ROUTLEDGE

STRENGTH AND CONDITIONING FOR TEAM SPORTS

SPORT-SPECIFIC PHYSICAL PREPARATION FOR HIGH PERFORMANCE

PAUL GAMBLE

STRENGTH AND CONDITIONING FOR TEAM SPORTS

Drawing on the very latest scientific research, *Strength and Conditioning for Team Sports* is designed to help students, coaches, researchers and sports medicine professionals devise more effective high-performance training programmes for team sports. The only evidence-based study of sport-specific practice for team sports, this book introduces the core science underpinning any strength and conditioning regime, combining the best of applied physiology, biomechanics, sports medicine and coaching science.

The book addresses all aspects of training prescription and key components of any degree course related to strength and conditioning, including:

- Physiological and performance testing
- Strength training
- Metabolic conditioning
- Power training
- Agility and speed training
- Training for core stability
- Periodization
- Training for injury prevention.

Each chapter features guidelines for evidence-based training prescription as well as recommendations for novel ways in which to approach physical preparation for team sports players, bridging the traditional gap between sport science research and sport performance. Fully illustrated throughout, this book is essential reading for any serious student of strength and conditioning, and for any coach looking to extend their professional practice.

Paul Gamble currently works at Heriot-Watt University in Edinburgh where he serves as National Strength and Conditioning Lead for Scottish Squash and is responsible for national level athletes in a variety of sports. He has also worked in professional rugby union with London Irish Rugby Football Club.

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Sport-specific physical preparation for high performance

Paul Gamble

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This book is dedicated principally to my friends, who remain the biggest achievement of my life to date.

With thanks also to the athletes and coaches I have worked with; you have taught me much and no doubt will continue to do so.

CHAPTER 1

PRINCIPLES OF SPECIFICITY

INTRODUCTION

Specificity of training is increasingly acknowledged as fundamental in shaping training responses (Baechle et al., 2000; Kraemer et al., 2002). Training specificity encapsulates two key concepts. The first is that the nature of a training response is dependent – hence *specific to* – the nature of the particular training stimulus. The second, a corollary of the first, is that the degree to which training resembles – i.e. is *specific to* – conditions faced during competition influences the transfer of training to performance. These two concepts arise repeatedly in all aspects of physical preparation.

The essence of training specificity is that training responses elicited by a given exercise mode are directly related to the physiological elements involved in coping with the specific exercise stress (Kraemer et al., 2002). Accordingly, there is very little impact upon muscles and metabolic pathways that are not directly employed during the particular exercise (Millet et al., 2002a).

The degree of carry-over of training to competition is described in terms of transfer of training effect (Stone et al., 2000a). This is heavily influenced by the levels of mechanical and bioenergetic (energy systems) specificity of training in relation to competition. The probability of transfer to athletic performance can therefore be viewed as dependent upon the degree to which training replicates athletic performance conditions (Stone et al., 2000a).

It follows that applying mechanical and metabolic specificity as the basis for designing training programmes can positively influence transfer of training effects. In this way, training specificity offers a means to improve both the effectiveness and time-efficiency of an athlete's physical preparation.

The impact that training specificity has on training outcomes also grows with exposure to training. With advances in training experience, training specificity influences the athlete's training responses to an increasing degree. Hence, specificity considerations assume increased relevance and importance as young players progress through their careers. Training specificity becomes a critical factor in terms of physical preparation as athletes approach elite levels of performance.

Presented is an outline of general principles of specificity, and a discussion of how they relate to training. Brief examples of the ways in which specificity is manifested are also given, and what this information means for coaches and athletes will be discussed.

PRINCIPLE OF INDIVIDUALITY

Inherited traits will influence athletes' performance capacities and trainability for a particular physiological property (Beunen and Thomis, 2006). *Genotype* influences the individual athlete's responsiveness to a particular form of training, and also effectively sets the ceiling for any training effect (Smith, 2003). Hence these factors will impact upon both the rate of development and also the upper ceiling for training adaptation for each individual. The athlete's genotype exerts considerable influence upon athletic capabilities such as speed, power, strength and cardiorespiratory endurance, and their propensity for developing these qualities (Beunen and Thomis, 2006).

Although genetic potential may be beyond the control of the coach and athlete, the training performed and the environment the athlete is exposed to will influence the degree to which inherited traits are expressed (Beunen and Thomis, 2006). This is the *phenotype* of the athlete, which will be specific to the history of the individual and other environmental factors (Smith, 2003). Phenotypic expression of physical qualities is thus determined by the interaction of genetics, the athlete's training, and other environmental factors (Beunen and Thomis, 2006). In a squad setting, even with a fixed external training load, such factors will determine the specific 'internal load' placed upon each athlete, which in turn will define their individual training response to the training prescribed (Impillizzeri et al., 2005).

The degree to which the athletes' inherited traits translate into performance abilities in the competition arena will depend not only upon the quality of the training prescribed, but also upon athletes' motivation and dedication when undertaking training. Likewise, the key technical and tactical elements that determine success in skill sports are teachable (Smith, 2003). The quality of coaching and coach–athlete interaction are thus important factors. The athlete's personality traits will further determine the effectiveness of physical preparation as well as both athletic and sports skill acquisition. Self-discipline, appetite for work, and willingness to learn are all important in determining whether the athlete fulfils the many hours of quality training and practice required for elite-level performance (Smith, 2003).

PROCESS OF TRAINING ADAPTATION

Broadly, the process of training adaptation is that exposure to an effective training stimulus prompts the physiological and/or neuromuscular systems affected to respond by increasing their capacities in order to be better able to cope if faced with a similar challenge in the future. The original theoretical basis of training adaptation is the General Adaptation Syndrome (GAS) proposed by Hans Selye (Selye, 1956), which describes a generic response of an organism to a stressor (Wathen et al., 2000). According to this model, the first phase of response to any stressor is characterized as *shock* or *alarm* (Brown and Greenwood, 2005). Following this is a *supercompensation* phase, whereby the body adapts to increase the specific capabilities affected by the particular stressor. Over time if the stressor continues the organism may enter a terminal phase, termed *maladaptation* (Brown and Greenwood, 2005).

However, each individual physical capacity has its own individual window of adaptation:

- the rate of adaptation varies according to the individual athlete (genetic factors) and also depends upon their training history – i.e. how much adaptation has already taken place;
- the total degree of adaptation that is possible is dependent on genetic aspects, which effectively sets the ceiling for adaptation of a particular physical capacity for each athlete.

Accordingly, this GAS paradigm has since been refined by the Fitness–Fatigue model (Chiu and Barnes, 2003, Plisk and Stone, 2003). A key distinction is that the Fitness–Fatigue model differentiates between the actions of a given stressor on individual neuromuscular and metabolic systems (Chiu and Barnes, 2003). A corollary of this is that there are effectively individual windows for adaptation for each physical capacity. Particular acute adaptive responses are described as being restricted and specific to the systems employed in the training stimulus. The Fitness–Fatigue model also stipulates that the extent and length of any short-term effects following training will be specific to the training stimulus – rather than a generic response (Chiu and Barnes, 2003).

The other major advancement of the Fitness–Fatigue model is that it describes a dual adaptive response – resulting in both fitness and fatigue after effects, as opposed to the single common response described by GAS. These fitness and fatigue responses exert opposing effects on performance and are described as having defined characteristics – i.e. there are distinct differences in both magnitude and duration of fitness versus fatigue response (Chiu and Barnes, 2003). The athlete's physiological status is effectively determined by the net effect of these two opposing factors at that given time (Chiu and Barnes, 2003).

SPECIFICITY OF TRAINING

A foundation of training is described by the acronym SAID: *Specific Adaptation to Imposed Demands* (Baechle et al., 2000). Simply, any physiological adaptation produced is dependent on the specific form of overload provided by the training stimulus (Stone et al., 2000a).

Metabolic specificity

Metabolic specificity of training adaptations applies to the energy systems mobilized during exercise. The amount of muscle mass involved and overall exercise intensity dictate the scope of central and peripheral training effects. Specifically these factors decide whether training responses are limited to adaptations at muscle level, or if central cardiovascular changes are elicited (Millet et al., 2002a).

Adaptations following purely anaerobic training are mainly restricted to increased activity of enzymes involved in anaerobic metabolism (Wilmore and Costill, 1999). Conversely, continuous submaximal aerobic training is reflected in improved oxidative enzymes, whilst the anaerobic enzyme profile remains largely unchanged (Wilmore and Costill, 1999a). Simply, to elicit anaerobic adaptations requires anaerobic training, whereas improvements in oxidative capacity can only be derived using conditioning activities that stress the aerobic system.

Depending on the format, interval training may stress both aerobic and anaerobic systems (Tabata et al., 1996; Tabata et al., 1997). This training format can thus exhibit a combined training response. However, the relative adaptations in both aerobic and anaerobic performance measures remain specific to the format of interval training. The key factors are the intensity of work intervals and the particular work:rest ratios employed (Tabata et al., 1997).

Conditioning responses also observe exercise mode specificity. The running and cycling training completed by elite triathletes are shown to be unrelated to their swim performance (Millet et al., 2002a). Accordingly, improved performance measured via a swimming test mode following swim training is not reflected in treadmill test scores. In trained non-athletes, cross training (swimming) is likewise shown to be inferior to running training in improving running performance parameters (Foster et al., 1997).

Biomechanical specificity

Strength training effects are specific to the muscle contraction type employed in the training exercise (i.e. concentric, eccentric, or isometric) (Morrissey et al., 1995). Consequently, superior strength responses are observed in the particular mode of contraction featured in training (Morrissey et al., 1995). It follows that greatest improvements in strength expressed under dynamic conditions are seen with dynamic training. Conversely, isometric training elicits greater isometric strength improvement (registered under static conditions) than dynamic strength training (Morrissey et al., 1995).

Biomechanical specificity also concerns exercise range of motion and joint angles (Stone et al., 2000). This is applicable both to dynamic and isometric training, with superior strength gains observed within the range of motion and at the joint angles featured in training (Morrissey et al., 1995). Accordingly, it follows that exercise selection should reflect the full range of motion and joint angles featured in the sport or athletic event.

Biomechanical specificity also extends to structural elements, such as posture and limb position. Consequently, greatest strength responses are manifested during closed kinetic chain movements following closed kinetic chain training, whereas the opposite applies to open kinetic chain exercises (Stone et al., 2000). Similarly, a lift performed in a standing position (e.g. barbell squat) has greater carry-over to most types of athletic performance than a similar movement performed in a seated or supine position (e.g. leg press).

Biomechanical specificity is also evident in the relationship between unilateral (single limb) and bilateral (both limbs working simultaneously) strength measures (Enoka, 1997; Newton and Kraemer, 1994). Cyclists are shown to exhibit greater overall strength when single-leg press scores are summed in comparison to their bilateral leg press score – an effect known as 'Bilateral Deficit' (Enoka, 1997). This reflects the fact that cyclists work unilaterally – alternately exerting force with each leg – during training and competition. Conversely, athletes for whom training is bilateral can exhibit bilateral facilitation (Enoka, 1997). For example, it is reported that rowers' bilateral leg press scores are greater than the sum of their single-leg press scores (Enoka, 1997; Newton and Kraemer, 1994). It follows that exercise selection should emphasize either bilateral or unilateral movements, corresponding to what occurs during competition in the sport or athletic event.

Kinetic and kinematic specificity

In addition to biomechanical factors, other aspects of movement, including relative force, velocity and timing characteristics, are also important. Such considerations include magnitude and duration of loading, acceleration/deceleration profile of the movement, and movement velocity.

The duration and rate of force generation for a particular athletic task has a major bearing on the relation to other measures, despite similarities in biomechanics between tasks (Cronin and Sleivert, 2005). For example, jump squat training was reported to produce gains in jump height that were not seen in another subject group trained with traditional barbell squat and leg press, despite the two training modes having very similar biomechanical characteristics (Newton et al., 1999). Differences in acceleration and rate of force development between the two training modes were suggested to account for the difference in training effects observed.

Velocity specificity is evident in that strength gains will tend to be restricted to the velocities at which the muscles are trained (Morrissey et al., 1995). It appears that there is a greater degree of velocity specificity in training responses at the higher end of the training velocity spectrum (Morrissey et al., 1995). At slower contraction speeds there may be some carry over to velocities at and below the training velocity. In contrast, within the upper region of the force–velocity curve strength improvements are typically only registered within the narrow range of velocities used in training (Morrissey et al., 1995).

Psychological specificity

Physiological capabilities are manifested in a sports setting as part of co-ordinated and skilled movements. A corollary of this is that strength and conditioning specialists should consider the context in which physiological training is performed (Siff, 2002). Specificity considerations therefore also include psychological aspects of performance conditions. Cognitive and perceptual elements of performance conditions should therefore likewise be accounted for in training design (Ives and Shelley, 2003).

The principles of specificity thus also apply to psychological aspects. For athletes in team sports in particular, physical and mental capabilities are irrevocably linked. Three crucial interrelated components that are identified as influencing training responses are attention, mental effort, and intention (Ives and Shelley, 2003).

Attention is a key factor in perception–action coupling and superior decision-making of elite performers. Elite athletes attend to relevant cues from the competition environment and process them better as the basis for their movement responses (Ives and Shelley, 2003). During competition and practices attention is also crucial to anticipatory responses and associated postural and motor control. The athlete's locus of attention, in terms of whether it is externally or internally focused, is shown to impact upon motor learning and performance (Ives and Shelley, 2003).

It is recognized that directed mental effort has the potential to directly affect the magnitude of training response (Ives and Shelley, 2003). Conscious effort to exert maximal force has been found to significantly influence gains in strength and power (Jones et al., 1999). It has been reported that greater gains in strength are manifested when subjects were specifically instructed to focus on maximally accelerating the barbell for every repetition, as opposed to lifting without specific focus or instruction (Jones et al., 1999).

Intent is integral to neural factors associated with adaptations in high-velocity strength and rate of force development (Behm and Sale, 1993; Ives and Shelley, 2003). Recruitment and firing of muscles during training are in part dictated by what is anticipated prior to the movement (Behm and Sale, 1993; Behm, 1995). An illustration of this is that training effects associated with ballistic training can be derived with isometric training under certain conditions. If the lifter trains with the conscious intention of moving a static resistance explosively, significant improvements in the rate of force development can take place – despite the fact that no movement actually takes place (Behm and Sale, 1993). Physiological adaptations are therefore specific to and partially determined by the athlete's intention and corresponding neuromuscular patterns during training (Ives and Shelley, 2003).

It is important therefore to consider not only mechanical and metabolic specificity, but also address other aspects of the training environment. Imposing sport-specific constraints may help appropriately shape movement responses during training. It is suggested that this approach may encourage more adaptive learning and likewise develop decision-making (Ives and Shelley, 2003).

Conversely, excessively restricting training either by mechanically fixing the planes and range of movement or through overtly prescriptive coaching intervention will tend to discourage development of directed mental effort, task-specific attention, and sport-specific intent (Handford et al., 1997). Conducting physiological training in isolation of the athletic performance the athlete is training for is likely to hinder transfer of training effects (Ives and Shelley, 2003).

Specificity in relation to training experience and athletic status

The extent to which specificity principles apply appears to vary according to initial training status and degree of training experience (Young, 2006). In untrained individuals, training specificity does not exert the same degree of influence to that observed with trained individuals. This is illustrated by the lesser training mode specificity of untrained subjects' endurance training responses (Millet et al., 2002a). Untrained and recreationally trained individuals show transfer of endurance training responses to other exercise modes; this is not the case with elite athletes. What limited cross training effects have been observed in trained athletes fall far short of performance improvements elicited by mode-specific training (Millet et al., 2002a).

