not able to differentiate between playing levels, and it has been suggested that 10m sprint times may be better able to differentiate between elite and sub-elite players (Chamari et al., 2004).

No significant differences were found between playing positions for the YIET, 30m Sprint Test, and Balsom Run in this study. In terms of the YIET, these results contradict the study by Bangsbo and Michalsik (2002), who reported that central midfielders and full-backs performed significantly better than forwards and central defenders on the YIET. However, a similar trend was observed in this study, with central midfielders and full backs achieving the highest YIET scores (2653m and 2982m respectively), and this may be attributed to the greater distances covered by these positions during a game

(Bradley et al., 2009). The 30m sprint times in this study are similar to those reported for players of a similar standard by Todd et al. (2002), with forwards achieving the fastest times. Whilst some studies have previously reported that forwards are more agile than other playing positions (Gil et al, 2007), this was not the case in this study. It would therefore appear that higher levels of aerobic endurance, sprint speed, and agility are not required for different positions in female soccer at the playing levels used in this study, and the demands placed on players in different positions at these levels may be relatively homogenous.

Conclusions:

The results of the present study suggest that playing position has no effect on aerobic endurance, speed and agility for female soccer players. However higher levels of aerobic endurance and greater agility may be required to perform at the National playing level.

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Original research

Acute affects of dynamic and static stretching on vertical jump performance

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KEY WORDS

Static stretching
Dynamic stretching
Power
Vertical jump
Force plate.

ABSTRACT

Static stretching (SS), as an effective means of injury prevention, has recently come under scrutiny, with dynamic stretching (DS) seemingly appearing to be slowly replacing it in warm up protocols. The purpose of this study was to investigate the acute effects of DS and SS on power output measured by vertical jump performance (VJP) using a force plate. Thirty recreational athletes, 16 female (height = 1.74 ± 0.08m, mass = 72 ± 7kg, Age = 21 ± 1yrs) and 14 male (height = 1.8 ± 0.07m, mass = 89 ± 20kg, age = 21 ± 1yrs) completed the DS, SS or control protocol with pre-testing and post-testing of their VJP. DS and SS interventions were used in accordance with the American College of Sports Medicine (ACSM) guidelines. Despite an 11% decrement in VJP pre- (0.37±0.1m) and post- (0.33±0.08m) SS, this was not significant (p>0.05). Similarly, despite a >14% increase in VJP pre- (0.32±0.07) and post- (0.36±0.06) DS this was also not significant (p>0.05). The control group also experienced a small, but non-significant (p>0.05), increase in VJP of 2.83% from pre- (0.36±0.06) to post- (0.37±0.06) measures, attributable to normal fluctuations in performance. There were no significant changes in VJP and nothing could be directly inferred from these results as the range of VJP scores was very large. The large VJP range raises issue of the muscles sensitivity to stretching and was postulated as a possible contributor to mixed results throughout the literature.

It is important for Sports Therapists to understand stretching modalities, their effects on power output and subsequently their use and placement within a training regime (Weerapong et al., 2004). Static stretching (SS) is a sustained hold at the point of discomfort (American College of Sports Medicine, 1998), whereas dynamic stretching (DS) is a controlled agonistic movement through range of motion (ROM) (Chattong et al., 2010; Weerapong et al., 2004). Stretching is utilised by many athletes as a means of increasing range of motion (ROM), with the rationale that it has the potential to reduce injury risk (Small et al., 2008); though hypoflexibility has been shown to increase the risk of musculotendinous injury (Malliaropoulos, 2011). Studies have shown that SS increases ROM (Amako et al., 2003; Bandy et al, 1998; Ford and McChesney 2007; Meroni et al, 2010; Radford et al., 2006; Small et al., 2008). However other studies have shown that SS can temporarily reduce power output (Babault et al., 2010; Power et al., 2004; Yamaguchi et al., 2007) by up to 30% (Young and Behm, 2002) for up to one hour (Fowles et al., 2000). As power output is essential to success in some sports (Burr et al., 2007), traditional SS immediately before exercise may be detrimental to power performance possibly via neural inhibition reducing contractile potential (Sekir et al, 2010). Using SS supplementary to training, in order to achieve long-term increases in ROM thereby decreasing musculotendinous injury risk, is supported by moderate evidence throughout the literature (Small et al., 2008). This may allow for ROM training to be incorporated into a regime without causing performance decrements.

While DS has been gaining popularity, as it has been found to increase power output measures from Isokinetic force (Yamaguchi et al., 2007), the gains may not translate to gains in vertical jump performance (VJP) (Jagger et al., 2008). The mechanisms are currently unknown; neural excitation, reduced antagonist inhibition, increased deep muscle tissue, post activation potentiation (PAP) or a combination of these have all been proposed (Robbins, 2005; Sale, 2002); therefore hastily calling for drastic alterations in training may be premature. Before any new consensus is formulated, the effects of SS and DS should be compared to uncover their logical placement within training for optimal performance as per recommendations (Weerapong et al., 2004). The use of VJP as a power output measure is recommended due to its greater ecological validity than peak torque (Jagger et al., 2008) and is widely respected as a valid and reliable power measure; consistently reporting r values of 0.89-0.93 (Aragon-Vargas 2000; Caruso et al., 2010; Sayers et al., 1999; Menzel et al., (2010), found that a contact plate, similar to the current measure, had an intra-class correlation of 0.97, showing VJP to be an excellent measure of power. However, a gap exists in the literature concern--ing comparative studies investigating the

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effect of SS and DS on power output (Weerapong et al., 2004). This study did not measure any injury related variables or attempt to investigate injury risk; rather it aimed to investigate the effects of stretching techniques on power performance. Therefore, the purpose of this study is to investigate the acute effects of SS and DS techniques on power output measured by vertical jump.

Methods

Following approval from the Teesside University ethics board, Thirty (n=30) recreational athletes, 16 female (height = 1.74 ± 0.08m, mass = 72 ± 7kg, Age = 21 ± 1yrs) and 14 male (height = 1.8 ± 0.07m, mass = 89 ± 20kg, age = 21 ± 1yrs) agreed to take part in this study. All participants had no experience of sports which include regular jumping, in order to control for different levels of expertise being studied simultaneously. All participants completed medical questionnaires and gave informed consent and indication of no current injuries. Participants were randomly assigned into one of three groups; SS, DS and control. Both dynamic and static procedures were performed for 90 seconds on the respective muscle groups with 5 second rests between stretches. The timing of the protocol was monitored with a stopwatch. The same timing was used for both conditions to ensure uniformed timing. All stretches were demonstrated to the group and all participants verbally confirmed their understanding of the technique.

Static Stretching Protocol

All SS were performed to ACSM guidelines. 3 sets of 30 seconds stretches held at the point of mild discomfort with 5 second breaks between each stretch. Stretches were performed in the following order. Kneeling Lunge; with one knee on floor and other leg in front. The heel of the front leg touched the floor and with a straight back the participant then leaned forward and repeated for other leg. Standing knee flexion; the participant held the ankle and pulled the knee into flexion as though the participant was pulling heel to bottom, while leaning against a wall for balance, and repeated for the other leg. Sit and reach; participant sat down and flexing the hip only (no lumbar flexion) reached for their toes and pulled into further hip flexion. Knee extension Lying supine; the participants raised their hips to 90 degrees, and pulled the knee with their arms into extension, to straighten them out.

Dynamic Stretching Protocol

All DS were performed for 3 sets of 30 repetitions on each leg at a moderate pace, described at 60% of maximal speed. Heel kicks; while jogging in a straight line they kicked the heel to the bottom. Pull back phase of a kick; while stood on the spot they pulled the leg back as far as possible, similar to the preparation phase of kicking a soccer ball. High kicks; with a straight knee kicked as high a possible on the spot. High knees; while jogging in a straight line, allowing the knee to flex the participants raised their knees as high as possible.

Control group

The control group rested for the length of the stretching protocols in a seated position.