The limiting factor in terms of oxygen transport also appears to vary between untrained individuals and athletes (Hoff, 2005). Untrained subjects' muscles are not fully able to utilize available oxygen delivered via the blood. Conversely, the locomotor muscles of trained individuals have the capacity to handle significantly more oxygenated blood than the heart is able to pump. Hence, for athletes during dynamic activity utilizing large muscles – as occurs in team sports – the limiting factor is their cardiac output (Hoff, 2005).

There is also evidence that the relationship between stroke volumes and VO_2 are also different for well-trained versus moderately trained and untrained individuals (Hoff, 2005). What occurs in untrained and moderately trained is the classical textbook pattern of a levelling off in stroke volume as workloads increase beyond around 60 per cent VO_2max (Hoff, 2005). However, it now appears that well-trained athletes continue to increase stroke volume with increasing workloads up to VO_2max (Hoff, 2005).

A similar scenario is evident with strength training. Almost any training represents a novel stimulus to the untrained neuromuscular system. As a result, untrained individuals demonstrate an array of training effects, regardless of the nature of the training (Newton and Kraemer, 1994). Consequently, a wide variety of training interventions will produce favourable adaptations in a given aspect of neuromuscular performance with untrained individuals (Kraemer et al., 2002). This again is not the case in advanced lifters and elite strength-trained athletes.

There is increasing evidence that the dose-response relationships pertaining to volume, frequency, and intensity of strength training are specific to the level of training experience and athletic status of the individual (Peterson et al., 2004; Rhea et al., 2003). The optimal strength-training prescriptions differ for untrained individuals and those with strength-training experience. Furthermore, strength-trained athlete subjects differ markedly on all three of these training variables in comparison to both untrained and trained non-athletes (Peterson et al., 2004; Rhea et al., 2003). The trends in each training parameter between groups appear to form a continuum of optimal levels of volume, frequency, and intensity with progression in training experience and athletic status.

ACCOUNTING FOR SPECIFICITY IN TRAINING PROGRAMME DESIGN

The first step in deriving the benefits of training specificity is a thorough needs analysis. One aspect of this is identifying the biomechanics and bioenergetics associated with the particular sport or playing position. By defining the specific demands of competition it will be possible to account for the relevant parameters in the design of players' training. Another aspect of the needs analysis process involves identifying the individual profile of each athlete in terms of different aspects of physical preparedness.

Theoretically, the most 'sport-specific' or 'functional' form of training is to perform the actual movement(s) of the sport (Siff, 2002). However, this tends to neglect the element of overload required to elicit a training response and ultimately improve performance. Training modes must not only replicate the movement patterns of the sport and account for the bioenergetics of competitive performance, but also incorporate the element of overload and develop individual aspects that contribute to sports performance. Similarly, there is a need for variation in exercise selection throughout the training year; hence, a range of exercises across the spectrum of specificity for the given sport is required.

Considerations for biomechanical specificity include direction and range of movement, type of muscle contraction, movement velocity, and the rate and duration of force development (Stone et al., 2000). Exercise selection should cater to the full range of motion identified from competition, as well as the conditions under which movements are initiated (Sheppard, 2003). The degree of loading that is appropriate will vary according to the movement. In the case of fine motor skills, excessive loading may interfere with the proper execution of the movement (van den Tillar, 2004).

Applying metabolic specificity basically requires that the format of conditioning reflects the parameters of competition. One approach used in other sports and athletic events involves setting target training paces, based upon actual or desired competition performance (Plisk and Gambetta, 1997). Identifying such parameters (work rates, movement patterns, work:rest ratios) in order to design sport-specific conditioning programmes for team sports poses a greater challenge. This will be explored further in a later chapter.

Performance benefits may be derived by accounting for psychological aspects in the training environment. There are early indications that incorporating practice-related cognitive strategies during training leads to greater carry-over of training effects to sports performance (Ives and Shelley, 2003). For example, visual and verbal cueing has been suggested to enhance the effectiveness of plyometric jump training for volleyball players (Ives and Shelley, 2003). In the case of strength training, psychological interventions may take the form of mental imagery or specific cueing to lift explosively from the strength coach whilst lifting (Jones et al., 1999).

Coaches must also recognize that skill level and training experience influence the training parameters that will be effective in developing athletic performance (Cronin et al., 2001; Peterson et al., 2004; Rhea et al., 2003). With progression in training status, training specificity assumes further importance and programme design must be increasingly specific to elicit the desired response when addressing a particular aspect of performance (Newton and Kraemer, 1994).

Training should be tailored to the specific needs of the individual. Each player will have different relative strengths and weaknesses, both of which should be accounted for in their individual training programme. Players will also vary in terms of their tolerance and responsiveness to different forms of training.

CHAPTER 2

PHYSIOLOGICAL AND PERFORMANCE TESTING

INTRODUCTION

The principles of training specificity have implications when assessing athletic performance (Abernethy et al., 1995). Fundamentally, in order to be relevant any physiological tests selected must match the specific capabilities identified as contributing to performance in the sport (Bosquet et al., 2002). For team sports this requires consideration not only of the sport but also the playing position.

It follows that physiological tests selected should therefore be specific to the sport the player is training for (Murphy and Wilson, 1997). Tests that are most game-specific tend to be given greatest credence by those involved in the sport. In basketball, the vertical jump test is shown to be the best predictor of playing time given to players of any athletic performance test (Hoffman et al., 1996). This is a reflection of the specificity – and hence relevance to performance – of vertical jump testing for basketball players.

Test specificity is again manifested in the observation that the greatest degree of improvement in muscle function following training is registered with the test modality that most closely matches the training movement (Morrissey et al., 1995). It follows that testing should be specific to the movement patterns and velocity used in training in order to be sensitive to training-induced changes in muscle function (Abernethy et al., 1995).

Fundamentally, training is aimed at improving the player's performance. From this point of view, physiological tests should ultimately be judged upon the extent that they reflect changes in sports performance (Murphy and Wilson, 1997). In order to be relevant, tests must be sensitive not only to adaptations elicited by the training intervention but also capable of registering any resulting improvements in performance (Murphy and Wilson, 1997).

One consideration with test specificity is taking account of the conditions under which tests of muscle function are measured. Neuromuscular properties such as Rate of Force Development (RFD) and high-velocity strength are relevant to dynamic performance (Newton and Kraemer, 1994). However, the corresponding test measures for these capabilities are only related to athletic performance if they are measured under appropriate conditions (Wilson et al., 1995).

RATIONALE FOR TESTING TEAM SPORTS PLAYERS

Testing in sport is typically undertaken with one of two broad aims in mind:

- The first of these is to evaluate the abilities or current state of preparedness of the player in the context of the demands of their sport (Impellizzeri et al., 2005).
  - This may be from a talent identification viewpoint (Abernethy et al., 1995).
  - Or in order to identify specific strengths and weaknesses of the players assessed in order to guide training prescription (Lemmink et al., 2004).
- The second application of testing is to monitor progression and evaluate the effectiveness of training prescribed (Abernethy et al., 1995; Impellizzeri et al., 2005).

Application of testing

There are notable cases in sport where players' scores on a particular performance test or battery of tests are given a great deal of credence by those involved in the sport. Possibly the best example of this is the National Football League Combine – the standard battery of tests that is employed for selection in professional American football. Performance on these tests has been identified as a significant factor that distinguishes players successful in being drafted onto NFL teams from those who were unsuccessful (Sierer et al., 2008). In recognition of this, some authors have advocated targeted training to improve a player's performance specifically for particular tests that hold a lot of weight in the sport, with the aim of improving their prospects of selection – and financial package when they eventually sign professional contracts (McGee and Burkett, 2003). Indeed the degree to which players' performance on these tests apparently influences chances of selection has led entrepreneurial strength coaches to change their approach and train players specifically for these tests, as opposed to focusing on preparing them to compete in the sport. Increasingly, this is becoming standard practice in the strength and conditioning 'industry'.

The application of testing to guide training prescription has been described as 'strength diagnosis' (Wilson and Murphy, 1996). The rationale for this use of testing is that a player's relative scores on different measures of muscular performance – in the context of the specific demands of the sport – can be used to identify deficits in particular areas. Addressing the areas of relative weakness identified then becomes the priority in the player's subsequent training block.

Testing is also widely used to track improvements in players' fitness and performance, and as a means to assess the effectiveness of training prescribed (Impellizzeri et al., 2005). One consideration with team sports is that the individual stimulus provided by training prescribed to a group of players will vary for each player (Impellizzeri et al., 2005). Even if the external load in terms of intensity and volume prescribed is constant, genetic endowment and training background will both influence the magnitude of the 'internal load' imposed upon each player – which will in turn affect their individual training response (Impellizzeri et al., 2005). In view of this, testing will only provide a partial reflection of the effectiveness of the training prescribed, unless accompanied by ongoing monitoring and manipulation of players' individual daily training load. An extension of this is that evaluating the day-to-day training process is as important as periodic assessment of the training outcome in order to determine the effectiveness of the training programme (Impellizzeri et al., 2005).

Practical relevance of physiological and performance tests

Whether testing is carried out in the laboratory or in the field, both reliability and validity are key issues. Reliability pertains to how consistent the scores of the given test are – hence how repeatable the test is. Validity concerns the extent to which the test actually measures the physical capability it is intended to assess. Both criteria must be met for any given test to be of any value as a means for assessing players' performance. It is possible to have a reliable test – one that gives highly consistent scores – that may not necessarily be a valid test, in terms of its ability to measure the particular aspect of motor performance the coach wishes to assess. Conversely, a highly valid test from the point of view of closely reflecting the movement or aspect of performance the test is designed to measure is of little value if it is not reliable in terms of producing consistent scores. In the latter case the tester cannot be confident that any measured change over time is due to actual change in performance rather than just the error inherent to the test measure. A good illustration of this comes from basketball where a sport-specific test battery was designed to measure performance capabilities, which the authors named the Performance Index Evaluation (PIE) (Barfield et al., 2007). The tests chosen appeared highly specific to the sport of basketball; however, further study by Barfield and colleagues (2007) investigated the validity and reliability of the PIE with male and female collegiate players and found it to have unacceptable test–retest reliability. Furthermore, the PIE showed scores also appeared to lack criterion-related validity on the basis that they failed to correlate to playing time allocated to these collegiate players (Barfield et al., 2007).

In order to provide a framework upon which players can then be evaluated, it is important to identify the specific parameters that influence performance for the particular sport (Muller et al., 2000). Once identified, tests that are sensitive enough to discern changes in the particular parameter should be sought. Specificity considerations have a major bearing on both these aspects. In order to be relevant, the parameter must be specific to performance of the sport in question, and correspondingly the test measure must be specific and therefore sensitive to the parameter the coach wishes to test.

One approach is to identify potentially important aspects of motor performance based upon qualitative assessment of the sport and then identify tests that are designed to measure each of these areas (Muller et al., 2000). The next step is for players competing at different levels to undergo the battery of motor performance tests derived. The degree to which each test correlates to players' level of performance can be taken as an indication of the importance of the corresponding parameter to success in the sport (Muller et al., 2000). In this way the tests that appear most strongly associated with success in the sport can be identified.

Biomechanical specificity is a key factor with respect to test specificity, but it is only part of the equation – other elements such as acceleration/deceleration profiles are similarly important. An illustration of this is the difference between three-repitition maximum (3-RM) squat and jump squat scores and their relationship with dynamic measures of performance such as sprint times with team sports players. In the case of the 3-RM squat test, there was no relation to sprint performance found over any distance, whereas jump squat scores were observed to be significantly correlated to 5-, 10-, and 30-m speed of professional and semi-professional rugby league players (Cronin and Hansen, 2005). Players' 3-RM squat and jump squat scores were also not related to each other in this study, despite the fact that the two movements are biomechanically similar.

If the objective of testing is to evaluate the effectiveness of players' training, then specificity with regard to the training used must be considered. Greatest effects are observed during testing at velocities in the range featured in training (Morrissey et al., 1995). It follows that testing should be specific to the movement patterns and velocity used in training in order to be sensitive to training-induced changes in muscle function (Abernethy et al., 1995). However, it is not sufficient for test measures to be specific only to the type of training employed. Testing to monitor training effects must also bear relation to the sport in order to be sensitive to sports performance. When these conditions are not met, improvements in neuromuscular and athletic performance (maximum strength and sprint scores) can be observed following training despite the chosen test measures registering no change (Murphy and Wilson, 1997). The particular test mode and outcome measures chosen must therefore be selected carefully in order to meet the objective of monitoring the effectiveness of players' physical preparation (Cronin and Hansen, 2005).

Practicality of testing modes for athletic assessment

Two major issues concerning modes for physiological and performance assessment are cost (expense of test apparatus and skilled personnel to operate it) and time demand. Considering both these factors – aside from concerns regarding specificity and relevance – individual laboratory assessment for large squads of players is not likely to be affordable or practical. Field-based tests are generally more conducive to team sports testing as these can be conducted in the field (avoiding the related travel and cost implications of using a laboratory) and also enable larger numbers to be tested in a relatively shorter time than tends to be possible with laboratory-based testing.

Whatever the mode of assessment, subject motivation is a crucial factor. Field tests have more obvious relevance from the players' viewpoint, and also benefit from context specificity: field tests are conducted in a setting where the players habitually train and perform as opposed to the more alien environment of a laboratory. In addition, field tests can be carried out with larger numbers of players, which allows those conducting the test to incorporate a competition element. Due to these factors, field-based tests are therefore likely to engender greater compliance and motivation among team sports players, which improve the chance of consistent and maximal effort when testing is repeated over a period.

Design of field test protocols are often modified in an attempt to make them more specific to the sport. Many sport-specific field tests are described in the literature (Barfield et al., 2007; Graham et al., 2003; Mirkov et al., 2008). With any 'sport-specific' field test there is inevitably a trade-off between replicating game conditions and standardizing test conditions to obtain a reliable measure. Likewise, with any novel test protocol there is a need for sufficient normative data for the sporting population in question to allow a reference for comparison.

Schedule of testing

Testing is only useful if it is repeated at regular intervals. Only in this way can progress be monitored or issues affecting performance be identified (e.g. errors in training design, competition, and other stressors). The full battery of tests need not be undertaken at every test session: an abridged version of the test battery can be used at most regular test sessions and the full array of tests reserved for key points in the training year.

STRENGTH AND POWER ASSESSMENT

Maximum strength

Strength is generally defined as maximal force or torque generated during a maximal voluntary contraction under a given set of conditions – key parameters include posture, movement (single-joint versus complex movements), contraction type, and velocity (Abernethy et al., 1995). As such, strength qualities can be divided into static, concentric, and eccentric muscle actions. In recognition of the force–velocity curve, authors similarly make a distinction between low-velocity strength and high-velocity strength; the latter can be considered a component of speed–strength, which is discussed in the following section.

Modes of strength assessment can be categorized as 'isometric', 'isokinetic', or 'isoinertial'.

Isometric strength assessment

Isometric assessment typically uses a force transducer integrated into a fixed apparatus against which the player (statically) applies force. This can also be undertaken using a force platform in a squat rack or other rigid structure for static actions performed standing – measuring the force applied to the ground through the feet (Wilson and Murphy, 1996). In either case the defining aspect of isometric assessment is that force is applied against immovable apparatus and that there is no change in joint angle (Abernethy et al., 1995). By definition, isometric assessment measures strength qualities under static conditions – hence provides little information regarding concentric or eccentric strength capabilities – and scores also vary considerably with changes in joint angle.

Isokinetic strength

Isokinetic assessment uses a dynamometer to control the velocity of movement while the subject exerts maximal force against the moving lever arm – hence such assessments typically involve open chain movement, for example, a seated knee extension. This mode of testing assesses the players' ability to generate torque through a fixed range of motion for a restricted single-joint movement at a constant angular velocity (Abernethy et al., 1995). The controlled conditions under which isokinetic strength measures are recorded assist in producing reliable (i.e. repeatable) measurements. Conversely, the controlled and restricted nature of isokinetic dynamometry would seem to render this mode of strength assessment less applicable to athletic movements. In most sports, strength is expressed during movements that are commonly not performed seated and involve complex rather than single-joint actions. In accordance with this, isokinetic strength measures are typically not reported to be sensitive to changes in measures of athletic performance (Murphy and Wilson, 1997).

Isoinertial strength

Isoinertial strength assessment employs free weights or fixed resistance machines to quantify the greatest resistance the player can lift for a specified range of motion. Common machine-based assessments include leg press, chest press, or shoulder press performed using fixed resistance machines. Free-weight isoinertial strength assessment typically involves maximal lifts with one of the powerlifting competition lifts – i.e. barbell squat, deadlift, and bench press. This mode of testing allows strength to be assessed during closed kinetic chain movements and couples eccentric and concentric actions. These tests require the players to balance both themselves and the resistance whilst generating force, as opposed to having the plane of movement fixed and the body supported in a sitting or lying position as occurs during fixed-resistance machine assessments. As such, isoinertial assessment with free weights is considered the testing mode that bears closest resemblance to what occurs during athletic movements (Newton and Dugan, 2002). By definition, players' isoinertial test scores will to some extent be limited by their level of skill in performing the given strength exercise movement (Abernethy et al., 1995). However, such issues will likewise influence a player's ability to express their strength capabilities during sports skill and athletic movements. Of the two forms of isoinertial assessment, free weights-based testing would appear to be more specific for evaluating athletes.

RM testing is widely used in physical assessment in sports: a player's one-repetition maximum (1-RM) for a particular lift is defined as the highest weight they are able to lift for one repetition through the full range of motion for that lift (Morales and Sobonya, 1996; Harman and Pandorf, 2000). In terms of practicality, 1-RM testing can be carried out in the weights room as it does not require specialized equipment and therefore can be undertaken at the team's training facility. Free weights 1-RM testing does demand a level of technical competence – from a safety viewpoint it is important that lifting form does not break down under the maximal loads used, particularly in the case of barbell squat and deadlift. An alternative to 1-RM testing that attempts to avoid such issues involves the use of submaximal strength testing at lower RM loads, from which 1-RM values can be predicted (Morales and Sobonya, 1996). One such approach is to assess the maximum load the player can lift for a specified number of repetitions – e.g. 3-RM or 5-RM testing. The number of repetitions chosen for submaximal RM testing influences the accuracy of the 1-RM prediction. The submaximal repetition test that most closely predicts 1-RM load reportedly also appears to vary according to the lift. A study of collegiate power athletes (football players and athletics field event throwing athletes) identified that 95 per cent 1-RM loads best predicted 1-RM values for bench press, which equates to a 2-RM test (Morales and Sobonya, 1996). Conversely, the best prediction for power clean lifts were made at 90 per cent 1-RM (equating to a 4-RM test), whereas for barbell back squat the best prediction was made using 80 per cent 1-RM (8-RM test) in these athletes.

Assessing eccentric strength

Assessment of eccentric strength has traditionally been undertaken using isokinetic devices – i.e. the player resists with maximal force the movement of the lever arm of the dynamometer as it moves in the opposite direction at a set angular velocity. This mode of eccentric strength testing carries the same biomechanical and postural specificity issues as described above for concentric strength assessment. However, isoinertial tests of eccentric strength – although not widely used currently – do also exist (Meylan et al., 2008). Some protocols employ variations of standard strength exercises and impose a 3-second eccentric phase – i.e. maximum weight the subject could lower over three seconds through the full eccentric range of motion for the particular lift. Other methods employ a force platform and measure ground reaction forces during high load or high-velocity eccentric movements. The use of these latter protocols will be restricted by access and trained staff to operate the force platform equipment required. Maximum force developed under eccentric (lengthening) conditions will always exceed maximum voluntary force developed during concentric or isometric contractions. As such, the loads involved during eccentric strength testing exceed those used during isometric or concentric strength testing (Meylan et al., 2008). The higher level of loading imposed raises concerns over the safety of this form of assessment for some players. This is particularly the case with young players who are still maturing physically, and conversely older players who may also not tolerate the physical stresses involved.

Strength-endurance

Strength-endurance is identified as an independent aspect of neuromuscular performance, as opposed to just a derivative of other strength properties (Yessis et al., 1994). This capability is commonly assessed by evaluating the number of repetitions the player is capable of completing at a given submaximal load. The load used is usually set as a percentage of their 1-RM for the particular strength exercise or body weight (e.g. maximum chin up test). The number of repetitions through the full range of motion the player is able to complete with the predetermined load is then used as the outcome measure.

One notable example of a commonly administered strength-endurance test is the 225-lb bench press repetition test that is performed as part of the NFL Combine. This is categorized as a test of strength-endurance for these American football players on the basis that the average number of repetitions completed by eligible players tested in the NFL Combine is reported to be 10 reps or above (Sierer et al., 2008). This may not be the case for other players in other sports, however.

Anaerobic power or 'speed-strength'

Testimony to the high perceived importance of 'explosive' power or speed-strength with respect to sports performance (Abernethy et al., 1995) is the numerous different testing modalities that exist to assess this particular quality:

Isokinetic dynamometry

Isokinetic testing using higher angular velocities on the dynamometer have been used as a measure of both high-velocity strength and speed-strength. As was discussed for strength testing the validity of this form of testing for evaluating speed-strength performance is questioned. Isokinetic measures of speed-strength, in the form of hamstring and quadriceps torques, show no relation to sprint times over any distance (0–5m, 0–10m, or 0–30m) in team sports players (professional and semi-professional rugby league players) (Cronin and Hansen, 2005). This finding is in keeping with the lack of biomechanical specificity with respect to the co-ordinated multi-joint movement that features in athletic performance of the single-joint open kinetic chain movements involved in this form of assessment (Cronin and Hansen, 2005).

Rate of force development

Rate of Force Development (RFD) is identified as a key component of speed-strength performance (Newton and Kraemer, 1994). However, in accordance with test specificity, the conditions under which this aspect of neuromuscular function is measured have a major bearing on its validity. When measured under isometric (static) conditions RFD scores showed no change in response to either ballistic, plyometric, or strength-oriented lower body training, even though improvements were demonstrated in measures of dynamic athletic performance (Wilson et al., 1993). A concentric measure of RFD was, however, shown to be capable of discriminating between good and poor performers on a sprint test, where the isometric RFD test failed to do so (Wilson et al., 1995).

Measurement of RFD does, however, require expensive and not easily portable equipment – typically a force plate. For these reasons, assessments of this type tend to share the same issues of cost and practicality as other forms of laboratory-based testing.

Assessment of maximal power 'P_{max}' load

Much attention has been given to the load at which peak power output is achieved – termed P_{max} – from both a training and testing viewpoint. Athletes' power outputs across a spectrum of loads for a ballistic speed-strength exercise (typically barbell jump squat or bench throw) have been used to identify both the P_{max} value and athletes' power output curves (plotted against load) (Harris et al., 2007). Similarly, an increasingly common practice when testing an athlete's speed-strength capabilities is to plot their individual load versus power output curve for the jump squat. One application of this is as a diagnostic tool to guide athletes' training prescription in order to shift their load/power curve in a certain direction.

However, a number of authors increasingly question the practical importance of this P_{max} value; likewise such application of the load versus power output curve is also debated. A study of senior elite rugby union players did provide load–power curves that allowed a peak in power output at a particular (P_{max}) load value to be identified (Harris et al., 2007). However, the difference in power outputs either side of this P_{max} value was minimal: loads 10 per cent and 20 per cent above or below the player's identified P_{max} load on average only affected power outputs by 1.4 per cent and 5.4 per cent respectively (Harris et al., 2007). In terms of practical application, P_{max} values also appear to relate only to the training movement tested and thus cannot be generalized to other training exercises.

Jump squat assessment of power output

As discussed above, jump squat assessments of speed-strength performance are often conducted over a range of loads. From a methodological point of view, it appears that the use of apparatus such as a Smith machine or Plyometric Power System may impact upon the relationship between jump squat power output and measures of athletic performance (Cronin and Hansen, 2005). Scores on an unrestricted squat jump using a free-weight Olympic barbell were found to correlate with sprint performance in rugby league football players (Cronin and Hansen, 2005) whereas absolute squat jump scores measured in restricted apparatus reportedly did not (Baker and Nance, 1999b). By restricting the plane of motion of the bar it may be that this apparatus affects the functionality of the test by reducing the degree of specificity to sports movements, such as balance and co-ordination aspects (Cronin and Hansen, 2005). However, devices are now commercially available that allow free-weight barbell jump squats to be used for the same form of assessment to evaluate power output.

Olympic weightlifting repetition-maximum testing

Another common measure of speed-strength capabilities against greater resistance involves RM testing using Olympic weightlifting movements. The power clean is generally chosen due to the familiarity of this lift for most players and the fact that it has a distinct end point – i.e. the player either fails or succeeds to catch the bar at the top of the lift. In much the same way as for free weight isoinertial strength tests, players' scores tend to be limited by their technical proficiency with the lift. To avoid such limiting factors some practitioners employ the pulling derivatives of the Olympic lifts for RM assessments – i.e. without the catch portion of the movement at the top of the lift. This may help to offset issues relating to lifting skill associated with the 'catch'. However, there may be other issues using the Olympic pulling derivatives for RM testing. In the absence of the catch as a distinct end point, there are challenges standardizing how high the barbell must be raised in order to deem that the player has successfully completed the pulling lift with a given weight.

RM testing using the hang power clean (i.e. a power clean initiated with the bar at the 'hang' position at mid-thigh) is also often used to assess maximum speed-strength capabilities. Australian Rules football players' scores on the 1-RM hang power clean were found to be related to their vertical jump, maximum strength (squat 1-RM), and sprint performance (Hori et al., 2008).

Vertical jump assessment

Variations of the vertical jump are the most commonly employed measure of lower body 'explosive power' or speed-strength performance for both athletic and non-athletic populations (Klavora, 2000). Some have questioned the validity of using vertical jump as a specific measure of lower body power given that multiple segments (both lower and upper limb) contribute to the vertical jump movement and that motor skill or co-ordination also influence performance on the vertical jump test (Young et al., 2001a). Regardless of these debates, from the point of view of assessing athletic performance, vertical jump is a common action in most sports and is reflective of 'triple extension' speed-strength movements employed during acceleration and various game-related dynamic movements. From this viewpoint, inclusion of some form of vertical jump in a battery of tests to assess speed-strength expression and athletic performance would appear valid.

The standard test for concentric power production is the squat jump, executed from a set squat depth without any countermovement. The countermovement jump, performed continuously without a pause, is the standard test of combined concentric and stretch-shortening cycle performance. The difference between the two measures – (concentric only) squat jump and countermovement jump height – has been used to evaluate stretch-shortening cycle contribution to the player's performance. Drop vertical jumps may also be used in this way (Ford et al., 2005) – however, these tests also involve reactive strength (discussed in following section).

One study reported that of a range of field-based vertical jump tests, the squat (concentric-only) and countermovement jump tests executed with hands on hips had the greatest reliability with recreationally active subjects (physical education students), in terms of producing consistent scores across trials (Markovic et al., 2004). However, restricting the use of arm swing would appear to compromise the biomechanical specificity of the jump movement – very few jumping movements in sport are executed without using the arms. Removing arm swing also has the effect of reducing jump height (in comparison to the corresponding test performed with arm swing) (Feltner et al., 1999; Markovic et al., 2004). Arm swing is shown to augment torque-generation at hip and knee joints during the propulsive phase of the vertical jump (Feltner et al., 1999). Another related methodological consideration is that jumping (with arm swing) to reach a target overhead has been shown to influence both movement mechanics and jump height (Ford et al., 2005). It follows that an overhead goal should be a feature of the field test apparatus used to measure jump height where possible – and that arm swing (and reach) should be permitted during the test movement.

In accordance with the methodological and specificity considerations discussed, a field testing device using a jump and reach protocol (with arm swing and reaching up to touch measurement vanes positioned overhead) was reported to have the highest correlation with selection in a sample of elite ice hockey players (Burr et al., 2007). This study examined both squat (concentric-only) and countermovement jumps and compared correlations with the respective tests performed using a contact mat system and performed without arm swing. Jump and reach scores using the overhead measuring vane apparatus correlated more closely with the order of players' eventual order of selection in the National Hockey League draft than the corresponding squat and countermovement jump (no arm swing) scores on the contact mat system (Burr et al., 2007). The authors of this study concluded that the overhead measurement vane apparatus using a jump and reach protocol – in particular the concentric only squat jump and reach – was the most appropriate for office testing for elite ice hockey players.

It has been shown that a one-step initiation movement before executing a (bilateral) countermovement jump increases jump height (Lawson et al., 2006). The one-step lead in technique also alters the biomechanics and kinematics of the movement (joint angles and ground reaction forces) despite the fact that the jump is still executed from both the legs (bilateral stance). A study of male and female volleyball players found that players preloaded their lead leg during the step close version of the test, resulting in greater hip, knee, and ankle torques and ground reaction forces measured in lead leg versus trail leg (Lawson et al., 2006). Assessing both dominant and non-dominant leg as the lead leg during step close jumps can also indicate bilateral differences in performance between lower limbs. Single-leg variations of the standard vertical jump tests can be used in the same way (Newton et al., 2006). Likewise, vertical jumps with run-up of various distances (1-step, 3-step, 5-step) have also been used to assess power and athletic performance (Young et al., 2001a).

Horizontal jump tests

Standing long jump and standing triple jump are also used to measure lower body power in a horizontal rather than vertical movement. Such tests – particularly those involving multiple jumps, hops, or bounds – demand co-ordination and balance, in addition to speed-strength of the locomotor muscles (Hamilton et al., 2008). Consequently, one apparent methodological consideration with these horizontal jump tests is that subjects' familiarity with the movement will tend to influence the reliability of scores between trials (Markovic et al., 2004). Specifically, a motor learning effect has been observed with physical education students during a single test session – so that both standing long jump and triple jump performance tended to improve with consecutive trials (Markovic et al., 2004). For this reason practice trials are recommended prior to assessing performance, particularly during the initial stages when these tests are first introduced.

Triple-hop distance is another horizontal measure of speed-strength performance (Hamilton et al., 2008). Executing repeated hops again requires athleticism, balance, and postural stability in addition to speed-strength. Performance on the triple hop test was shown to be related to vertical jump performance in male and female collegiate soccer players (Hamilton et al., 2008). The strength of the association between triple hop test and vertical jump performance led the authors to conclude that the triple hop test was a valid measure of power performance in these players. The unilateral nature of repeated hop tests also allows comparison of performance between limbs. A five-hop variation of this test was shown to identify differences in performance between dominant and non-dominant limbs among collegiate female softball players (Newton et al., 2006). Accordingly, single-leg hop tests of this type have seen application in a rehabilitation setting to evaluate functional performance of injured versus uninjured leg (Hamilton et al., 2008).