Vertical Jump Performance Measurements

Jumping performance was measured using the Kistler 9821CA (Kistler Instrument AG Winterthur, CH- 8408 Winterthur, Switzerland), using Bioware (version 3.2.5. Build 16) to calculate peak height. The sampling frequency used was 250 MHz and data was collected over 4 seconds allowing for collection of 1000 data points. Participants performed three initial jumps for the pre-test after a demonstration of jumping technique and one practice jump. All jumps were counter movement; bending knees to approximately 90 degrees, keeping hands on hips throughout the technique. After achieving 90o of knee flexion participants were instructed to jump maximally and land in a comfortable manner. According to their assigned groups the participants received their treatments; they then performed the post test as soon as possible after wards; the maximum time before the repeat jumps being six minutes.

Statistical Analysis

A 3 by 2 Mixed Analysis of Variance (ANOVA) was performed using SPSS 18.0.2 stable release statistical analysis software. Mean, Standard deviation, Skewness and Kurtosis, minimum score, maximum score and range, to identify the similarity of the participants' expertise were used for descriptive statistics. All descriptive statistics were also calculated using SPSS.

Results

Despite an 11% decrement in VJP pre- (0.37±0.1m) and post- (0.33±0.08m) SS, this was not significant ($p>0.05$). Similarly, despite a >14% increase in VJP pre- (0.32±0.07) and post- (0.36±0.06) DS this was also not significant ($p>0.05$). The control group also experienced a small, but non-significant ($p>0.05$), increase in VJP of 2.83% from pre- (0.36±0.06) to post- (0.37±0.06) measures, attributable to normal fluctuations in performance. Multiple comparisons revealed no statistically significant differences. Levene's test for equality of variances was insignificant for pre-VJP ($p=0.387$) and post-VJP ($p=0.192$) showing that equality of variances was not significantly different, meaning that variance homogeneity is acceptable and the F-ratios are reliable. Mauchley's test of sphericity returned a significant result and so sphericity can be assumed. Box's test of equality of covariance matrices was insignificant (p>0.05), indicating equal covariance's and allowing the use of the Wilks' lambda test, which was returned as significant (P=0.004), meaning that it is very likely that the VJP score had changed across the pre-test to post-test. The effects size derived from Partial eta2 was 0.335; this is a very large effect size. Regardless multiple comparisons display no statistically significant differences using Tukey's Honestly Significant Difference. There were also no significant differences between or within participants' effects. There was no between or within participants' main effect.

Stretching Condition	Pre-test (m)	Post-test (m)	Difference (m)	Difference (%)
Static Stretching	0.37 ± 0.1	0.33 ± 0.08	- 0.04 ± 0.02	-11.31
Dynamic Stretching	0.32 ± 0.07	0.36 ± 0.06	0.04 ± 0.01	14.76
Control	0.36 ± 0.06	0.37 ± 0.06	0.01	2.83

Table 1

Discussion

The current study was designed to investigate the effects of SS and DS on power output measured by VJP. Results suggest that SS decreases VJP, while DS increases VJP, possibly through a reduction and improvement in neuromuscular performance respectively. However, despite observing the DS VJP 14.76% increase and SS VJP 11.31% decrease, the values themselves are small with SS VJP decreasing by -0.04m, and DS VJP increasing by 0.05m, which were not statistically significant. The reduction in SS group is similar to other findings in studies conducted in the recreationally active (Curry et al., 2009; Holt and Lambourne, 2008; Hough et al., 2009; Manoel et al., 2008; Young and Behm, 2003) and other measures of power output (Babault et al., 2010; Fowles et al., 2000; Kokkonen et al., 1998; Manoel 2008; Young et al., 2003) however they were all statistically significant and have quite different methodologies to the current, in some cases. Others have found there to be no effect on power output in the recreationally active Chaouachi et al., (2010) who found that after SS, DS and control VJP scores in height, force and power output scores were very similar when stretched; before, and to the point of discomfort (p < 0.05). Other studies have found similar alterations to the current study in DS VJP (Holt and Lambourne, 2008; Hough et al., 2009), and other power output measures such as peak force (Chaouachi et al., 2010) and maximum voluntary contraction (MVC) (Fowles et al., 2000). Others have reported that these did not translate to time losses during a sprint (Kistler et al, 2010). However Mcmillian et al, (2005) also found statistically insignificant improvements and reductions in DS and SS VJP scores respectively. This discrepancy between the results of previous studies and the current results may be due to stretching protocol time and intensity or participant expertise (Murphy et al., 2010).

The specific stretching protocol chosen for DS may also have affected the results obtained. Abbate et al. (2000) found that higher velocity contractions increased power output, whereas slower velocities had no effect. The current methodology used a sub-maximal moderate contraction velocity, described to the participants as 60% of their maximal velocity. This suggests that the current methodology may use a quick enough contraction velocity to evoke power output alterations, however the small gains in DS VJP may be due to the sub-maximal nature of the protocol. Studies have shown that DS protocols similar to the current study have increased EMG while simultaneously increasing power output (Hough et al, 2009), suggesting that neural excitation may contribute to VJP. Comparable PAP studies are sparse as most PAP studies use isometric contractions to evoke PAP. Muscle contraction type may affect the force frequency relation and at which range PAP occurs. During concentric contractions at high velocities, the force-frequency relation is farther to the right when compared with isometric contraction; to cause a given power output more contractions are required (Abbate, et al., 2000). Power performance requires a short maximal effort, and for all motor units to be required at maximal firing rates and patterns. While PAP may not be able to increase unloaded shortening velocities (Gossen and Sale 2000) it may be able to affect force development measures, such as time to peak force. Yamaguchi et al. (2005), found that DS decreased time to peak force using a high velocity and high frequency protocol. However, it must be noted that Jagger et al. (2008) used a similar protocol to Yamaguchi et al. (2005; 2007); they found that PAP's effects on time to peak force and MVC did not translate to VJP gains. These results suggest that if power output alterations are present they are insufficient to affect performance under full weight bearing load.

This study attempted to control for different levels of pre-test power output by using only recreational athletes of sports with no major power output required. However the range of scores was very large in pre-test throughout groups. The ranges within each group were very large indicating large differences in power production capabilities. These means were lower than the values obtained by Curry et al., (2009), who tested recreational women. So while it is likely that the target population of recreational athletes was attained, the ranges of scores highlight a need for deeper discussion. It has been reported among the literature that those with higher power outputs suffer more from the effects of stretching compared to those with lower scores (Gelen, 2010; Zakas et al., 2006). Therefore, it is likely that different participants were affected to a greater degree than others. This may explain the mixed results gained throughout the literature. Elite athletes have been shown to have stiffer muscles and due to this may perform better during power output tests via the stretch shortening cycle (Gerodimos et al., 2008) and a better capability to transfer muscular force to the insertion point (Wilson et al., 1992). A wide range of scores indicates a wide range of expertise within the recreational sub-group. This may have caused those with lower scores to suffer less from the effects of static stretching, and so have very similar VJP pre-to-post test scores (Gerodimos et al., 2008). Static stretching may have caused an acute increase in ROM (Ford and McChesney 2007) making the muscle less stiff and compromising its force translation capabilities (Wilson et al., 1992). This greater sensitivity to DS and SS seems true between elite level (Unick, 2005) and untrained individuals (Yamaguchi et al., 2004), but this cannot be certain for those of differing capabilities who identify themselves as recreational athletes according to Iyaguchi and Demrua, (2008). Only one force plate was available for testing, and sometimes several participants were tested immediately following each other, allowing time for the effects of the protocols to wear off slightly, however it should be noted that torque returned back to normal after 15 minutes in a study by Avela et al., (1999) and Fowles et al. (2000) found that VJP was still significantly decreased in the recreationally active for 5 minutes; the maximum time to testing being six minutes.

Conclusion

Results of the current study suggest that SS decreases VJP, while DS increases VJP when compared to a control group. However, this cannot be directly inferred due to a very large range of scores affecting statistical significance, and having scientific implications to trained muscle sensitivity to stretching protocols. However, it should be considered that despite the large range differences still occurred. There are many studies on the effect of SS duration on performance changes, but no such study for DS; it may be advisable to consider this for future studies. This study did not include ROM, measurements before testing; evidence has shown that muscle stiffness and ROM may affect VJP scores and the muscles sensitivity to stretching. It may also be advisable to use several measures of power output simultaneously; several force plates are capable of estimating peak power output as well as jump height, making it a practical suggestion. It may be advisable to also report the minimum and maximum scores obtained from power measures and ROM to help clarify the effects of expertise-score interactions. Alternatively it may be advisable to exclude and include participants based on pretest scores, or to group them accordingly. This study suggests that acute pre-activity SS stretching is not useful within a performance context, while DS, shown to increase vertical jump, and preliminary evidence shows it to be safe at the least, may become a useful alternative to SS. Other studies have shown that combining the two modalities has no useful effect, but it is beyond the scope of this study to conclude anything regarding combined techniques. However, DS may indeed be useful for pre activity warm ups.

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Case Study

Effects of vibration on disease activity scores in a patient with rheumatoid arthritis: a case study

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KEY WORDS

Rheumatoid Arthritis
Disease Activity Score
Whole Body Vibration
Exercise
Flexibility

ABSTRACT

Rheumatoid arthritis (RA) is a disabling disease characterised by chronic inflammation. Moderate to high intensity exercise is recommended for the management of RA, although this is not always achievable due to pain caused by local inflammation. Identifying the current status of the swollen, tender joints and the patient's perception of pain can be assessed using the 'disease activity score' (DAS28). Recently, vibration training has been shown to improve performance within healthy individuals, but has yet to be used in the treatment of RA. One female patient (age: 43yrs; height: 1.53m; mass: 48kg) with active RA was recruited for the current study. A sit and reach test was performed pre- and post- vibration. The DAS28 was recorded pre-, immediately post-, and 24hrs post- vibration. During vibration exposure, the patient performed three exercises (squat, lunge and calf raise), each for 30s with 60s recovery, at a frequency of 30Hz, and amplitude of 2mm. Results of the DAS28 showed no change in swollen joints 15 minutes post- vibration, but a reduction 24 hours post- vibration. There was no change in the number of tender joints 15 minutes post- training, but an increase 24 hours post- training. There was a 10% increase in the patient's perception of health 15 minutes post-training, with no change 24 hours post- training. There was also an increase (0.02m) in sit and reach test scores post- training. The current study suggests that a single bout of vibration training can have positive affects on patients' perceived health, flexibility measures, and potentially reduce factors contributing to inflammation. However, the increased joint tenderness post-vibration warrants further investigation, in a randomised controlled trial, to verify the effectiveness of vibration on inflammation and joint tenderness.

Rheumatoid arthritis (RA) is a chronic, disabling disease characterised by chronic inflammation, often resulting in progressive joint destruction and varying degrees of incapacitation (Rasker and Cosh, 1989). As a consequence of the disease and its treatment, RA sufferers are, compared with their healthy counter-parts, at increased risk of osteoporosis, significant muscle mass loss with subsequent increased fat deposition, and for cardiovascular morbidity and mortality (Metsios et al., 2008; Summers et al., 2010). Evidence is accumulating that intensive weight-bearing exercise improves the aerobic fitness and muscle strength of RA patients without any increase in disease activity (Häkkinen et al., 2001; Van den Ende et al, 1998: Westby, 2001; Munneke and Jong, 2000; Stenstrom and Minor, 2003; de Jong et al., 2003). One mode of exercise that has shown benefits in a range of populations, but has yet to be investigated with regards to RA, is whole body vibration (WBV). WBV is a mechanical stimulus characterised by a recurring motion back and forth over the same pattern. WBV presents a strong stimulus to musculoskeletal structures as a result of changes in muscle stiffness in response to the vibration; this in turn is believed to produce physiological adaptations, known as the tonic vibration reflex (TVR), to accommodate these vibratory waves (Hawkey, 2007). Since vibration training has been found to improve BMD and increase muscle mass in a diverse range of populations (Hawkey, 2007), it may be an effective intervention to combat these highly prevalent manifestations in RA. Therefore, the aim of this case study was to evaluate the effects of a single bout of WBV on symptoms of joint swelling, joint tenderness, perception of health, and flexibility in one RA patient.

Methodology

Following institutional ethics approval, one female participant (age = 43yrs; height = 1.53m; mass = 48kg) suffering from RA was recruited for the current study and completed an informed consent form and a physical activity readiness questionnaire (PAR-Q). For the assessment of disease activity the DAS28 (Van de Heijde et al, 1993) was used. The DAS28 consisted of a 28-joint count for the presence or absence of swelling, 28-joint count for tenderness, and patient assessment of general health (Pincus et al, 2003). The instrument

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produces a score from 100% (totally inactive disease) to 0% (very active disease). This assessment was conducted by a trained health allied professional with significant experience in these assessments. Following completion of the DAS28, the patient completed a three minute warm up on a Monark Ergomedic Bike at a steady pace in accordance with the American College of Sports Medicine (ACSM) guidelines (ACSM, 2000). Following this, the patient performed a range of motion (ROM) test following the exact validated ACSM guidelines (ACSM, 2000). After the familiarisation session and a demonstration of correct positioning, the participant performed three exercises on a NEMES Bosco vibration platform. Each exercise was performed for 30s, with a 60s recovery after each exercise. Where appropriate the patient used the handles on the platform for support. For each exercise the frequency was pre-set to 30 Hz, and the amplitude controlled at 2mm in accordance with Broekmans et al. (2010), as these frequencies and amplitudes respectively have been shown to illicit improvements in a variety of performance measures (Cochrane and Stannard, 2005; Hawkey, 2009a; 2009b; 2011; Wyon et al., 2010). The three exercises performed on the platform were the squat, lunge, and calf raise in accordance with Cochrane and Stannard (2005) and Shelton and Hynes (2005) respectively. After a recovery period of 5 minutes, the complete circuit was repeated once more. The participant was given a rest period of 15 minutes post- vibration training, where the DAS28 was re-assessed. The ROM (sit and reach test) was then reassessed. The DAS28 was also assessed again 24 hours post- vibration training.

Statistical analysis

There was no statistical analysis performed on the data collected for this study. Instead, evaluation of the descriptive statistics was undertaken. The three scores for swollen joints, tender joints and the patient's perception of health were calculated separately and given a total score to determine the

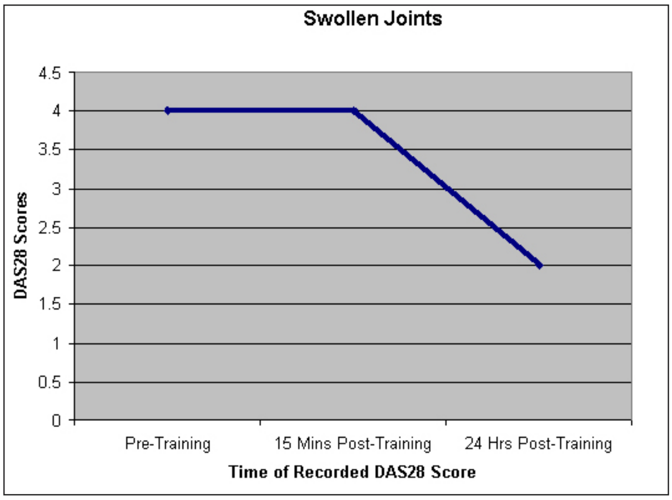

Figure 1. Swollen joints (DAS28 scores)

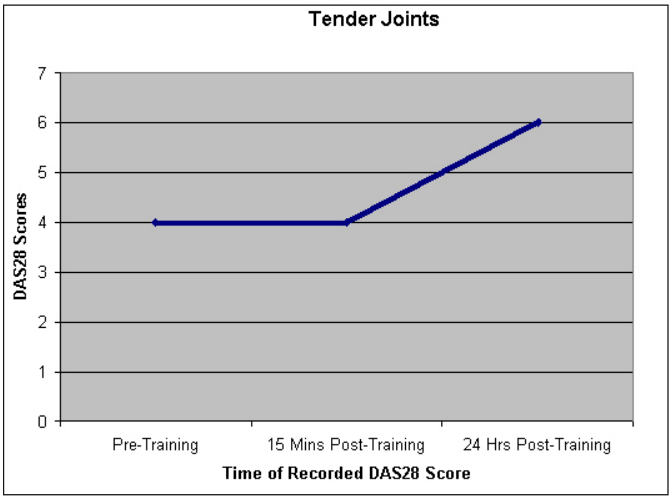

Figure 2. Tender joints (DAS28 scores)