Reactive (speed-)strength

Reactive strength concerns the coupling of eccentric and concentric muscle actions, and as such comprises both eccentric and concentric speed-strength qualities – in addition to stretch shortening cycle (SSC) components. Measurement of reactive strength for slow SSC movements involving longer ground contact are derived from comparing jumping tasks that are concentric only (e.g. squat jump height) versus those performed with countermovement (e.g. countermovement jump height). Lower limb reactive strength and fast SSC performance is likewise typically assessed via measures of drop jump height – so that the player must first decelerate and reverse their downward momentum before initiating an upward concentric jumping action (Newton and Dugan, 2002). When conducting drop jump tests to measure reactive strength, subjects are instructed to maximize jump height whilst minimizing the time in contact with the ground – so that they aim to initiate the jump as soon as the touch down after dropping down from the box. Drop jump height is also often expressed with respect to the player's corresponding countermovement jump height score.

If drop tests are carried out using a force platform or contact mat, then a 'reactive strength index' can also be used. This is calculated as a ratio between flight time (during the jump) and contact time (Newton and Dugan, 2002). The validity of these drop jump height measures is supported by the observation that drop jump height index scores correlated with sprint performance in female high school sprinters (Hennessy and Kilty, 2001). This form of assessment often involves multiple drop jumps executed from various box heights: drop height can then be plotted against heights jumped to provide a profile of the player's drop jump and fast SSC reactive strength capabilities. Players with a plyometric training background will tend to jump higher from a drop jump – so that the box height used in training can be increased until they reach a drop jump height that exceeds their fast SSC reactive strength capabilities. A study assessing athletes from different sports using a drop jump test from a relatively large height (60cm) showed that team sports (soccer, volleyball, handball, and basketball) players employed different motor strategies when compared to track and field athletes and rowers when performing the drop jump test (Kollias et al., 2004). Like other types of jump, the presence of vertical goal during drop jump testing appears to influence movement mechanics, lower limb biomechanics, contact time, and even jump height (Ford et al., 2005).

EVALUATING ENDURANCE PERFORMANCE

One approach used when assessing endurance capabilities of athletes is to test the individual physiological parameters that underpin endurance performance (Jones and Carter, 2000). Aerobic endurance is determined by both the athlete's aerobic fitness and their ability to sustain a high percentage of VO_2max. The latter component is in turn linked to the athlete's propensity to clear lactate and buffering capacity. The final factor in aerobic endurance is running economy or work efficiency. In the context of team sports it follows that any test should aim to replicate the type of locomotion that occurs during a game in order to address this movement economy factor when assessing aerobic endurance (Aziz et al., 2005). In the case of intermittent sports, such as team sports, anaerobic capacity which underpins repeated sprint ability is another critical factor that determines endurance performance.

Laboratory testing requires specialized equipment that is expensive and requires trained personnel to operate it. Given these cost issues, as well as the time demands of testing each player individually, laboratory testing is not generally amenable to application with squads of players (Impellizzeri et al., 2005). In the case of intermittent sports, and particularly team sports, laboratory testing is typically restricted to a research setting. Field tests have therefore been developed that offer a more practical alternative for use with players who compete in intermittent sports. As the field test protocols are often closer to what occurs in intermittent sports, these tests are also often considered more relevant by players and coaches in these sports than laboratory tests (Bosquet et al., 2002). Scores with these field tests exhibit high correlations with laboratory test measurements (Bosquet et al., 2002) and regression equations can be used to derive estimated scores for VO_2max (Impellizzeri et al., 2005).

Field-based maximal tests of cardiorespiratory fitness

20m Multi-stage shuttle test

The most popular field tests of aerobic fitness for field sports players typically involve variations of a shuttle run protocol (Castagna et al., 2006). The 20m multi-stage fitness test has become a standard field test for aerobic endurance, for both athletic and other populations (Flouris et al., 2005; Wilkinson et al., 1999). Measured VO_2max during the 20m multi-stage shuttle test (MST) has shown to correspond well with laboratory measured VO_2max during a maximal treadmill test for team sports players (rugby players and field hockey players) (Aziz et al., 2005). The fact that endurance athletes' (triathletes and runners) scores showed different VO_2max scores between the field and treadmill tests points to the greater familiarity and specificity of the shuttle run test mode for team sports players as opposed to endurance athletes.

The 20m MST has been adapted for other sports: an on-ice version of the test was devised and validated for ice hockey players (Leger et al., 1979). Variations of the original 20m MST have also been proposed. These include a modified incremental 20m shuttle test that increases running speed after each shuttle (Wilkinson et al., 1999), as opposed to increasing velocity at 1-minute intervals as occurs with the original version of the test. The authors of this study argue that such an approach avoids the tendency of players to drop out at the start of a given level, as can happen with the original test protocol (Wilkinson et al., 1999). Such a scenario may make the original 20m MST less sensitive to changes in training status as players may voluntarily drop out once they have achieved their target level rather than continue to volitional fatigue.

Yo-Yo intermittent test

Other field tests of aerobic endurance that are widely used in team sports include the Yo-Yo intermittent fitness test, which has become particularly popular in soccer (Metaxas et al., 2005). The most striking feature of the Yo-Yo intermittent test protocol is that players do not run continuously. The test requires subjects to perform repeated bouts of running (two sets of 20m shuttle runs) at increasing intensity; these work intervals are interspersed with 10-second rest periods (Bangsbo et al., 2008). A correlation study concluded that, although the two measures were correlated, this intermittent test protocol assessed additional physiological qualities to the continuous 20m shuttle test (Castagna et al., 2006). The Yo-Yo intermittent test protocol would appear to more closely resemble the intermittent nature of exertion that players engage in during competition. Two versions of the Yo-Yo intermittent test protocol exist: Yo-Yo Intermittent Recovery Level 1 (IR1) begins at a slower running velocity and so features more progressive increases in running speed; Level 2 (IR2) starts at a faster velocity so that subjects engage in high-intensity exertion much sooner (Bangsbo et al., 2008). Both versions of the test have been found to have acceptably high levels of test–retest reliability with various groups of subjects.

Regression equations also exist to predict VO_2max from both IR1 and IR2 Yo-Yo Test performance. However, some studies have found that the Yo-Yo intermittent field test offers a less-accurate measure of VO_2max than laboratory-based treadmill tests that directly measure oxygen consumption (Metaxas et al., 2005). From a practical viewpoint it should be borne in mind that obtaining a measure of VO_2max is of relatively less importance than providing an assessment of the endurance capacity of players competing in intermittent sports, which will inevitably feature an anaerobic component to a varying extent. Two studies offer data to support this assertion: the first was a study of Australian Rules football that showed VO_2max scores showed no difference between starting players and substitutes, whereas Yo-Yo IR2 test scores did differentiate between starting and non-starting players (Young et al., 2005). The second study – this time in soccer – found that Yo-Yo (IR1) test scores recorded by soccer players were shown to correlate to their on-field performance (quantity of high-intensity running total undertaken during games), whereas their treadmill VO_2max scores did not (Krustrup et al., 2003). Both these studies indicate that it appears to be beneficial for field tests of endurance to feature an anaerobic component – such as is demanded by interval-based protocols – in order to be reflective of the specific endurance capabilities required by intermittent sports.

The Yo-Yo IR2 protocol is intended for use specifically by trained athletes: it is run at faster cadence – hence test duration is shorter – and based upon lactate profiles and muscle biopsy samples, is considered to have a large anaerobic component (Bangsbo et al., 2008). For this reason it has been suggested that the IR2 protocol has greater scope for discriminating between elite players and those competing at lower levels of competition, given the greater demand for high-intensity exertion during matches at elite level. Crucially, both IR1 and IR2 tests also appear sensitive to training-induced changes in fitness and improvements in on-field performance (time spent engaged in high-intensity running and maximum distance covered in five-minute interval during a match) (Bangsbo et al., 2008).

Sport-specific test protocols

An alternative approach to assessing endurance performance for sports is to test players' scores on specific tests designed to replicate the endurance demands of the sport (Hoff, 2005; Impellizzeri et al., 2005). Both treadmill (laboratory-based) (Sirotic and Coutts, 2007) and field-based (Hoff, 2005) sport-specific endurance tests of this type have been developed. Such tests aim to simulate movement patterns and even incorporate technical skills that feature in the sport in order to increase the level of specificity of the test measure (Impellizzeri et al., 2005). The integrated approach used by such sport-specific protocols thus attempts to assess endurance performance in a way that reproduces the bioenergetics of the sport. As such, these tests do not offer insight into individual physiological components; rather energy systems and performance abilities are assessed in combination (Impellizzeri et al., 2005). Serious limitations to this approach however exist – such as the difficulty in standardizing conditions in order to obtain a reliable and repeatable test measure. Similarly, the challenge with these sport-specific test protocols is accumulating sufficient normative data to provide reference values to evaluate players' scores against. In the case of treadmill 'sport-specific' simulations, the usual practical issues with regard to laboratory-based testing for large numbers of players also arise.

Submaximal tests of endurance fitness

When performing serial measurements with players, repeated use of maximal tests may engender motivation and compliance issues. Progressive tests to exhaustion are dependent upon the motivation of players to perform maximally (Lemmink et al., 2004). In view of this, attention has been given to submaximal tests for endurance performance. Submaximal tests would seem to be more conducive to repeated testing at regular intervals given that they avoid such complications with respect to motivation and compliance (Impellizzeri et al., 2005; Krustrup et al., 2003; Lemmink et al., 2004).

Such submaximal tests are often modified versions of existing progressive maximal test protocols – essentially the test is just terminated at a predetermined submaximal workload. The test scores recorded are generally based upon measurement of physiological responses (e.g. heart rate) during and/or following the standardized final (submaximal) workload (Lemmink et al., 2004). In the laboratory, ventilatory and heart rate responses can be recorded to provide a measure of how taxing the submaximal workload was for the player on a given test occasion. A notable example of an equivalent field-based test is the submaximal 'non-exhaustive' version of the Yo-Yo test of aerobic fitness (Bangsbo et al., 2008). The protocol used is identical to the maximal version of the test – up until the point when it is terminated 'early' at a submaximal workload. One practical issue with field-based submaximal tests is that these tests do still require that physiological responses (typically heart rate) are monitored – consequently, all participating players must have access to relevant equipment (i.e. heart rate monitors) (Krustrup et al., 2003).

It appears that submaximal test protocols must exceed a minimum threshold duration in order to ensure that the outcome measure does show the desired relationship with maximal performance. A 3-minute submaximal version of the Yo-Yo test was reported to be insufficient, whereas a 6-minute protocol did show correlation to maximal Yo-Yo test scores (Bangsbo et al., 2008). Similarly, the data suggest that the higher the final workload (running speed) chosen for the final stage of the submaximal test, the greater the reliability of the physiological measure – particularly in the case of heart rate (Lemmink et al., 2004). This final test workload may be determined by baseline testing for the squad of players using a maximal version of the test: the protocol would of course remain standard for the duration of a season of testing. As these tests involve serial measurements, each player essentially acts as his/her own reference for evaluating scores against.

Lactate threshold

Although lactate-handling capacity may be more sensitive to changes in endurance performance with team sports players, the measure used to assess this parameter has a major bearing in terms of comparing players' scores. Classically, the criterion for 'onset of blood lactate' (OBLA) or lactate threshold (LT) has been a fixed concentration of blood lactate (BLa) – typically 4mmol/l (Bosquet et al., 2002). Deflection point(s) in the curve between running velocity and measured BLa are also used as a measure of LT. Such tests are typically carried out in the laboratory to allow running velocity to be standardized and facilitate BLa sampling.

Methods for indirect evaluation (without taking BLa samples) of LT or the equivalent 'anaerobic threshold' (AT) also exist, which are based upon changes detected in ventilatory or heart rate responses (Bosquet et al., 2002). The validity of the 'ventilatory threshold' (VT) model has been questioned on the basis that its determination is highly subjective and also highly variable, as well as being dependent on the criteria chosen. It has also been demonstrated that the LT and VT can be manipulated independently under different conditions (Bosquet et al., 2002). Similarly, heart rate-based procedures are undermined by serious doubts about whether such a physiological deflection point in heart rate responses actually exists, and, if it does, whether it bears any relation to LT (Bosquet et al., 2002).

Serial measurement of LT has been used to track fitness among junior professional soccer players via repeated measurements at preseason and periodically during the subsequent playing season (McMillan et al., 2005a). The only significant change on these measures was observed between baseline preseason scores and the in-season test scores – there were no changes subsequent to the start of the playing season. These serial LT measures were therefore sensitive only to the gross changes in fitness between preseason (which players entered in a relatively detrained state following a five-week off-season period without structured training) and the start of the playing season (McMillan et al., 2005). This apparent lack of sensitivity combined with the lack of specificity and aforementioned practical issues of laboratory testing a squad of players, in addition to the methodological concerns regarding LT measurement, would seem to call into question the validity of this form of testing for team sports players.

Maximum lactate steady state (MLSS) has been proposed as an alternative form of assessment of lactate handling for athletes. MLSS is defined as the maximum intensity at which lactate clearance matches lactate production – i.e. the highest workload that can be sustained without accumulation of BLa (Billat 2003). From this point of view MLSS is equivalent to the theoretical upper LT at the deflection point in the curve of lactate concentration plotted against exercise intensity. Classically, this LT has been taken to correspond to a concentration of BLa of 4 mmol.l^{-1} – this has been widely used to denote the OBLA. However, recently it has been documented that the actual concentration of BLa that corresponds to this MLSS workload varies widely between individuals, falling between a broad range of values from 2 mmol.l^{-1} to 8 mmol.l^{-1} (Billat 2003). This 4 mmol.l^{-1} OBLA value thus appears to be an arbitrary figure, which bears little resemblance to the actual BLa concentration at MLSS for many individuals. For the same reasons, comparing absolute values of BLa concentration sampled within and between studies would also appear spurious without the appropriate reference MLSS BLa concentration values for each subject.

Given these methodological and theoretical concerns regarding traditional LT measures, the MLSS measure would appear to be a more robust and valid marker for use as a parameter of endurance performance. However, determination of MLSS involves a time-consuming protocol typically carried out in a laboratory. Direct measurement of MLSS is also invasive in the sense that it relies upon repeated BLa sampling. Such considerations raise questions about the practicality of including assessment of MLSS in a standard battery of performance tests for a squad of players.

Assessment of running economy or work efficiency

Exercise economy is typically assessed as the oxygen uptake (VO_2) at a given work intensity (Jones and Carter, 2000). Running economy is therefore commonly assessed in the laboratory by measuring the athlete's oxygen uptake at a reference running velocity on the treadmill. Portable gas analysis equipment does exist that allows similar assessments to be made in the field implementing appropriate pacing on the track to standardize velocity; however, this tends to be less widely used. Running economy and work efficiency measures will be highly specific to both the mode (Millet et al., 2002a) and velocity of locomotion (Jones and Carter, 2000) used in testing. Measuring work economy measurement for team sports players would therefore require that both the different modes and velocities of locomotion that feature in a game are accounted for. To date, no such protocol exists for team sports players.

Repeated sprint endurance or 'anaerobic capacity'

The standard measure of anaerobic capacity in the laboratory evaluates maximally accumulated oxygen deficit (MAOD) – the measured difference between estimated oxygen demand and measured oxygen uptake during a maximal exercise test (Moore and Murphy, 2003). As discussed previously, such laboratory-based physiological testing is generally impractical for routine assessment of team sports players. A field protocol that has been reported to correlate well with MAOD measured in the laboratory involves a maximal 20m shuttle running test over a total distance of 300m – the time taken to cover this distance is the outcome measure (Moore and Murphy, 2003).