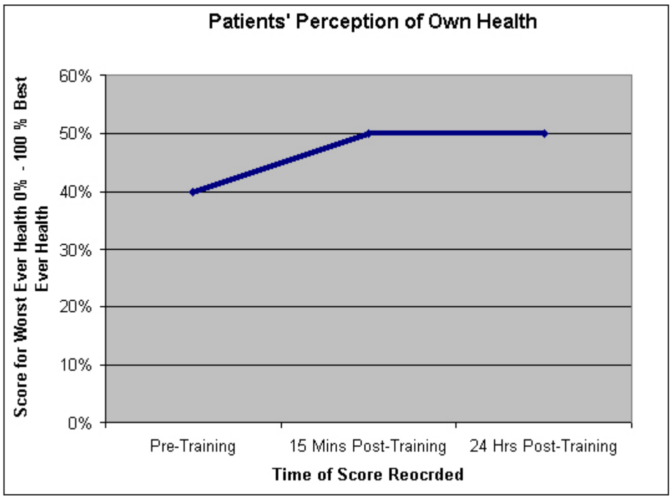

Figure 3. Patient perception of health (DAS28 scores)

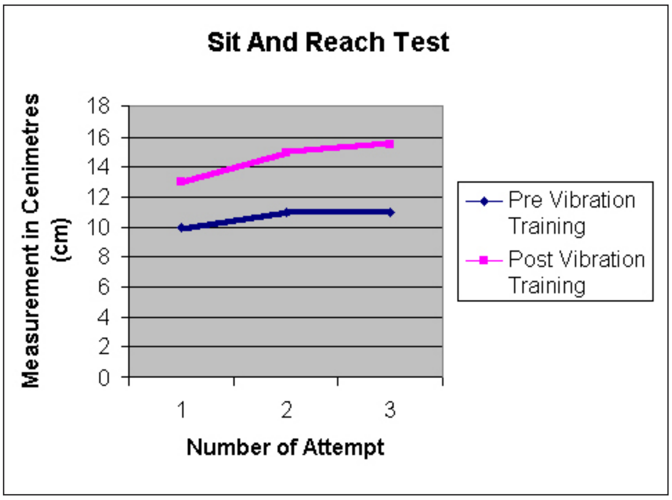

Figure 4. Range of Motion (sit-and-reach-test)

extent of disease activity. The sit and reach scores were analysed using Microsoft Excel.

Results

The results indicated no change in the number of swollen joints (DAS28 scores) 15 minutes post- training; however there was a decrease in the number of swollen joints 24 hours post- vibration training (Figure 1). The results also indicated no change in the number of tender joints (DAS28 scores) 15 minutes post- training; although there was an increase in the number of tender joints 24 hours post- training (Figure 2). The results indicated an increase in the percentage of the patients' perception of own health (from 40% to 50%), 15 minutes post- training, with no change in that percentage 24 hours post- training (Figure 3). The results also showed an improvement in ROM from pre- (0.11m) to post- vibration training (0.13m) (Figure 4).

Conclusions and Recommendations

Currently there are no studies investigating the effects of whole body vibration training in individuals with RA. Findings of the current study suggest that vibration training could be an effective exercise intervention in the management of the disease; including positive affects on patients' perceived health and flexibility measures. However, the increased joint tenderness post- vibration warrants further investigation. There is evidence demonstrating that vibration training may be an effective stimulus to improve both bone mineral density and fat free mass in different populations (Hawkey, 2007), two symptoms that are highly prevalent in RA (Metsios et al., 2008; Summers et al., 2010). Despite that our study demonstrates some benefits, the short-term effects of vibration on inflammatory load and functional ability has to be appropriately investigated using reliable equipment and appropriately designed trials, before this method of exercise could be formally introduced to this population.

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Original research

Biomechanical analysis of a single-limb flat squat versus a single-limb decline squat: implications for ACL injury prevention

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KEY WORDS

Squatting
Knee
Biomechanics
Rehabilitation

ABSTRACT

The motions of hip internal rotation, adduction, and knee valgus have been reported to increase strain on the anterior cruciate ligament in the female athlete. While strengthening programs attempt to eliminate these at risk motions, exercises are often performed by the athlete at the expense of poor body mechanics thus mitigating their effectiveness. The aim of the current study was to ascertain whether better control of hip internal rotation and subsequent knee valgus is facilitated when performing a single leg squat on a decline board as compared to a single leg squat on a level surface. Twenty (n=20) healthy active females between the ages of 18-25 years old were participants for this study. Hip and knee muscle strength was collected on Day 1. On Day 2, participants performed five single limb squats on flat ground and five single leg squats on a 25° decline board while joint angle and force data were collected. During the single limb decline squat condition, participants had 138% less knee valgus ($p=0.0001$), 47% less hip internal rotation ($p=0.0001$), 44% less hip adduction ($p=0.0003$) angles as compared to a single-limb flat squat. The decline squat resulted in a significant increase in the muscle demand placed on the hip external rotators (28%; $p=0.0002$) and knee extensors (37%; $p=0.0001$). There was no correlation found between hip or knee strength and the magnitude of knee valgus angles ($r=0.14$, $p>0.05$). The decline board allowed the participants to perform a single leg squat with an improved biomechanical alignment of the lower extremity. These results suggest that strength alone may not be indicative of a person being able to control knee position during squatting. In athletes who are having difficulty with squatting, the decline board might be best used as a precursor to the single leg flat squat.

Recent studies have reported a relationship between posterior lateral hip weakness and heightened knee valgus forces which increase the risk of anterior cruciate ligament (ACL) ruptures (Jacobs et al 2007). As a result, increased emphasis has been focused on strengthening hip musculature using activities such as single leg squatting (Wallace et al 2008; Zeller et al 2003). The single leg squat is typically used because it best matches the muscle demands necessary to participate in specific sports while also promoting improved dynamic knee stability. However, very often, females have difficulty performing the activity with proper limb alignment. Zeller et al (2003) reported that women tend to display greater valgus knee motion when compared to men throughout the entire phase of a single leg squat. Therefore, the athlete is strengthening their lower extremities, but at the expense of an improper biomechanical alignment that has been shown to stress the ACL (Markolf et al 1995). Single leg decline squats using a 25 degree decline board has been shown to be effective in treating patellar tendonopathy (Johnson et al 2005; Purdam et al 2004; Young et al 2005); however our review of literature suggests it has yet to be to be used in the rehabilitation of other knee pathologies. In comparison to a single leg squat on a level surface, the single leg decline squat places a greater demand on the knee extensors versus the hip extensors as a result of the body's center of mass moving more posterior throughout the squatting motion (Zwever et al 2007; Richards et al 2008). Because of the reduction in demand at the hip, we expect individuals will have improved control of hip internal rotation thus reducing the knee valgus loading at the knee. However, to date, we found no published study that investigated the frontal plane lower extremity joint motion and loading during decline single leg squatting. Our aim is to demonstrate that decline board single leg squatting can be performed without excessive knee valgus and therefore, might be utilized in ACL prevention programs as a precursor to flat squatting. We hypothesize that participants performing a single leg decline squat will demonstrate a significant decrease in frontal plane hip and knee joint angles when compared to a single leg squat on a flat surface.