Other approaches to assessing repeated sprint ability and also prescribing intensity for interval conditioning aim to assess Maximal Aerobic Speed (MAS). This is defined as the minimum work intensity at which VO_2max can be attained (also known as '$v\text{-}VO_2max$') and has traditionally been assessed using laboratory protocols with direct measurement of expired air. Field tests of MAS have, however, also been developed that have greater ease of application for team sports players particularly. The 20m multi-stage shuttle run test and Yo-Yo test described previously can be applied in this way. Another protocol – the 30–15 intermittent Fitness Test ($30\text{–}15_{IFT}$) – has also been developed specifically for the purpose of identifying running speed at VO_2max in the field and in turn individual prescription of interval conditioning (Buchheit, 2008). This protocol is intermittent in nature: subjects run shuttles for 30 seconds at a given velocity interspersed with 15 seconds active recovery bouts; running velocity for the work bouts is progressively increased. The $30\text{–}15_{IFT}$ has been validated against other $v\text{-}VO_2max$ directly measured in the laboratory and standard field tests that provide a measure of MAS. Scores on the $30\text{–}15_{IFT}$ correlated with these measures and other tests of speed (10m sprint) and power (vertical) in young team sports players (Buchheit, 2008).

More common field-based methods of evaluating repeated sprint endurance evaluate performance on a series of maximal efforts. A protocol of this type employing a series of shuttle sprints over 5m increments (up to 25m) was reported to be reliable for field hockey players. This protocol measures total distance covered over the shuttle run course in 30 seconds; the players then have a 35-second recovery prior to completing the next effort – in total, players complete a set of six 30-second maximal efforts interspersed by 35-second recovery intervals (Boddington et al., 2001). Total distance covered over the six 30-second efforts was reported to be the most reliable performance measure with this protocol.

Other field tests of repeated sprint endurance have been developed in various sports. One such test that is widely used in basketball is known as the 'suicide run'. The suicide run test involves shuttle sprints between markings on the court (nearest baseline, nearest free throw line, midcourt line, farthest free throw line, farthest baseline); a set rest period is allowed between repeat runs. Interestingly, it has been reported that active recovery (light jogging) rather than passive (standing still) recovery during the 90-second interval between trials did not appear to affect performance on a second suicide run (Graham et al., 2003). However, based on other studies concerning the physiological and performance effects of active versus passive recovery between bouts of high-intensity exercise (Bogdanis et al., 1996a) it seems prudent to allow players active recovery between trials when assessing repeated sprint endurance.

Similar field test protocols assess repeat performance on straight-line sprints rather than shuttle sprints. One such protocol, known as the RSA (Repeated Sprint Ability) test, involves six 40-m sprints; players start each consecutive sprint at 30-second intervals (Lakomy and Haydon, 2004). Players are scored on both sprint times and 'fatigue index' – i.e. percentage drop off in sprint times over the six sprints. This test is reportedly widely used, particularly with field hockey players (Lakomy and Haydon, 2004). A similar test has been devised for basketball players: sprints are over a shorter distance of 15m and ten sprints are completed in total, with 30 seconds passive recovery between each sprint (Castagna et al., 2007). As discussed previously, the utility of tests of this type is dependent to a large extent on sufficient normative data for the athletic population to provide reference values to compare players' scores against.

ASSESSING SPEED COMPONENTS

In the context of team sports, speed comprises the ability to move at high velocity in a variety of directions – often not in a straight line. Another critical factor is the player's ability to change direction at pace. Players' scores on straight line sprinting and tests of change of direction performance typically show only limited statistical relationship. In a study of professional soccer players' scores on acceleration, maximum speed, and change of direction, tests were reported to share low coefficients of determination (Little and Williams, 2005). The authors concluded that these are distinct and separate abilities – accounting for the fact that the corresponding scores were relatively unrelated in these players (Little and Williams, 2005). Furthermore, correlations between measures of these abilities reportedly decrease markedly when any sport skill component is incorporated in the agility test (Young et al., 2001b). This appears to reflect the dissimilarity of movement mechanics between straight-line running and the locomotion employed during change of direction tasks (Sheppard and Young, 2006; Young et al., 2001b). Major differences include stride mechanics and the requirement for deceleration and lateral acceleration – including hip abduction and generation of medial–lateral ground reaction forces (McLean et al., 2004).

The contention that straight-line sprinting and change of direction abilities are relatively independent of each other is supported by the very limited transfer to change of direction performance shown following a period of straight-line sprint training (Young et al., 2001b). As the complexity of the agility test increased (greater number of changes in direction and more acute angles of cutting), the degree of improvement following the straight-line sprint training became less. The converse also appears to be true of agility training. Following agility training, performance was improved in a selection of tests with varying numbers of changes in direction – however, no improvement was seen on a straight-line test (Young et al., 2001b). Again, the greatest carry-over was observed on the tests with similar change of direction complexity and angles of cutting to that featured in the agility training undertaken (Young et al., 2001b). Given that these change of direction abilities which underpin agility performance are independent of straight-line sprinting ability, a number of authors have advocated that separate test measures are required and that these abilities should be addressed via specific training (Jeffreys, 2006).

A number of electronic timing gate systems are commercially available that offer high degrees of accuracy (to nearest hundredths or thousandths of a second) and reliability. Such timing gates are amenable to both straight-line sprinting tests and change of direction tests; this equipment is also portable and therefore suitable for field testing. From a context specificity viewpoint it would appear advantageous that testing should take place on a similar surface and setting to that upon which players train and perform (Handford et al., 1997). One caveat for sports that are played outdoors on a grass surface is that weather and pitch conditions may vary, which can influence serial measurements over time. From the point of view of standardization it may therefore be preferable to use an all-weather artificial surface or indoor artificial turf facility for field-based running speed assessments in these outdoor field sports.

Measures of straight-line acceleration abilities

Split times over 5m have been used as a measure of 'first-step quickness' (Cronin and Hansen, 2005), and the player's split time over 10m or 15m is often used to evaluate acceleration ability. Whereas the 'first-step quickness' time over 5m and 'acceleration' 10m time correlated closely in semi-professional and professional rugby league players, their 5m times were much less closely related to their maximal speed scores over 30m (Cronin and Hansen, 2005). This would appear to indicate that acceleration and maximal speed are quite distinct abilities in team sports players – hence should be evaluated as such.

Assessment of straight-line running speed

Sprint tests commonly used in team sports use similar total distances – typically 30- or 40-m when assessing maximal running speed – for example, the NFL Combine features the 40-yard dash (Sierer et al., 2008). In addition, these tests often include split times over specified distances (5m, 10m, 20m) in order to concurrently assess acceleration ability, as discussed above.

Commercially available timing gate systems offer greater ease and accuracy of measurement – particularly if attempting to evaluate split times.

TESTING AGILITY PERFORMANCE

Commonly employed 'agility tests' in fact assess only change of direction performance: 'agility' is defined in terms of change of direction or velocity in response to a stimulus (Sheppard and Young, 2006). This stipulates that there must be some element of reaction and/or decision-making in any true assessment of agility. Some change of direction tests do incorporate simple reaction cues, such as responses to lights or similar cues. However, this does not represent a valid measure of the game-related information-processing and decision-making factors that contribute to team sports agility performance (Sheppard and Young, 2006).

Regardless of these issues, change of direction tests are of relevance: change of direction abilities are a foundation of agility performance. As such, tests of change of direction performance do provide important information, which justifies their inclusion in any battery of tests for team sports players.

Tests of change of direction performance

A variety of tests exist that measure change of direction ability (Sheppard and Young, 2006; Young et al., 2001b; Little and Williams, 2005). Typically, these tests are run over a course that features 90-degree and/or 180-degree change of direction angles – with a start/stop timing gate or stop watch to record time taken to complete the course. A large number of protocols exist that are used in different sports, just a selection are presented here. As with other tests of athletic performance, there are two major considerations when selecting a test protocol. The first is the extent to which the protocol resembles the movement demands required in competition. The second is how much normative data exist for the test to provide a reference to evaluate players' scores against.

The '505 Test' features just one 180-degree pivot and turn: the player sprints forward 5m, pivots and turns to sprint 5m back to the start line (Sheppard and Young, 2006). The Pro Agility shuttle test that features in the NFL Combine is an extended version of the 505 Test: the player sprints 5 yards, pivots 180-degrees to sprint 10 yards in the opposite direction before executing a final 180-turn to sprint 5 yards back to the start line (Sierer et al., 2008).

Another test that features in the NFL Combine is the 3-cone drill – this change of direction performance test was actually found to have the greater correlation to draft pick rank (Sierer et al., 2008). The course players run features a cone placed 5 yards in front of the start/finish cone, with a third cone placed 5 yards to the right of the second cone. The course thus features a 90-degree cut to the right, a 180-degree pivot and turn, and a 90-degree cut to the left before the player returns to the start/finish cone.

A standard test of change of direction performance is the T-test: this consists of a 10m sprint forwards to a cone placed at the centre of the 'T', followed by 90-degree lateral cuts to reach cones placed 5m away to the left and right of the centre cone before sprinting 10m back from the centre cone to the start/finish cone. The Illinois agility test is another well-established protocol that features multiple slalom cuts through cones and 180-degree turns (Sheppard and Young, 2006). Possibly due to the complexity of the movement required, this protocol appears to have fallen out of favour among coaches.

Change of direction tests that incorporate a sports skill component have also been studied. For example, the reliability of a range of field-based tests of change of direction, sprinting ability, and power for soccer players have been investigated. Comparison of performance (i.e. run time) on a change of direction course when performed without a ball and whilst dribbling a ball have also been used in order to provide a 'skill index' measure (Mirkov et al., 2008). While such tests may be useful for comparing scores of players within a squad, a lack of adequate normative data for different populations makes further interpretation difficult.

BALANCE AND STABILITY TESTING

Single-leg balance and stabilization

Postural balance

Postural balance is defined as the ability of an individual to maintain their centre of mass within their base of support (Hrysomallis, 2007). Practically, balance ability involves input from visual, vestibular, and somatosensory systems (Hamilton et al., 2008) – the latter comprises pressure receptors in the skin, joint receptors, and muscle/tendon mechanoreceptors. When assessing balance it is important therefore to account for each of these subsystems which contribute to balance ability. For example, an eyes-closed variation of a test removes visual system input. Similarly, balance tests involving turning the head or raising/lowering the chin attempt to isolate vestibular system input.

Standard tests of balance ability commonly measure time that the player is able to maintain equilibrium under a given set of conditions (e.g. stable/labile surface, eyes closed/open). Alternatively, the number of attempts taken to balance under a given set of conditions for a specified time period is recorded (Hrysomallis, 2007). A field test of single-leg balance performed standing with eyes closed for 10 seconds was employed with collegiate players competing in (men's) American football, men's and women's soccer and women's volleyball (Trojian and McKeag, 2006). Players' scores on this test were reportedly predictive of subsequent ankle injury incidence during the playing season. Equipment such as ankle disks, foam mats, and wobble boards are also widely used for balance testing. Some balance board apparatus are built with contact sensors incorporated into the device in order to detect loss of equilibrium – and thereby provide a quantitative measure when scoring the test (Hrysomallis, 2007).

Force platforms (both laboratory-based and portable systems for field testing) are commercially available that allow postural sway to be measured by recording movement of the subject's centre of pressure. Such equipment can similarly be used to assess (static) balance ability under given conditions (bilateral vs unilateral stance, eyes open/closed, etc). In a research setting, force plate centre of pressure and ground reaction force measurement have been used in combination with tibial motor nerve stimulation, in order to create 'external' disruption of balance and derive a 'time to stabilization' measure (Brown and Mynark, 2007). However, such testing involving costly equipment and specialist staff to interpret the data is unlikely to be feasible for routine testing of healthy players.

Tests of postural balance ability described above are commonly used as part of screening prior to beginning a programme of physical preparation – see section below. Scores on postural balance are frequently used to identify players with chronic ankle instability (Brown and Mynark, 2007). The other common application is during rehabilitation – particularly following knee or ankle injury – providing a tool to guide progression and to serve as a basis to make judgements regarding readiness to return to full training or competitive play (Wikstrom et al., 2006).

Dynamic stabilization

Dynamic stabilization can be defined as postural balance – i.e. maintaining centre of mass over base of support – during movement (Brown and Mynark, 2007). This capacity comprises both neuromuscular control and integrated function of various systems that provide dynamic stability to the lower limb joints (Wikstrom et al., 2006). It has been asserted that dynamic stabilization and static postural balance are discrete abilities and that measures of the two abilities are not strongly related to each other (Brown and Mynark, 2007). Tests of dynamic stabilization typically assess the player's ability to make the transition from movement to a static stance – for example, jumping or hopping onto either a stable or labile surface and holding the landing. Assessments of dynamic stabilization in a laboratory or clinical setting commonly involve hopping or landing from a box onto a force plate. Measures recorded include postural sway, ground reaction force, and time to stabilization (Wikstrom et al., 2006). Another assessment that has been used in clinical and research settings uses electromyography (EMG). Surface EMG electrodes are used to detect preparatory and reactive muscle recruitment and activity when subjects perform movement tasks or respond to challenges in balance (Wikstrom et al., 2006). Such laboratory and clinical assessments do, however, require specialized equipment and appropriately trained personnel to interpret the test data. Given the cost, time, and access to specialized staff and equipment involved, these tests are therefore likely to be impractical for routine testing for a squad of players.

Lumbopelvic 'core' stability

There are different subsystems that each contribute to stabilizing the trunk and lumbar spine (Gamble, 2006). The particular combination of muscles that contribute to providing lumbar spine stabilization varies depending on posture and nature of the activity (Juker et al., 1998). Furthermore, in a weight-bearing posture – the position in which lumbopelvic stability is most commonly exhibited during sports performance – the hip musculature that helps stabilize the pelvis and support lower limb(s) also plays a critical role. As such, during weight-bearing, lumbopelvic stability has elements in common with postural balance and dynamic stabilization. There is therefore inevitably some cross-over into postural balance and dynamic stabilization when attempting to assess lumbopelvic stability during upright stance or weight-bearing movements.

Given the complex and multidimensional nature of lumbopelvic stability described, no standard test for core stability currently exists. Standard endurance tests for the trunk muscles measure the time an athlete is able to maintain a given position or posture (McGill, 2007). Examples of such tests include the side bridge, flexor endurance test, and static back extension 'Biering–Sorensen' endurance test (Carter et al., 2006). Normative data have been published for these tests with healthy subjects as a reference for comparison from the perspective of identifying low-back injury risk (McGill, 2007). Ratios of flexor versus extensor scores and comparisons between sides (in the case of side bridge) are suggested to be most useful in identifying low-back pain and injury risk.

Another test more typically performed in a laboratory or clinic assesses the player's ability to maintain trunk muscle activation during challenged breathing. The laboratory version of the test involves the player maintaining a quarter squat position with weights held in the hands whilst breathing a lowered oxygen/raised CO_2 mixture – activity of core muscles is assessed via EMG recordings (McGill, 2007). In the field-based variation of the test, the player first performs a bout of exercise to raise their respiration rate and the clinician then assesses their ability to maintain muscle activation by palpating the player's oblique abdominal muscles. The laboratory test carries the usual issues of time, cost, equipment, and need for specialist staff common to all laboratory-based assessments – for this reason, it is unlikely to be included in a standard battery of tests for a large squad of players. The field-based version of the test, whilst more practical and less costly, is subjective and relies upon the judgement of a suitably trained clinician (physiotherapist or athletic trainer).

Field-based clinical tests of torsional stability that are becoming routinely employed in functional screening protocols also exist (see next section). Two examples are the 'push-up test' (of which there are two variations) and the 'back bridge test' (McGill, 2007). The push-up test is performed in an extended plank (push-up) position with the player alternately lifting off each supporting arm whilst attempting to maintain a static posture (McGill, 2006c). A variation of this test involves alternately raising a supporting foot from the same extended plank position. The back bridge is performed from a full bridge position (player is supine, supported on the heels and shoulders, knees flexed, hips raised off the ground): whilst maintaining a stable position the player attempts to raise each foot off the ground alternately (McGill, 2007). These tests are qualitative: they are subjectively scored by the assessor based upon set criteria (Cook, 2003a). Similarly, tests of torque generation involving projecting a medicine ball from a seated posture have been used as a measure of the concentric 'power' of the core stabilizer muscles (Cowley and Swensen, 2008). While preliminary data suggest these scores on these tests may satisfy reliability criteria the relationship with athletic performance and/or injury risk remains to be established.

In much the same way as for postural balance, devices have also been converted in order to measure ability to maintain equilibrium whilst holding a core stability exercise posture. One study examined subjects' core stability by evaluating their attempts to maintain core stability postures on a stability platform device commonly used to assess postural balance in standing (Liemohn et al., 2005). There did appear to be a considerable learning effect associated with this form of testing. Subjects were studied on four consecutive days with the device: the data recorded on day three was found to be the most reliable (Liemohn et al., 2005). Whilst this appears a promising area of study, there is currently a paucity of published data with such testing apparatus.

MUSCULOSKELETAL PROFILING AND MOVEMENT SCREENING

Traditional musculoskeletal assessment protocols comprise static measurement of posture and passive examination of joint integrity and range of motion (Ford et al., 2003). There are limitations to assessing neuromuscular and musculoskeletal factors in this way: the way that joints and muscles respond during passive tests provides limited information on how the body behaves under dynamic conditions. Another issue is that there is commonly inadequate follow-up to screening: it has been reported that although musculoskeletal problems are identified via such tests in 10 per cent of athletes, appropriate intervention is typically undertaken in only 1–3 per cent (Ford et al., 2003).

That said, some clinical tests of musculoskeletal function have been shown to be predictive of intrinsic (athlete-related) injury risk. Tests of joint range of motion and muscle flexibility are recommended as a means to identify players at risk of muscle strain injury. Preseason baseline scores on quadriceps and particularly hamstring flexibility were shown to be predictive of subsequent muscle strains in Belgian professional soccer players during the following playing season (Witvrouw et al., 2003). The authors concluded that scores below 90 degrees on a passive test of hamstring muscle flexibility identified players at risk of hamstring injury. A similar relationship was reported with reduced ROM scores and adductor muscle strains in a study of soccer players in Iceland (Arnason et al., 2004). Clinical tests of joint integrity also typically identify joint laxity in the majority of players who have suffered previous joint strains (Arnason et al., 2004). Previous injury is often identified as a significant risk factor, so injury history and such clinical tests of joint laxity are important to identify players at risk.

Although the application of isokinetic testing and training has been questioned from a performance viewpoint, it does have applications for injury prevention and monitoring rehabilitation. Isokinetic assessment of strength ratios – for example, between internal and external rotators of the shoulder – can help identify muscle strength imbalances that can predispose players to injury. Comparison of isokinetic measures between previously injured and healthy contralateral limbs appears to identify players at risk of recurrent hamstring injury. These isokinetic scores and ratios (particularly eccentric and mixed eccentric/concentric ratio measures) show potential for use as a test for readiness to return to competition following a programme of rehabilitation (Croisier et al., 2002). Similarly, isokinetic testing profiles assessing the optimal angle (knee angle at the highest recorded concentric knee flexor torque) are also shown to differentiate between injured leg and uninjured contralateral limb in players with a history of recurrent hamstring injury (Brockett et al., 2004).

Increasingly, movement-based screenings are being used alongside or even in place of standard clinical musculoskeletal assessments. These commonly comprise active tests of mobility to supplement the passive tests of joint range of motion and dynamic tests of stability. Movement screens also typically feature in this form of assessment: these involve qualitative assessment of how well the player is able to perform fundamental movement skill tasks – such as variations of squat and lunge movements (Cook, 2003). These practices were popularized by Gray Cook a noted physiotherapist and strength and conditioning coach, and their use has become widespread in recent years among sports medicine professionals as well as those working in strength and conditioning.

Evaluation of motor patterns and abilities for fundamental movements is identified as a key part of athletic assessment that is likely to have implications both for performance and injury prevention (Cook, 2003a). Players will tend to compensate for imbalances or areas of poor mobility and reduced stability by adopting altered movement mechanics. By their nature, these compensatory movement patterns are less efficient, will tend to inhibit performance, and can predispose the player to injury (Cook, 2003a). For these reasons it is argued that flaws in movement patterns for these fundamental movements must first be identified and addressed before progressing onto more advanced training (Cook, 2003a). Likewise it is advocated that areas of poor mobility and stability identified be addressed as part of the player's individualized programme.

The rationale presented by Cook for movement screens and 'functional' assessment of mobility and stability appears sound in theory, and anecdotally many practitioners have used this form of assessment with some success. However, there remains a lack of published data validating these methods. To date, there is no body of evidence to support the hypothesized relationship between performance on these tests and subsequent injury incidence or athletic performance. Whilst this is an area that does show considerable promise, there remains a need for studies to provide evidence in support of the use of these methods.

There are examples in the literature of clinical tests designed to assess functional performance that were not subsequently found to be predictive of injury risk. Performance on a balance board test was found to have no relation to ankle sprain injury incidence among high school athletes (McHugh et al., 2006). The rationale for assessing proprioception and postural stability in this way would appear to be sound in theory from the point of view of injury prevention, given that these are risk factors for ankle injury. However, the lack of correlation found reinforces that a causal relationship cannot just be assumed and that tests must be validated in order to be confident of their relevance. Given this, the inclusion of such tests in players' musculoskeletal screening and movement profiling would have to be considered until their efficacy has been demonstrated.

CHAPTER 3

STRENGTH TRAINING

INTRODUCTION

Specificity is manifested in both the ability of the athlete to express their strength in a particular athletic movement and the capacity for a particular mode of strength training to carry over to sports performance. Fundamentally, a player's strength capabilities when lifting in the weights room is of less relevance than their ability to express that strength when executing athletic and skilled movements on the field of play.

A foundation of strength training is described by the acronym SAID: *Specific Adaptation to Imposed Demands* (Baechle et al., 2000). Simply, any physiological adaptation produced is dependent on the specific form of overload provided by the strength training stimulus (Stone et al., 2003). The obvious application of specificity with regard to strength training is exercise selection. Biomechanically, the closer the particular training exercise to the movement patterns and velocity of the sports-related action, the greater the degree of carry-over is likely to be (Stone, 1993). For this reason, lifts that are closer to what the player faces on the field of play are viewed as preferential to alternative exercises for the same muscle group(s).

In turn, the requirement for a particular strength quality for a team sports player will depend on the typical demands placed upon them during competition. It follows that sport-specific and position-specific considerations should be addressed in the design of the player's strength training, in order to develop the required combination of strength qualities for the sport and playing position.

The final consideration for strength and conditioning specialists is that strength training design should also be specific to the needs of the player. From this viewpoint a starting point in attempts to tailor a programme for a player might include musculoskeletal and movement profiling, in combination with a battery of performance tests to identify any areas in need of particular attention.

Components of strength

Strength is typically defined in terms of the greatest amount of force or torque an individual can generate during a maximum voluntary contraction under a given set of conditions (Abernethy et al., 1995). Individual testable qualities can be isolated that comprise the global term strength (Newton and Dugan, 2002). For instance, there is a distinction between force-generating capacities (i.e. strength) at faster movement velocities and slow velocity or zero velocity.

High-velocity strength comprises force-generating capacities at faster contraction velocities (Newton and Dugan, 2002).

There is a further distinction between slow velocity maximum strength and isometric strength.

Slow-velocity strength is defined as the maximum weight that can be lifted in a dynamic fashion, such as during an isoinertial lift (squat, deadlift, bench press, etc.).

Isometric strength is quantified as the maximum force that can be applied under static conditions.

At negative movement velocities – i.e. when the muscle is lengthening while contacting, as happens during braking and lowering movements – maximal torques are described in terms of ***eccentric strength***. For example, eccentric strength can be quantified as the maximum weight an athlete is able to lower through the full range of motion for a strength training exercise for a specified period (e.g. 5 seconds). Eccentric strength has the greatest magnitude of force of all strength components.

The combination of eccentric and concentric strength yields a further component, termed ***'reactive strength'***. Depending on the time interval across which force is applied this capability also involves stretch-shortening cycle (SSC) components. These can be further subdivided into fast SSC and slow SSC performance. Fast SSC reactive strength is demonstrated in tasks with very brief contact time (100–200ms) – such as sprinting. Slow SSC reactive strength is exhibited when time for force application is relatively longer (300–500ms) – for example, a countermovement jump.

All of the separate strength components described can be developed by strength training; the particular combination of strength training variables employed will determine the qualities that are developed. Training intensity, repetition scheme, and volume all interact to influence the specific strength training response (Baechle et al., 2000). The mode of strength training is another training parameter that greatly impacts strength training outcomes. Particular modes of strength training have greater transfer of training effect for a given strength quality than others, based upon the mechanics and kinetics of the training exercise (Stone et al., 2000a). Such factors determine the requirements for both intramuscular and intermuscular co-ordination. In turn, this influences the nature of the training adaptation elicited (Young, 2006) – for example, slow velocity strength versus high velocity strength (Baker and Nance, 1999).

Strength endurance

When athletes are required to perform movements repeatedly, other capabilities are implicated that relate to the strength qualities described. Strength-endurance, speed-endurance, and power-endurance are identified as discrete elements and should be considered independently, as opposed to merely derivatives of strength, speed, and power (Yessis, 1994). The capacity to activate musculature under conditions of fatigue has been identified as a trainable quality (Behm, 1995). Under conditions of fatigue, trained individuals appear to have superior ability to fully activate the musculature (Behm, 1995).

Neuromuscular co-ordination is implicated in speed-endurance and power-endurance, as movement efficiency plays a key role in both. Two key adaptations identified as underlying strength-endurance are acid-base buffering (Kraemer, 1997) and neural mechanisms (intramuscular co-ordination) that make the athlete better able to more fully activate fatigued motor units (Behm, 1995).

POTENTIAL ADAPTATIONS TO STRENGTH TRAINING

Neural adaptations to strength training

- Inter-muscular co-ordination:
  - Enhanced recruitment patterns and co-ordination of (agonist, antagonist, and synergist) muscles employed during the particular strength training movement (Young, 2006).
  - Reduced co-contraction of antagonists.
- Intra-muscular control:
  - Increased 'supraspinal' descending neural drive (increased firing frequency to motor neurons) from motor cortex (Aagaard et al., 2002).
  - Increased net excitatory input to motor neurons at local spinal level (Aagaard et al., 2002).

Hormonal responses and adaptations to strength training

- For most hormones, the acute release following each training session appears to be the more critical factor (Kraemer and Ratamess, 2005):
  - Resting concentrations of the major anabolic hormones (testosterone, growth hormone, insulin) are unchanged following a period of strength training when normal volumes and frequencies of training are being performed.
- Following a single bout of strength training exercise there is an acute (i.e. transient) reported up-regulation of hormone receptors.

- Following a period of strength training players may show an altered hormone response to individual bouts of strength training (Kraemer and Ratamess, 2005).
- Strength training also appears to elicit an adaptive response associated with catabolic hormone receptors:
    - Down-regulation of glucocorticoid (catabolic hormone) receptors is apparent following a period of strength training – indicative of reduced catabolic response to a bout of strength training exercise in strength trained individuals (Kraemer and Ratamess, 2005).

Morphological changes and muscle remodelling

- Transition between muscle fibre *subtypes* (no conversion between muscle fibre *types* – i.e. the proportion of Type I and Type II fibres remains unchanged) (Fry, 2004):
    - In particular there is a conversion of subtype IIB (Fast, glyocolytic fibres) to subtype IIAB (intermediate) and onto Type IIA (fast, oxidative, glycolytic).
- Conversion of Myosin Heavy Chain (MHC) isoforms (Fry, 2004):
    - Increase in proportion of Type IIA MHC.
- Increase in protein synthesis and protein breakdown following strength training workout (Fry, 2004):
    - Remodelling of contractile tissues.
- Changes in architecture of trained muscle (Aagaard et al., 2001):
    - Increases in pennation angle reported following a period (14 weeks) of strength training.
    - Allows for greater increase in muscle strength than can be accounted for solely by gross changes in muscle cross-sectional area.
- If favourable hormonal and environmental factors (e.g. nutrition status) post session then protein synthesis > protein breakdown (Fry, 2004):
    - Hypertrophy of muscle fibres recruited – net increase in whole muscle cross-sectional area.
    - Depending on strength training employed, there is typically a greater relative increase in cross-sectional area of Type II fibres compared to Type I fibres (Fry, 2004).

STRENGTH REQUIREMENTS OF TEAM SPORTS

There is currently a lack of contemporary strength testing data published from professional team sports players; what studies have been published have mainly concerned contact team sports. Scores on strength and power measures are shown to distinguish elite professional players in collision sports from those at lesser levels (Baker, 2001b; Baker, 2001d). This asserts the importance of developing strength properties for contact sports such as rugby football – in fact it appears to be a prerequisite for participation at the highest level (Baker, 2002). There is a significant progression reported in these strength qualities at each stage from high-school level, through college age, to senior professional level (Baker, 2002). Independent of any difference in lean body mass, elite professional rugby league players are able to express greater upper-body strength and power than semi-professional and college-aged players (Baker, 2001b; Baker, 2001d). Upper and lower body power measures of elite rugby league players are shown to be heavily dependent on their levels of strength (Baker and Nance, 1999a). Given the observed importance of strength and lean body mass it is thus crucial to maximize the effectiveness of the strength training players are able to perform within the constraints of other training and team practices.

In collision sports such as American football and rugby football, physical size and muscularity confer an advantage to the player during contact situations. Accordingly body mass and size of players in these sports have risen disproportionately in recent times. It is reported that over the past 25 years, the body mass and levels of mesomorphy of top-level rugby union players has shown consistent increases at five times the rate of that seen for the general population in the same period (Olds, 2001). Individual players are similarly predisposed to, and selected for, particular playing positions on the basis of their anthropometric characteristics and strength capabilities (Quarrie et al., 1995; Quarrie and Wilson, 2000; Duthie et al., 2003). Site-specific hypertrophy is also important in contact sports such as American football and rugby football (Kraemer, 1997). The shoulders are a key area for development as this is frequently the point of impact when tackling opponents.

Based upon what data exists in the literature, there appears to be significant differences in strength demands between playing positions in the sports studied. For example, it has been identified that different playing position groupings in professional rugby league vary in their performance on various strength, speed, and endurance measures (Meir et al., 2001). Specifically, rugby league forwards exhibit greater upper body strength than backs. Conversely outside backs in rugby league are faster over 15m than forwards – and faster than all other positional sub groups over 40m (Meir et al., 2001). All playing positions irrespective of differences in body mass and positional demands require high levels of dynamic muscular strength relative to body mass in order to contend with the physical aspects of the sport (Baker, 2001b; Meir et al., 2001).