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Methods

Participants

Twenty women, ages 18-25 years old were recruited through a convenience sample sent out to students enrolled in a physical therapy education program. Inclusion criteria consisted of being a female between the ages of 18-25, moderately active (3-6 hours of sport activity per week), and be able to perform a single leg squat to 90 degrees of knee flexion pain free with their dominant leg. The dominant leg was determined by asking the participant which leg they would kick a ball with. Participants were excluded from the study if they had any previous history of lower extremity surgery, any lower extremity pain in the last six months, or back pain in the last six months. Each participant signed an informed consent form approved by the university institutional review board prior to their participation in the study. All twenty participants completed the study's protocol; however three participants were excluded from data analysis due to loss of retro-reflective markers during the squatting trials. The data used in the study consisted of seventeen participants (Average age of 21.88 ± 1.69 years old, average height of 163. 23 ± 6.67 cm, average weight of 57.15 ± 6.22 kg).

Equipment

A decline board placed fixed to the force plate was used for the decline squat condition. The board made out of two inch thick plywood, reinforced in position by four hinges and 1.5 inch wood screws. The board was set at a decline angle of 25 degrees (Kongsgaard et al 2006; Zwerver et al 2007). The base of the board was a 12 inch x 12 inch square with a 14 inch x 12 inch standing surface. The standing surface was covered with grip tape to prevent any slipping off the board. Strength measurements of the participant's dominant leg were taken using the Biodex isokinetic dynamometer (Biodex Multi Joint System Pro. Shirly, NY) set at an angular velocity of 90°/sec. Marker position and ground reaction force data was collected using a 10 camera motion analysis system (Motion Analysis Santa Rosa, Ca) and an AMTI Forceplate (Advanced Mechanical Technical Inc. Watertown, Ma). Marker data was sampled at 120 frames per second and force data was sampled at 2400 Hz.

Procedures

Data was collected over two sessions held within one week. Lower extremity strength measurements were obtained and squat technique instruction was provided during the first session (DAY 1). Participants returned for testing approximately one week later where they performed single leg squats on flat ground and a decline board while angle and force data was simultaneously collected (DAY 2).

Day 1

Biodex strength testing consisted of three sets of five repetitions of concentric muscle activity for hip abduction/adduction and external/internal rotation. The motion of hip internal/external rotation was performed in a seated position. The dynamometer was moved in front of the participant and the axis was aligned with the center of the participant's patella. Each participant was instructed to move their foot inward toward their other leg and outward away from their body. Hip abduction and adduction was performed in sidelying with the testing leg facing toward the ceiling. The dynamometer was orientated behind the participant, with the axis going through the greater trochanter of the tested limb and the pad positioned one inch above the lateral condyle of the femur. Each participant was instructed to keep their toes pointing forward during the testing and a tester held the pelvis in a neutral position to avoid hip flexion during the test. The participant was instructed to move the leg up toward the ceiling and back down toward to the chair. Upon the conclusion of strength testing, a physical therapist instructed each participant on the squatting technique to be used at the Day 2 data collection session. Participants used the same technique when squatting on the flat ground and the decline board. The requested squat technique included having the participant's back straight, weight on their heels, and arms in front of them during the ascending and descending phases of the squat. The arms were held out in front of the body. During the squat the participant was instructed to keep their non-dominant leg in front of them, making sure it does not touch the ground (Zwerver et al 2007). Participants practiced the single leg squat on the decline board and on flat ground until their technique was approved by the principle investigator.

Day 2

Participants were outfitted with tight fitting elastic compression shorts and sports bra. The participant's height, weight and foot size were recorded. Twenty-six retro-reflective markers were placed on the bilateral upper and lower extremities (Wu et al 2002). Participants practiced each squatting condition until they were comfortable. Data collection consisted of five trials of three repetitions performed on the flat ground and decline board. The order of testing was randomly assigned. A brief rest period, approximately 20 seconds, was provided between each trial while a longer two minute rest period was allowed between each squatting condition. During the squat, the cameras collected the marker position data while the force plate collected the ground reaction force data simultaneously. Each squatting trial began with the participant standing off of the force plate. The participant was then instructed to step onto either the force plate itself or the decline board positioned directly over the force plate. They were then instructed to execute each squat from a neutral position (approximately 0⑤of knee flexion) to a depth of approximately 90⑤ of knee flexion. Individual squatting maneuvers were constrained to four seconds in duration (measured from initiation of knee flexion through the return to full knee extension). A metronome was provided to assist with pacing. Prior to the initiation of data collection, participants were allowed one to two sets of practice trials. Verbal feedback regarding both the depth and duration of the movement was provided after each practice squat.

Data Analysis

Cortex software (Motion Analysis Santa Rosa, Ca) was used to identify and digitize the retro-reflective spherical markers. Following procedures from Richards et al (2008), lower extremity internal joint moments and angles were calculated using Labview software (National Instruments, Austin, Tx). Joint moments were normalized to body weight. Each squatting trial was divided into two phases: (1) Eccentric and (2) Concentric. The beginning of knee flexion to the deepest part of the squat was labeled as the eccentric phase and the deepest part of the squat to the return to zero degrees of knee flexion was the concentric phase. Each squat was normalized to 100 % of the knee motion and averaged across all fifteen trails. Peak knee angles and moments were determined for each participant.

Statistical Analysis

Statistical comparisons between the decline and flat squatting conditions were conducted using twelve paired t-tests. The independent variables were the decline squat and the flat squat. The dependent variables were peak hip flexion angle and moment, peak hip rotation angle and moment, peak hip abduction angle and moment, peak knee flexion angle and moment, peak knee abduction moment and angle, peak internal knee rotation angle, and peak knee internal rotation moment. Using the bonferroni correction to maintain experiment error at $\alpha=0.05$, p level was set at 0.004. A person product moment correlation was used to determine if there were relationships between peak hip strength and knee valgus motion.

Results

Joint Motion

Hip: These results indicate that participants demonstrated 47.15% less hip internal rotation ($p<0.0001$) and 44.06% less hip adduction on the board as compared to flat ground ($p=0.0003$) (Figure 1). Mean peak values for hip flexion when squatting on the board were 11.55% higher as compared to the flat ground condition. ($p<0.0001$) (Figure 1).

Knee: During the decline squat condition, participants exhibited 137.98% less knee valgus ($p<0.0001$) without a significant difference in ($p=0.0389$) knee external rotation as compared to the squat on flat ground (Figure 2). There was no difference between peak knee flexion between the decline and flat squat condition ($p=0.042$) (Figure 2).

Decline versus Flat Single Limb Squat Peak Hip Angles

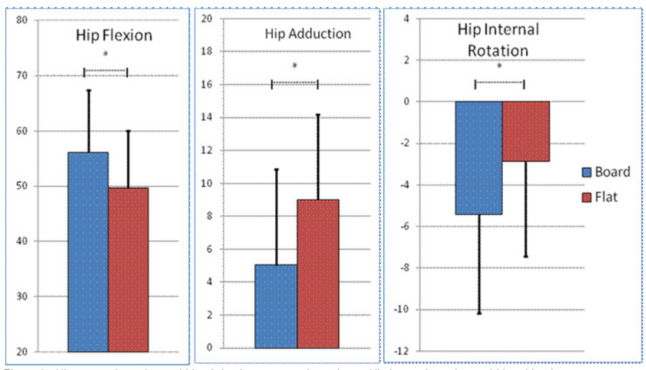

Figure 1. Hip external rotation and hip abduction are negative values. Hip internal rotation and hip adduction are represented by positive values. The differences for peak hip external rotation and peak hip adduction angles were found to be statistically significant (p<.004)

Decline versus Single Limb Squat Peak Knee Angles

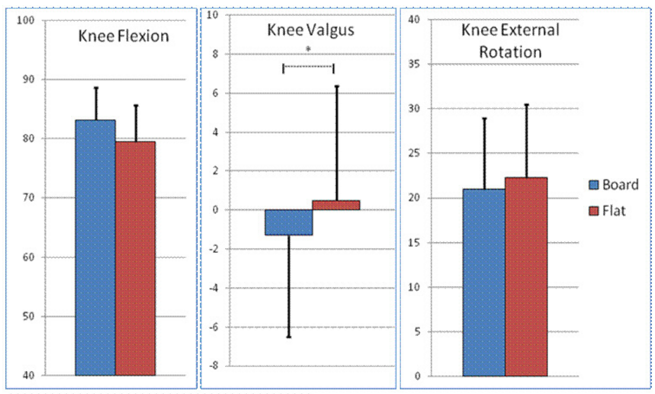

Figure 2.Knee Valgus and knee external rotation are represented as positive values. Knee Varus and knee internal rotation are shown as negative values. The differences between peak knee valgus and the peak knee flexion angles were found to be statistically significant. (p<.004)