Sport-specific strength

Strength training has become established as a key component of physical preparation for the majority of sports. However, the diverse physical demands involved in team sports pose unique demands for strength training design. For the majority of sports it is suggested that athletes require *optimal* levels of strength as opposed to *maximal* levels of strength in order to successfully compete in their sport (Murray and Brown, 2006). It is therefore important to recognize that ‘optimal strength’ may be a more important training goal than maximal strength for these athletes. The design of strength training should therefore reflect the specific demands of the particular sport – and in the case of team sports, the playing position.

What defines 'sport-specific' strength capabilities is the ability of the player to express their strength qualities during the execution of game-related activities or sport skills in the context of a match situation (Smith, 2003). Anecdotally, many coaches will be familiar with the scenario that their top performing players are not necessarily those that have the best strength test scores or lift the heaviest weights in the weights room (McGill, 2006a). One aspect of this is that team sports performance requires more than just strength performance. However, another implication is that the strength and speed-strength capabilities expressed in the context of team sports are somewhat different from the classical weights room definition of strength performance.

Fundamentally, strength and conditioning specialists cannot lose sight of the fact that they are preparing the athlete to perform on the field – not to increase the athlete's strength tests for their own sake. Strength tests may show some correlation to performance, playing level, or selection in certain sports. However, the aim should remain on building athleticism to allow the athlete to compete in their sport, not to convert the athlete into a powerlifter. Strength test scores may well improve – preferably those tests that resemble the demands of the sport – but this is secondary to improving athleticism and the athlete's ability to express functional or sport-specific strength. The ultimate measure of the success of the athlete's programme is the extent to which it improves their performance in the field of play, not in the weights room. Transfer of training effects is a crucial factor: one of the key criteria when judging the efficacy of a strength training programme is the degree of performance improvement relative to the training time invested (Young, 2006).

Strength training for injury prevention

Sport-specific physical conditioning can favourably influence injury risk when playing team sports. One general protective effect is that appropriately conditioned athletes are more resistant to neuromuscular fatigue, which renders athletes susceptible to injury (Hawkins et al., 2001; Murphy et al., 2003; Verral et al., 2005). This is illustrated in the common trend observed in many team sports for higher injury rates in the latter stages of matches when players are fatigued (Best et al., 2005; Brooks et al., 2005a; Hawkins and Fuller, 1999; Hawkins et al., 2001). Strength training also serves a general protective effect in making the musculoskeletal system stronger and thereby more resistant to the stresses incurred during games (Kraemer and Fleck, 2005). The addition of strength training to the physical preparation of male collegiate soccer players was followed by an almost 50 per cent reduction in injury rates during subsequent playing seasons (Lehnhard et al., 1996). One aspect of this is that trained muscle is more resistant to the microtrauma caused by strenuous physical exertion and also recovers faster (Takarada, 2003). The protective 'anatomical adaptation' (Bompa, 2000) function of strength training exhibits specificity in that it is restricted to the bones and connective tissues associated with the limbs and muscles employed during the training movement.

In addition to the general benefits of strength training and metabolic conditioning, targeted interventions have the potential to specifically guard against certain injuries that athletes may be exposed to. Injury prevention-oriented strength training employs particular exercises specifically designed to address certain risk factors and injury mechanisms associated with a particular type of injury in the sport. Specific neuromuscular and strength training can be employed in this way as a means to improve active stability provided to joints. This specific injury prevention role for strength training has not received the research attention it would appear to merit. Too often specific strength exercises are only prescribed for team sports athletes once an injury has already occurred (Wagner, 2003). Although there are a growing number of studies detailing injury data for different sports, studies that assess injury prevention strategies for sports remain relatively few. For example, despite soccer's status as the most popular sport in the world, a review of the literature pertaining to injury prevention for soccer players found only four relevant studies that met inclusion criteria (Olsen et al., 2004).

Preventative measures can only be taken by first gaining an understanding of the causative factors and injury mechanisms that are characteristic of the particular injury (Bahr and Krosshaug, 2005). The first step in prescribing sport-specific injury prevention training is identifying the risk factors relevant to the particular sport and playing position. The process of specific training prescription should therefore begin with a needs analysis of the particular sport, including research into the injuries commonly sustained during competition. The next step in designing an individualized programme is identifying the intrinsic risk factors that affect each individual player. Hence after examining injury data for the sport, the injury history of each athlete and any ongoing injury concerns will help to highlight the specific needs of each individual. Once identified, the design of the injury prevention intervention programme should aim to systematically address areas of risk for each specific injury relevant to the sport and the athlete (Nicholas and Tyler, 2002).

Application of strength training for improving endurance performance

Neuromuscular aspects that can influence players' endurance performance can be developed via appropriate strength training. Neuromuscular factors that contribute to endurance performance include neural and elastic components of stretch-shortening cycle capabilities, intermuscular co-ordination influencing running mechanics and movement economy, and also the strength qualities of locomotor and postural muscles (Paavolainen et al., 1999). Improving these aspects independent of any changes in aerobic or anaerobic endurance parameters has the potential to improve endurance performance (Mikkola et al., 2007; Millet et al., 2002b; Paavolainen et al., 1999).

Such beneficial effects of strength training on parameters of endurance performance have been demonstrated in endurance athletes. A study of endurance athletes showed that 5km run time was improved by the addition of strength training to their physical preparation, despite no change in their VO_2max scores (Paavolainen et al., 1999). Another study of endurance athletes (elite-level triathletes) showed that following a 14-week training period, athletes who performed two strength training sessions per week during the period scored significantly higher on speed-strength and running economy measures compared to those athletes who performed only endurance training (Millet et al., 2002b). Although VO_2max was unchanged in both groups, the running velocity attained at VO_2max was also slightly increased in the strength trained group. VO_2 kinetics remained consistent in both training groups pre- and post-training (Millet et al., 2002b). Similarly, replacing a quarter of the endurance training of cross-country skiers with general strength and specific speed-strength training improved these endurance athletes' work economy scores during a cross-country skiing test without any changes in VO_2max (Mikkola et al., 2007).

The force-generating capacity of the locomotor muscles and the ability to maximally recruit these muscles during conditions of fatigue are important factors when engaged in endurance activities (Paavolainen et al., 1999). It follows that improving strength, speed-strength, and strength endurance should positively influence economy and performance when engaged in endurance activities. In addition, neuromuscular control and co-ordination aspects also influence the stiffness and elasticity of the muscle-tendon complex during foot strike when running (Paavolainen et al., 1999). Increases in measures of lower limb muscle stiffness were shown following a period of strength training in elite triathletes (Millet et al., 2002b). Improving such capacities via appropriate strength and speed-strength training can increase the non-contractile contribution to work output during locomotion. Reducing energy cost of locomotion this way will improve movement economy and thereby improve endurance capacity (Millet et al., 2002b). Given that team sports feature a variety of modes of locomotion in multiple directions, it follows that selection of strength training exercises should reflect this in order to confer such improvements in movement-specific work economy.

APPROACH TO STRENGTH TRAINING FOR TEAM SPORTS PLAYERS

A number of the practices and conventions employed in athletic preparation – particularly with regard to strength training – have evolved from competitive powerlifting, weightlifting, and bodybuilding (Fleck and Kraemer, 1997). This should be recognized when evaluating and designing strength training programmes for team sports. It is important that strength and conditioning specialists are able to discern between practices, even at the level of exercise selection, that are based predominantly on convention as opposed to those that serve a specific purpose with regard to players' physical preparation for the sport.

A survey investigating the practices of strength and conditioning coaches in US Division One collegiate competition revealed that what most influenced their training design and prescription was the input and practices employed by their peers (i.e. other collegiate strength coaches) (Durell et al., 2003). In contrast, only 9 per cent of these collegiate strength and conditioning coaches ranked journals or books as their primary information source when designing programmes. Similar surveys of professional North American team sports did not include this question. However, responses of strength and conditioning coaches in National Football League, National Hockey League, Major League Baseball, and National Basketball Association indicated similar reliance on convention and non-scientific sources with respect to different aspects of training programme design and implementation rather than evidence-based practice (Ebben and Blackard, 2001; Ebben et al., 2004; Ebben et al., 2005; Simenz et al., 2005).

All team sports feature common fundamental movement abilities to some degree: these include gait/locomotion (e.g. running), squatting/lifting, pushing/pulling, lunging, twisting, and maintaining balance (McGill, 2006b). A logical starting point for a strength training programme is to address any deficiencies or areas of weakness that restrict the player's ability to efficiently execute these fundamental movements. Lower limb kinetic chain theory states any weakness at any point in the series of joints from the athlete's supporting limb to the lumbopelvic region has the potential to impact upon all the other links in the chain (Leetun et al., 2004). From a performance viewpoint a player can be deemed to be only as strong as the weakest link in this kinetic chain. Depending on the sport, the kinetic chain may extend all the way through to the joints of the upper limb, for example, when executing a throwing or striking movement. Lack of mobility or strength that impairs function at any one of the integrated system of joints in the kinetic chain linking the player's base of support to the point at which force is applied can cause loss of power – and potentially pain and injury – in the sports skill movement.

Traditional approaches to training can serve to strengthen areas where the athlete is already strong without addressing the weak links. Without corrective training this has the potential to make the athlete more imbalanced and place tissues around any weak links under further strain. For example, the barbell back squat is an exercise that is the cornerstone of many strength programmes for team sports players. Based upon electromyographic (EMG) data recorded from muscles during the classical barbell back squat this lift can be categorized as primarily an exercise for the quadriceps muscles – at least for the majority of the exercise range of motion (McGill, 2006a). The back squat is a good option if the aim is improving general strength of the knee extensors. However, an emphasis on the back squat in the training for an athlete who already exhibits quadriceps dominance and weak gluteal muscles might in fact exacerbate this dysfunction and further predispose the athlete to injury and impaired performance. Similarly, selection of exercises should reflect the programme goal. If the primary aim of the strength training programme is improving the speed capabilities of players who are already strength trained, then bilateral strength training modes such the back squat would not appear to be the best option

Figure 3.1 Barbell single-leg squat.

(Young, 2006). An 8-week strength training study with the back squat exercise reported this training mode to be highly effective in improving back squat 1-RM strength (21 per cent gain) and vertical jump performance (21 per cent); however, very limited improvement (2.3 per cent) was seen in sprinting speed (Wilson et al., 1996).

An alternative approach is to adopt a neuromuscular training emphasis similar to that applied in injury prevention training interventions. One aspect of such an approach is to shift the focus onto quality of movement rather than solely load lifted. Such a neuromuscular skill-focused approach would appear to make sense given that it is commonly motor control rather than gross measures of strength or power that distinguishes the best athletes from their peers (McGill, 2006a) – this is the case particularly in team sports. In this sense, rather than coaching by numbers and focusing on improving loads lifted, the players should be instilled with the principle that if they are unable to lift a given load with perfect form then they cannot lift it. In keeping with this approach, measures to facilitate maintaining posture and form and offset the effects of acute fatigue should be considered – for example, breaking a set up into smaller chunks (particularly during the initial stages after load has been increased). This is analogous to the use of cluster sets – a practice employed by Olympic weightlifters – and has been suggested to have applications for other athletes (Haff et al., 2003; Haff et al., 2008).

Strength training methods and modes

The biomechanics, kinematics, and kinetic profile of a particular strength training exercise will dictate its relative effectiveness in developing a given aspect of neuromuscular performance (Newton et al., 1999). Structural, mechanical, and neural elements of the lift will influence the training stimulus in terms of intramuscular and intermuscular co-ordination. For the majority of multi-joint training movements, free weight application of resistance is considered to be more functional as the lifter is required to stabilize their own body and the external resistance, whilst simultaneously controlling and directing the movement (Stone et al., 2000).

In this way, free weight exercises develop intra- and intermuscular co-ordination to a greater degree, which is reflected in superior transfer to athletic and ergonomic performance measures relative to machine-based resistance training (Stone et al., 2000). Similarly, free weight strength training is consistently shown to produce greater strength gains in comparison to resistance machines. For these reasons, it is commonly recommended that advanced strength training should emphasize free weight exercises, with resistance machine exercises having an auxiliary role (Kraemer et al., 2002).

The majority of game-related movements in team sports are executed supported partly or fully on one or the other leg. It follows that unilateral support exercises should necessarily comprise a significant portion of the team sport athlete's training (McCurdy and Conner, 2003). Differences in force production have been observed between dominant and non-dominant legs in collegiate female softball players even when performing bilateral strength training movements (back squat) (Newton et al., 2006).

Unilateral support exercises offer a means to address such imbalances in strength between limbs. Such exercises do not allow the athlete to favour

Figure 3.2 Barbell step up.

Figure 3.3 Barbell diagonal lunge.

their dominant limb during the movement as is shown to happen with bilateral lifts (Newton et al., 2006), and the number of sets and repetitions can also be manipulated to increase the training stimulus provided to the weaker side. This is important not only in terms of both function and performance, but also from an injury prevention perspective in view of the reported association between strength and flexibility imbalances with injury incidence (Knapik et al., 1991).

Similarly, upper body movements in team sports are typically unilateral. Accordingly, training to develop players' upper body strength and power should feature an appropriate emphasis on alternate arm and single-arm lifts. Such exercises also require greater stabilization of the trunk, as the unilateral resistance results in destabilizing torques that must be compensated for by the trunk muscles on the opposite (contralateral) side (Behm et al., 2005). This stabilizing challenge corresponds to what occurs during match-play, hence is similarly beneficial from a transfer of training effect viewpoint.

The quantity of muscle mass involved in the training exercise, as well as frequency and volume load (repetitions multiplied by mass lifted) of training, will influence adaptations in body composition (Stone et al., 2000). Free weight exercises that recruit a large amount of muscle mass have greater metabolic demand and hormonal responses, which tend to favour alterations

Figure 3.4 Dumbbell clockwork lunge.

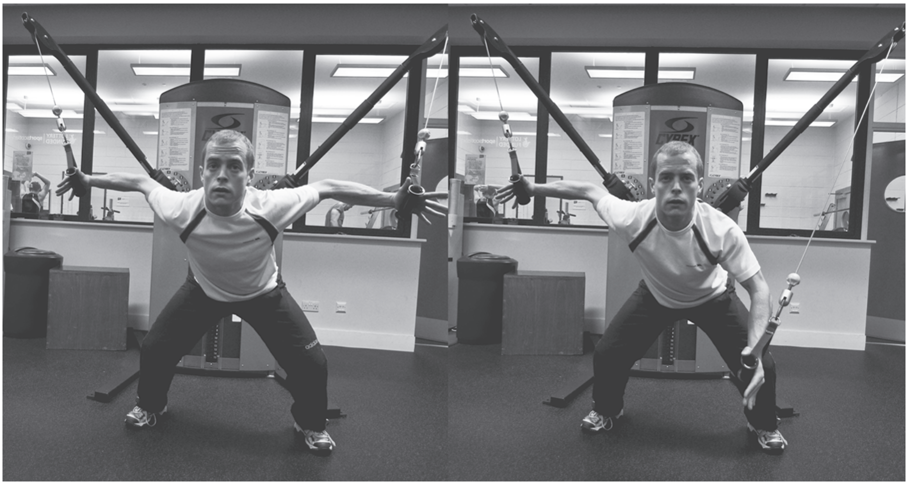

Figure 3.5 Alternate arm cable fly.

Figure 3.6 Single-arm cable row.

in body composition. This is important for contact team sports in which developing high levels of lean muscle mass are a key programme goal. Similar considerations underpin recommendations for multiple-joint free weight exercises recruiting large muscle mass to develop local muscular endurance and strength endurance (Kraemer et al., 2002).