Muscle Demand

Table 1 shows the average peak internal moments for both the hip and knee joints. According to our results, participants demonstrated a 36.67% ($p<0.0002$) increase in the hip external rotation moment and a 28.46% ($p<0.0002$) increase in the knee extensor moment when squatting on the board as compared to the flat ground. There was no significant difference between the sagittal plane hip moments ($p=0.14$). In addition, the frontal plane hip and knee moments also remained unchanged during the decline and flat squat condition

Internal Moments	Decline Squat (mean ± SD)	Flat Squat (mean ±SD)	*P* values
Hip external Rotation	.41±.11	.30±.11	0.0001*
Hip Abduction	.55±.14	.57±.17	0.4525
Hip Extension	.97±.23	1.05±.33	0.1416
Knee external Rotation	.03±.04	.06±.05	0.0046
Knee valgus	.17±.25	.21±.27	0.0844
Knee Extension	1.76±.23	1.37±.34	0.0002*

Table 1. This table shows the difference in internal moments between squatting on the decline board versus on flat ground. The positive values for the rotation moments indicate external rotation. The negative value for knee abduction indicates an valgus moment. The differences in hip rotation and knee extenstion moments were determined to be significant. (*p<0.05)

Strength Data vs Hip/Knee Angles

Strength Data (Nm/kg)	Peak Knee Valgus Slope	r^2	Peak Hip Adduction Slope	r^2
Knee Extension	.0629	.0167	-.1621	.1030
Knee Flexion	-.2613	.0917	-.1661	.0319
Hip Flexion	2.609	.1332	-.1920	.0660
Hip Extension	-.0473	.0120	-.0207	.0021
Hip Abduction	.1662	.0728	-.1936	.0903
Hip Adduction	.0024	$4.0e^{-6}$	-.2562	.0473

Table 2. Isokinetic strength data versus peak knee valgus and peak hip adduction angles. (r2) represents the correlation coefficient.

(p=0.45 and p=0.08, respectively). Finally, there was no significant difference in the transverse plane moments at the knee (p=0.05).

Strength Data
There was no significant correlation between the peak strength of hip or knee musculature and the peak frontal plane knee angles (Table 2).

Discussion

The primary finding of this study was that the participants demonstrated significantly less peak knee valgus when performing a single leg decline squat as compared to a single leg flat squat. The decline in knee valgus most likely occurred secondary to a reduction in internal muscular demand at the hip. The lower peak angles of hip internal rotation and hip adduction during the decline squat suggest that participants were able to better control femoral motion as a result of a reduced hip external rotator demand. These findings support our initial hypothesis that participants performing a single leg decline squat would be able to limit the peak angle of knee valgus in comparison with a single leg flat squat. Studies have suggested that tibiofemoral joint loading can be influenced by alterations in hip motion and muscle activation patterns at the hip, as a result of the closed kinetic link between the hip and the knee (Markolf et al 1995; Jacobs et al 2007). In a study by Hollman et al (2009), it was shown that at internal rotation and adduction of the femur contribute directly to increase knee valgus thereby making the athlete more susceptible to an ACL injury. The decreased peak angles of hip internal rotation and adduction in participants performing the single leg decline squat seen in our study suggests that there may have been improved control of femur motion on the decline board thus reducing the amount of valgus at the knee. As a result of the center of mass moving more posterior during a single leg decline squat as reported by Zwerver et al (2007), we anticipated that the participants would demonstrate a decreased hip extensor moment and a increased knee extensor moment when squatting on the board versus flat ground. Our results were consistent with previous studies in that participants exhibited significantly greater knee extensor moments (Kongsgaard et al 2006, Zwerver et al 2007. In addition, Richards et al (2008) reported a significant increase in EMG activity in the rectus femoris muscle when the single limb squat was performed at decline angles up to 24 degrees when compared to flat ground. This further substantiates the findings of an increased knee extensor muscle demand during the decline squat condition which would be in accordance with previous studies that have supported quadriceps strengthening as an important component of any ACL prevention program. In agreement with previous research, our results did not show significantly decreased hip extensor moments (Kongsgaard et al 2006; Richard et al 2008). We suspect that differences in methodology with respect to the instructions and performance of the squat may have affected the results of decline squat studies. In the study by Konsgaard et al (2006), it was not specified in the methods whether the single limb squat was performed with the non-stance limb in front of or behind the participant. The study by Richards et al (2008) had the participants place the non-stance limb behind the participant's body while performing the single limb squat while the study by Zwerver et al (2007) had the non-stance limb in front with the hands on the waist. Therefore, the contrasting findings may have been a product of the squatting technique. Finally, in the study by Richards et al (2008), participants average knee flexion angles on the board were 70 degrees, whereas the participants in our study were able to achieve an average of 83 degrees on the decline board. Since our participants were able to squat deeper, this could potentially alter the peak moments seen at the hip.

Despite the fact that there was no significant difference in hip extensor moment between the two conditions, our results showed a statistically significant increase in the hip external rotator moment during the single leg decline squat. This suggests that performing the single leg squat on a decline board allows the hip external rotators to generate a greater moment than the hip internal rotators. As previously discussed, the gluteus maximus is believed to be the primary external rotator at the hip into increased angles of hip flexion (Delp et al 1999). The posterior fibers of the gluteus medius and the piriformis function as external rotators in zero degrees of hip flexion, however as the hip flexes, the change in the biomechanical properties of these two muscles causes them to function as internal rotators (Delp et al 1999). Therefore, these findings may indicate that the participants were able to better use the gluteus maximus to control hip internal rotation during the decline squat. These results do not demonstrate any difference in frontal plane hip or knee internal joint moments suggesting that the differences between decline versus flat single leg squatting does not alter the demand on the frontal plane musculature. This finding was not unexpected as the primary difference in joint moments between the two conditions has been reported to occur in the sagittal plane; in response to changes in the location of the center of mass with respect to the hip or knee (Richards et al 2008; Zwerver et al 2007). Therefore, we hypothesize the decrease in knee valgus motion during the decline squat might be a result of a reduction in the hip external rotator moment. The results of this study support the current research on ACL injury prevention, that the biomechanics at the hip can play a role in frontal plane motion at the knee. A study by Carcia et al (2007) reported that the movements of ankle eversion, anterior tibial translation, tibial external rotation, knee adduction, hip adduction, and hip internal rotation all contribute to knee valgus. Our findings suggest that performing a single leg decline squat results in decreased peak hip internal rotation and adduction angles which may have contributed to the decrease in peak knee valgus angles seen. This is critical to ACL injury prevention as supported by McLean et al (2004) who reported that women with peak knee valgus angles that were only two degrees greater than those of men when performing a sidestep cutting maneuver, resulted in an increase in approximately 100% of valgus loads at the knee. Therefore, the 1.78 degree difference in knee valgus seen between knee valgus on the flat squat versus decline squat may be significant in terms of ACL injury prevention. Results of the current study showed no correlation between peak isokinetic torque/body weight of the hip/knee musculature and peak knee valgus angles or moments. This is consistent with recent research by Souza et al (2009) that has shown that strength testing is not predictive of knee valgus in dynamic exercises. The contrast in our findings between that of Wilson et al (2006) might be attributed to our inclusion of healthy active females versus females who have an underlying weakness of the hip musculature. This study's limitations include a limited amount of participants and that only healthy participants were recruited. More than twenty participants will be needed to further explore the effect of the decline squat on knee valgus. Also, our study did not screen for hip weakness. Participants with underlying strength deficits could have produced different results with the decline squat protocol.

Conclusion

These results may support the use of the single leg decline squat in ACL injury prevention as it appears the activity can be performed in a preferred biomechanical alignment. The decline squat at a 25 degree angle allows for decreased valgus angles at the knee and allows the individual to reinforce proper biomechanics while performing the squat. Utilizing the decline squat as a preliminary exercise can allow the individual to develop the neuromuscular control and strength necessary to prevent ACL injuries before moving onto more difficult exercises such as single leg flat squats.

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Original research

The reliability and validity of the reactive agility t-test

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KEY WORDS

Planned agility
Reactive agility
Change of direction speed

ABSTRACT

There is currently no 'gold standard' for testing agility, and a variety of tests are reported in the literature. Until recently, most tests of agility required participants to complete planned movements, or closed skills, and did not require a response to a stimulus. The purpose of the current study, therefore, was to evaluate the reliability and validity of a field-based test of reactive agility that incorporated both multiple changes of direction and an unpredictable stimulus, which could be easily replicated by the general coaching community. Eighteen soccer players from the USA National Collegiate Athletic Association (NCAA) Division 1 completed two testing sessions, one week apart. The first testing session required the participants to complete three tests; the Reactive Agility T Test (RATT), the Planned Agility T Test (PATT) and a 30m linear sprint test. The second testing session required the participants to complete the RATT. At test 1, the mean planned agility score (5.82s ± 0.17s) was significantly faster ($p < 0.01$) than the mean reactive agility score (6.11s ± 0.19s). The common variance (r2) between planned agility and 20m sprint speed was 52%, whereas the common variance between reactive agility and 20m sprint speed was 42%. The correlation between reactive agility at test 1 and test 2 ($r = 0.82$) was significant ($p < 0.01$). There was no significant difference ($p > 0.05$) in performance when participants turned left or right first on either planned or reactive agility tests. It would appear that the RATT used in this study may provide a reliable and valid test of agility that incorporates both the required elements of a change of direction speed test and a reactive component. The RATT also provides an agility protocol with a reactive component that could be easily replicated by the coaching community.

It is recognised in the literature that agility is an important fitness component in most field and team sports (Sheppard et al, 2006). Agility incorporates the coupling of acceleration and deceleration, and involves sudden changes of body direction in combination with rapid movement of the limbs (Sheppard, 1999; Farrow, Young and Bruce, 2005). The ability to make such sudden changes of direction is an important attribute for footballer players, as football involves an average of 1000 changes of direction per game (Sheppard, 1999). These changes of direction may be initiated to either evade or pursue an opponent, or to react to a moving ball (Young, James and Montgomery, 2002). The importance of this was emphasised by Farrow, Young and Bruce (2005), who suggested that the large majority of changes of direction (especially when defending) are triggered by an opponent's movement. Consequently, in addition to the ability to rapidly change direction, agility in a game situation also requires a response to a stimulus. Agility performance is therefore limited by both change of direction speed (CODS) and perceptual/decision making factors (Gabbett, Kelly and Sheppard, 2008; Young, James and Montgomery, 2002). CODS can be considered a players physical capacity to complete a planned movement requiring at least one change of direction, whereas perceptual skill in this context involves the payers ability to interpret and react to a stimulus and make at least one change of direction (Farrow, Young and Bruce, 2005). It would therefore appear that a test of agility requires both a CODS and a reactive component.

There is currently no 'gold standard' for testing agility, and a variety of tests are reported in the literature. Until recently, most tests of agility required participants to complete planned movements, or closed skills, and did not require a response to a stimulus. They therefore focussed on the CODS aspect of agility rather than the perceptual/decision making element. Based on the current view of agility, such tests may therefore be considered measures of CODS rather than agility due to their lack of a reactive component (Young and Montgomery, 2002; Oliver and Meyers, 2009). The reliability and validity of several CODS tests for football players were evaluated by Sporis et al (2010), who reported test-retest correlation coefficients of 0.738 – 0.944, and coefficients of

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variation of 2.9% - 5.6%. The validity of such CODS tests has often been assessed by their ability to differentiate CODS from linear sprinting, as these have been found to be distinct components of fitness (Young, McDowell, and Scarlett, 2001). To improve the ability of a CODS test to differentiate between CODS and linear sprinting (and therefore its' validity), it is important for the test to incorporate multiple changes of direction (at least 3), with the angles of directional changes being reasonably large (approximately 90°) (Young, McDowell and Scarlett, 2001). Common variances of 30% - 53% between CODS and linear sprinting have been reported by Young, McDowell and Scarlett (2001) and Pauole et al (2000). Many of the CODS tests have been reported to be able to differentiate football players by playing level and position, and this ability of a test to discriminate between higher and lesser skilled players within a sport is considered to be essential. If a test is not able to do this, it will have questionable use in detecting training-induced changes or making player selections (Gabbett, Kelly and Sheppard, 2008).

While these planned tests may be valid and reliable measures of CODS, they do not incorporate a reactive component, and may therefore be unable to accurately assess a player's agility (Farrow, Young and Bruce, 2005). More recent tests of agility have incorporated a reactive component, and it has been suggested that such tests are able to better discriminate between players of different levels than CODS tests (Gabbett, Kelly, and Sheppard, 2008). The common variance shared between these reactive (unplanned) and planned agility tests ranges from 10% (Sheppard et al., 2006), 16 – 34% (Gabbett, Kelly, and Sheppard, 2008), and 49% (Farrow, Young and Bruce, 2005). These tests could therefore be considered to measure relatively independent and specific qualities. The higher common variance between planned and unplanned agility tests reported by Farrow, Young and Bruce (2005), in comparison with Sheppard et al. (2006) may be due to the different procedures. Farrow, Young and Bruce (2005) compared times on a planned and unplanned version of the same test, and the common variance was relatively high. However, Sheppard et al., (2006) compared times on an unplanned reactive agility test with times on a range of different change of direction tests, placing different demands on the participants. Perhaps unsurprisingly, this resulted in a lower common variance between the planned and unplanned tests. The incorporation of the reactive component in to agility tests has been achieved in a variety of ways. For example, some tests of agility have required a change of direction in response to a generic stimulus such as a light bulb (Oliver and Meyers, 2009). However, it has been suggested that this type of stimulus does not allow an athlete to demonstrate expertise in movement pattern recognition. The use of a more sport-specific stimulus, requiring athletes to 'read and react', has therefore been suggested (Shepherd and Young, 2006). However, whilst the use of a sport specific stimulus is preferable, it is not always practical. For example, Sheppard et al. (2006), Gabbett, Kelly, and Sheppard (2008), and Farrow, Young and Bruce (2005), all provided a sports specific stimulus through the use of expensive video equipment which may not be practical for field based testing or use by the general coaching community.

In addition to the practical difficulties of recreating the sport specific stimulus used in many of the reactive agility tests, it is also interesting to note the design of the CODS component of the reactive tests. As discussed previously, CODS tests should incorporate at least 3 changes of direction with the angles of directional change being approximately 90° or greater. These elements of a CODS test were often missing from the reactive agility tests in the literature. For example, Sheppard et al, (2006) and Gabbett, Kelly, and Sheppard (2008) used a reactive agility test that incorporated one change of direction and a sport specific stimulus. Alternatively, Oliver and Meyers, (2009) used a generic stimulus and one change of direction of 37°. Alternatively, Farrow, Young and Bruce (2005), used a test that incorporated two movement patterns (side-stepping and forward sprinting), and 3 changes of direction with angles of 180°, 90° and 45°. The participants completed two versions of the test, with the final 45° change of direction being either planned or in response to a life-sized, interactive video display of a netball player initiating a pass. This test appears to be the only test in the literature that combines the key aspects of a change of direction test with the perceptual skill/reactive component element of an agility test. However, the test required the use of expensive video equipment and, as mentioned above, this may not be easy for others to replicate. The aim of this research was therefore to evaluate the reliability and validity of a field-based test of agility that incorporated both multiple changes of direction (90° left, 90° right, or 180°) and an unpredictable stimulus, and that can be easily replicated by the general coaching community.

Methods

Participants

18 soccer players with a mean ± SD height (1.65 ± 0.05m), and mass (63.4 ± 5.6kg), respectively volunteered for the current study. The players all competed in the USA National Collegiate Athletic Association (NCAA) Division 1 and were involved in the same training programme.

Testing Procedures

The players completed two testing sessions, one week apart. In order to assess the ability of the agility test to differentiate between reactive agility, planned agility and linear sprinting, the first testing session required the participants to complete three tests; the Reactive Agility T Test (RATT), the Planned

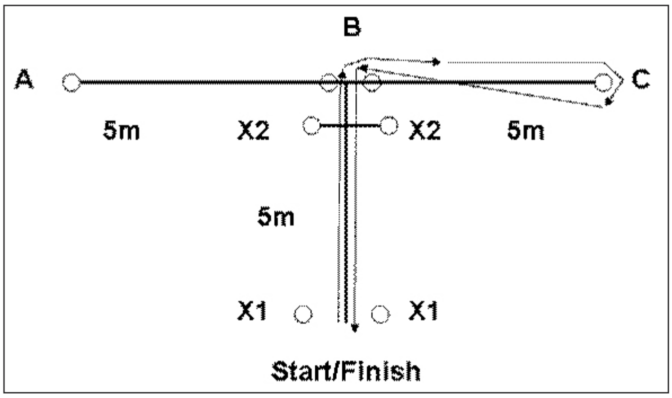

Figure 1

Agility T Test (PATT) and a 30m linear sprint test. The second testing session required the participants to complete the RATT again in order to assess its test-retest reliability. Testing took place on a grass pitch to maximise ecological validity, and players were instructed to wear the same footwear for both sessions. All results were recorded using Brower Photo-Gate infrared timing gates.

Reactive & Planned Agility T Tests (RATT/PATT)

The layout of the RATT/PATT is shown in figure 1. The top of the T is 10m long, whilst the vertical part of the T is 5m long. The intersection of the lines of the T is at the mid point of the top line. Marker poles were placed at the points represented by the circles on the diagram, and both poles at point B were placed 50cm from the intersection. Timing gates are placed at X1 and X2, with the poles at X2 being 1m from the top line of the T. The Tester stood at point B facing the finish line.

The RATT and PATT were started with the participant in 'athletic stance' at the start/finish line, with their preferred foot forward. They were in a position just behind the timing gates so that any forward movement caused the timer to begin. Participants then completed two versions of the test; the first version was a planned CODS test where participants knew the route that they would take, whereas the second involved reacting to a visual stimulus. The planned route required the participants to run as fast as possible towards point B. They then turned 90° to their left or 90° to their right, towards point A or C. They then turned through 180° at point A or C and ran back towards point B. From point B the participant then turned 90° to their left or 90° to their right and ran through the start/finish line. The unplanned version of the route was the same as the planned route, with the exception that when the participants first they broke the beam of the timing gates at X2, emitting an audible beep, the tester pointed in the direction that the participant was required to go next (either point A or C). Participants completed 4 trials of the planned version of the test (two turning left first and two turning right first) and between 4 and 8 trials of the unplanned version of the test (until they had completed two turning left first and two turning right first). The design of the test meant that the overall demands of each planned and unplanned trial were the same, e.g. a total distance of 20m, 1 x 180°, 1 x 90° Left, 1 x 90° Right.

20m Sprint Test

Participants completed a 20m linear sprint test. The test started with the participant in 'athletic stance' at the start/finish line, with their preferred foot forward. They were in a position just behind the timing gates so that any forward movement caused the timer to begin. Participants completed 2 trials with the best score being recorded.

Statistical Analysis

SPSS (v16.0; SPSS, inc., Chicago, IL, USA) was used for statistical analysis. Mean and SD were calculated for each of the tests. Test-retest reliability of the reactive agility test was assessed using Pearson's product moment correlation. In addition, within-subject variation (typical error) between test 1 and test 2 for the reactive agility test was assessed by calculating the coefficient of variation (CV) as described by Hopkins (2000). The ability of the planned and reactive agility tests to differentiate from linear sprinting was assessed using Pearson's product moment correlation. A paired samples t-test was used to explore the difference between the planned and reactive agility test scores.

Results

Descriptive statistics (mean ± SD) for planned and reactive agility, and 20m linear sprint speed at pre-test and post-test are shown in table 1. At test 1, the mean planned agility score (5.82s ± 0.17s) was significantly faster ($p < 0.01$) than the mean reactive agility score (6.11s ± 0.19s). Correlations showed that both the planned and reactive agility scores were significantly correlated ($p < 0.01$) with 20m linear sprint speed. The common variance (r2) between planned agility and 20m sprint speed was 52%, whereas the common variance between reactive agility and 20m sprint speed was 42%. The correlation between reactive agility at test 1 and test 2 ($r = 0.82$) was significant ($p < 0.01$). In addition, although a paired samples t-test indicated that the mean reactive agility at T1 (6.11s ± 0.19s) was significantly slower ($p < 0.01$) than at T2 (5.90 ± 0.18), the standard deviation of the differences was ± 0.109s and the coefficient of variation was 1.8%. There was no significant difference ($p > 0.05$) in performance when participants turned left or right first on either planned or reactive agility tests.

	Test 1	Test 2
Reactive Agility	6.11s ± 0.19s	5.90 ± 0.18
Planned Agility	5.82s ± 0.17s	-
20m Sprint	3.42s ± 0.14s	-

Table 1

Discussion

The aim of this study was to evaluate the reliability and validity of a field-based test of agility (RATT) that incorporated both multiple changes of direction at angles of at least 90°, and a reactive component. The test-retest correlation for the RATT ($r = 0.82$) is similar to the values of 0.83 – 0.92 for other reactive agility tests reported by Farrow, Young and Bruce (2005), and Gabbett, Kelly, and Sheppard (2008) respectively, and suggests a reasonable degree of reliability. In the current study, the time taken for the tester to react to the audible beep as the participants broke the beam of the timing gates at X2 was not recorded. Any differences in the reaction time of the tester would have resulted in inter-trial variability, although despite this potential source of variability, the test-retest correlation of the RATT remained acceptable. However, it must be acknowledged that there was a significant difference ($p < 0.05$) between the RATT times at T1 and T2, and this may have been caused by a motor learning effect (Sporis, 2010). This learning effect could have been reduced by increasing the number of trials (Hopkins, 2000), as demonstrated by Sheppard et al. (2006) who allowed participants a total of 12 trials on a reactive agility test. However, despite this apparent systematic change in the mean RATT times from T1 to T2, the CV was only 1.8% which suggests a high degree of reliability. This value compares favourably with the CV values ranging from 2.9% to 5% for a selection of agility tests reported by Sporis et al (2010). The scores on the PATT were significantly faster ($p < 0.01$) than the RATT, and this can be attributed to the delay caused by the perceptual/decision making processes in response to the stimulus required in the RATT. The RATT was therefore better able to differentiate from linear sprint speed as the common variance (r2) between the RATT and 20m sprint speed was 42% whereas the common variance between the PATT and 20m sprint speed was 52%. When the common variance between two variables is less than 50%, it suggests that they are distinct or independent in nature (Thomas and Nelson, 2001). This level of common variance between the RATT and linear sprint speed was similar to the value of 49% reported by Farrow, Young and Bruce (2005), who also compared times on planned and unplanned versions of the same test. A lower level of common variance may have been achieved by using a sport specific stimulus which would have required participants to use expertise in movement pattern recognition.

Conclusions

It would appear that the RATT used in this study may provide a reliable and valid test of agility that incorporates both the required elements of a CODS test and a reactive component. The low CV suggests that the protocol could be used to monitor changes in agility profiles of individuals or teams. Whilst the stimulus was provided manually by the tester in response to an audible beep, and was not sport specific, the RATT provides an agility protocol with a reactive component that could be easily replicated by the coaching community, using standard commercially available timing gates. Further research should explore the ability of a reactive agility test incorporating similar CODS components to those used in this study, to differentiate between players of different positions and levels. There may be a need to adapt such protocols for different positions due to the specific requirements of the roles (Sporis, 2010). In addition, future research should also look to develop a reactive agility test incorporating a reliable sports-specific stimulus that can be easily replicated and does not require expensive video equipment.

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