Figure 3.7 Alternate arm incline dumbbell bench press.

Figure 3.8 One arm incline dumbbell bench press.

Format of strength training

Another application of specificity, which is typically not fully accounted for, is the format in which strength training workouts are performed. Team sports involve a wide array of movements in multiple directions executed repeatedly in an unspecified order with high force. Contact field sports feature the added element of movements executed against resistance, often with the upper body as the point of contact. For team sports players, the optimal training format has yet to be adequately investigated. Anecdotally, some strength and conditioning specialists working with professional team sports players attempt to address this by incorporating the use of 'compound sets' – i.e. alternately performing sets of one exercise (for example a pushing lift) with another exercise (e.g. a pulling lift).

Taking this approach further, a circuit format might be considered for the entire workout. This should not be mistaken for traditional circuit training which features submaximal loads and relatively high repetitions: the same loads are used – it is solely the format of the workout that is altered. The circuit format would also appear to have the advantage of reducing workout time (as players move onto the next lift during the interval during which they would normally be resting) and potentially stimulating improvements in strength endurance. A study investigating this approach termed this approach 'heavy resistance circuit training' and found that subjects were able to lift the same load and volume with no alternation in bar kinematics compared to the traditional sequential format, and that it also elicited a greater cardiovascular response (Alcaraz et al., 2008). The authors concluded that this approach to strength training could be expected to elicit similar strength improvements with additional cardiovascular benefits. Kraemer (1997) reported improvements in strength endurance (number of repetitions the subject was able to complete at 80 or 85 per cent 1-RM) with American football players following a multi-set strength training at 8–12RM, performed in a circuit fashion. This was attributed in part to improvements in lactate buffering and whole body acid–base balance associated with the circuit format (Kraemer, 1997).

It has been shown that with adequate rest (3 minutes) between sets, RM loads can be lifted repeatedly (Kraemer, 1997). The crucial factor influencing capacity to repeatedly perform sets at RM load was identified as rest period between sets. When rest is reduced, ability to perform the prescribed number of repetitions at the RM load may be compromised (Kraemer, 1997). The sequential approach of lifting the prescribed sets for one lift before moving onto the next exercise may lead to insufficient rest between sets to successfully complete the stipulated repetitions with the RM load. Players typically self-select rest between sets and may rush through the sets in an effort to perform all the exercises within the limited time allotted for the workout. The circuit format described avoids this, as the muscle groups involved in a particular lift are allowed to rest whilst the player completes the intervening exercises in the circuit prior to performing the next set.

Progression of strength training

The overload principle dictates that the athlete needs to be challenged beyond what they are accustomed to in order to produce any adaptation (Baechle et al., 2000). When these conditions are met, the body is prompted to initiate adaptations in the nervous system, muscles, and connective tissues to be better able to deal with these new demands in the future. Commonly, overload is described purely in terms of increasing load lifted. However, a more accurate interpretation is that muscles and motor control systems require a novel stimulus in order to elicit a training response. This may be achieved by increasing force demands – either by increasing mass lifted or increasing the acceleration at which the movement is executed – or motor control requirements.

As such, there is a need for progressive increases in training stress applied as training advances to achieve continued adaptation. Even the best-designed programme will not produce significant gains over time without continuing to take the neuromuscular system beyond what it is accustomed to in terms of movement patterns being executed, training intensity (either mass lifted or acceleration), volume load, and the rest allowed between exercises and workouts. The most simple illustration of the need for progression is that as the athlete gains strength, a load that would previously have been challenging no longer offers the element of overload due to the athlete's enhanced capabilities (Rhea et al., 2003). Progression therefore is a continual process of marrying the programme variables to the level of adaptation that has already taken place. For a lifter with limited training experience almost any systematic strength training programme represents a novel training stimulus for the neuromuscular system. With increasing training experience and as training status advances, more challenging training regimes and more sophisticated manipulation of training parameters are required to elicit a training response (Newton and Kraemer, 1994; Kraemer et al., 2002).

Manipulating intensity by increasing load lifted is thus the most commonly used method of achieving progressive overload. However, this is not the only option for progression. As mentioned previously, force demands can also be progressed by increasing acceleration (in accordance with Newton's Law, force = mass × acceleration). For instance, ballistic lifts, Olympic lifts, and plyometric exercises can be progressively introduced in order to manipulate acceleration developed by the neuromuscular system during strength training workouts. Progression can likewise be achieved by manipulating volume load – repetitions performed, training volume (number of sets and exercises in the workout), and/or training frequency (weekly number of sessions per muscle group) (Kraemer et al., 2002).

A final option for achieving progression is by manipulating exercise selection in order to progress the neuromuscular and motor control demand – i.e. moving towards more technically demanding lifts and those that require greater balance and stabilization. Manipulating neuromuscular demand in this way as a means to achieve progression is in keeping with the alternative approach to strength training for team sports characterized by a neuromuscular emphasis that was described previously. Given that it is motor control rather than gross

Figure 3.9 Barbell overhead step up.

Figure 3.10 Single-leg cable press.

strength capabilities that commonly separates the best performers in many team sports (McGill, 2006a), it follows that the method chosen for achieving progression when designing players' strength training should reflect this.

Strength and conditioning specialists must, however, be careful with what constitutes an 'advanced athlete' with respect to strength training. Most players will have strength training experience to the extent that they have been engaged in some sort of resistance training for a period of time. However, despite – or potentially as a result of – having been resistance trained for a number of years, an individual player may still exhibit deficits in mobility and stability and/or imbalances in strength that impair their fundamental movement capabilities. Following a neuromuscular skill-based approach to strength training, training status and therefore the starting point for the individual player's strength training programme, will depend upon an assessment of their functional movement abilities in addition to their scores on strength, power, and performance tests. Similar ongoing qualitative assessment of the player's neuromuscular skill and movement abilities will likewise govern progression in their strength training programme.

Specificity of dose-response relationships with strength training experience

Training experience is a key consideration for strength training prescription: there is an obvious need to progress intensity, volume, and frequency of training, as the neuromuscular system grows more accustomed to strength training with increased exposure (Rhea et al., 2003). Exercise prescription guidelines accordingly make a distinction in terms of resistance training experience and feature separate recommendations for untrained, recreationally trained, and advanced lifters (Kraemer et al., 2002). Meta-analysis of the strength training literature demonstrates that training responses vary depending on subjects' training status (Rhea et al., 2003). Thus the levels of intensity, volume, and training frequency shown to maximize gains differ based upon the training experience of the subject population (Peterson et al., 2004). It appears logical that individuals with different training experience will require different 'doses' of training parameters in order to elicit a maximal training response, in terms of strength gains.

Such dose-response relationships with regard to optimal resistance load, volume, and frequency of strength training have previously not been identified in competitive athletes. There is a paucity of data from elite team sports athletes in particular – for example, the absence of contemporary data concerning strength levels of elite players in rugby union football has been highlighted (Duthie et al., 2003). However, one study has undertaken a meta-analysis of thirty-seven studies in the strength training literature that directly examined athlete subjects (Peterson et al., 2004). Summarizing the findings of these studies, the authors found that the training parameters that optimize training effects (measured strength gains) in competitive athletes differ from those based on similar studies employing strength trained non-athletes. Training volume (sets per muscle group), training frequency (days per week for each muscle group), and training intensity (resistance load) found to be most effective in the studies examined differed markedly from those for non-athletes – even non-athlete subjects experienced in strength training (Peterson et al., 2004).

Hence, competitive athletes show different dose-response relationships with regard to strength training in comparison even to strength trained non-athletes (Peterson et al., 2004). From these studies it appears that a continuum exists in terms of optimal training variables for maximal strength gains, which is dependent on the training status and training experience of the individual (Rhea et al., 2003) – and that elite athletes appear to exist further along this dose-response continuum (Peterson et al., 2004). As such, elite team sports players appear to require considerably different intensity, frequency, and volume of strength training to maximize strength gains – even in relation to published recommendations for strength trained non-athletes (Peterson et al., 2004).

This consideration raises questions regarding the relevance of findings in the strength training literature based on investigations involving non-athletic populations, even using subjects with strength training experience (Peterson et al., 2004). The lack of studies denies any opportunity for comparison of the current findings to existing data. There remains a critical need to gather data pertaining specifically to athletes, in particular those engaged in team sports. Obtaining access to elite athletes is likely to require some compromise in terms of study design (Millet et al., 2002a). However, only in this way will it be possible to provide an objective alternative to the ongoing tendency of strength and conditioning coaches working in many team sports to rely upon their own observations and personal experience as the primary basis for selection of training modes and methods (Kraemer, 1997).

Strength training prescription for elite athletes

The specific needs of competitive athletes are vastly different from those of recreationally trained individuals: it is logical therefore that, by extension, the optimal training for athletes will likewise be different. On this basis, elite performers should be treated as a special population (Cronin et al., 2001b). Maximal strength gains are demonstrated in untrained individuals training at an average intensity of 60 per cent 1-RM (Repetition Maximum), whereas individuals experienced with strength training exhibit maximum gains with 80 per cent 1-RM resistance; competitive athletes appear to exist still further along this continuum. From what data is available, some suggestions for training prescription applicable to team sports players can be made: a mean training intensity of 85 per cent 1-RM has been found to have greatest effect in competitive athletes from the majority of relevant studies (Peterson et al., 2004). This equates to an average intensity of 6-RM (i.e. the greatest weight that can be lifted for six repetitions with proper form).

This is in general agreement with the finding that loads greater than 80 per cent 1-RM were necessary to maintain or improve strength throughout the playing season in American college football players (Hoffman and Kang, 2003). Observation of elite weightlifters likewise noted a significant decrease in EMG recorded during the phase of the training year when training intensity dropped below 80 per cent 1-RM, which recovered once training intensity was increased above 80 per cent in the subsequent training period (Hakkinen et al., 1987). This requirement for greater average intensity appears to be a common theme for athletes as a special population. Of all training variables, training intensity was the only significant predictor of strength changes during an in-season period in American college football players (Hoffman and Kang, 2003). Training studies featuring protocols in which the athlete subject group lifted to failure report greater average strength gains (Peterson et al., 2004). Therefore it appears there is a need for strength training regimes to stipulate that the athlete must lift to failure at the specified load, as training at lesser intensities appears to elicit minimal improvements in competitive athletes (Hoffman and Kang, 2003).

In terms of frequency of strength training, recommendations are based on the number of times per week individual muscle groups should be trained. From data examining athletes, training a particular muscle group two or three days per week was observed to be similarly effective (Peterson et al., 2004). How many strength training sessions this equates to will depend on the layout of the workout. It could be two workouts per week in the case of both days being whole-body sessions. On the other hand, if a 'split routine' format is being used (for example, separating upper and lower body workouts), this may comprise four or more strength training sessions per week. There is some evidence that a five-day programme incorporating split routine loading may offer greater strength and muscle mass gains (Hoffman et al., 1990). However, given the time constraints imposed in many team sports, the former two- or three-day whole-body format may be more time-efficient during the majority of the season.

Recommendations for volume of strength training for competitive athletes are similarly made in terms of individual muscle groups. A mean number of eight sets per muscle group per week appears to maximize strength gains in groups of athletes (Peterson et al., 2004). This represents double the equivalent volume recommendations based on studies for non-athletes: the majority of studies employing non-athletes found four sets per muscle group per week to be effective in evoking maximal strength gains (Rhea et al., 2003). Competitive athletes thus appear to require a much greater volume of strength training to provide an effective training stimulus for gains in strength. Similarly, players in contact sports for whom hypertrophy is a programme goal require greater training frequencies to elicit the necessary gains. It has been identified that quite extreme training frequencies (four and five days per week) are required to elicit body mass gains in college-aged American football players experienced in strength training (Hoffman et al., 1990; Kraemer, 1997). These distinct differences in optimal training volumes again reinforce the specific needs of competitive athletes as a special population.

CONCLUSIONS AND TRAINING RECOMMENDATIONS

Given the time constraints imposed by extended playing seasons and high volumes of concurrent training and team practices common to all team sports at elite level, the efficiency and effectiveness of physical preparation is paramount (Peterson et al., 2004). Key criteria when evaluating a strength training programme for a team sports player is the degree of improvement in the player's capacity to perform and remain fit to participate in matches and team practices versus the training time invested (Young, 2006). This need to optimize any strength training performed is particularly important given the potential for interference effects from concurrent metabolic conditioning (Leveritt and Abernethy, 1999) – and in the case of contact sports particularly, the disruption due to the physical stresses of bodily contact during practices and matches (Hoffman and Kang, 2003). Such complications place even greater emphasis upon the effectiveness and efficiency of strength training for team sports players.

In this chapter a neuromuscular emphasis has been described for approaching strength training for team sports. Whatever the sport or training history of the player, the initial programme goal suggested is addressing any deficits in mobility and stability that have been identified that impair the player's ability to effectively perform fundamental athletic movements. Once this foundation is established, exercise selection should progress towards integrated multi-joint movements, which are specific to movements that are characteristic of the sport (Baechle et al., 2000; Stone et al., 2000). Accounting for specificity in this way will benefit gross motor activation or intramuscular co-ordination as well as enhance intermuscular co-ordination and control at peripheral level in a way that facilitates transfer to performance (Sheppard, 2003; Young, 2006). Progression of exercise selection within the strength training macrocycle might feature a gradual introduction of unilateral support lifts, as well as alternating upper limb and single limb variations of strength training exercises – in order to increase balance, stabilization, and neuromuscular control demands. Similarly, speed-strength and plyometric exercises that involve similar progressions can be introduced into players' preparation, particularly as they approach key phases in the playing season. In this way, acceleration can be manipulated as a way of progressing intensity in the players' programme. From a specificity viewpoint it follows that these speed-strength exercises should also be executed in a manner that corresponds to the rate of force development associated with competition (Sheppard, 2003) and features intermuscular co-ordination demands appropriate to the sport (Young, 2006).

In terms of the format of strength training for team sports players, strength and conditioning specialists might consider experimenting with the structure of the workout. Manipulations to the traditional set configuration for Olympic lifts (adopting short rest intervals between consecutive repetitions) have proven to reduce impairments in lifting kinematics in successive repetitions in a set, by reducing residual fatigue (Haff et al., 2003). It is possible that the circuit format may allow similar enhanced lifting kinematics by offsetting fatigue between consecutive sets of a particular exercise. There is also early evidence that such an approach might increase cardiovascular responses (Alcaraz et al., 2008) and confer similar benefits in terms of strength endurance (Kraemer, 1997), as well as reduce the time required to complete the workout.

CHAPTER 4

METABOLIC CONDITIONING FOR TEAM SPORTS

INTRODUCTION

The metabolic conditioning of a team sports player serves a crucial role in defining and ultimately limiting their contribution to the game (Helgerud et al., 2001). The effectiveness of players' conditioning and the resulting level of fitness is a critical factor that determines their ability to fulfil the specific demands imposed by the playing position.

Specificity in relation to metabolic conditioning involves both energy systems and modes of activity. The bioenergetics of the training activity will determine the impact of training on different aspects of metabolic conditioning – such as aerobic versus anaerobic adaptations. In simple terms, predominantly aerobic training will result in improvements in aerobic conditioning; the converse applies to anaerobic training.

In much the same way, the benefits of metabolic conditioning are reflected principally in the mode(s) of locomotion employed during training. Conditioning responses show a high degree of training mode specificity (Jones and Carter, 2000). There is only limited cross-over of training effects to other conditioning modes, particularly in trained athletes (Millet et al., 2002a).

To satisfy training specificity, it follows that the format of conditioning for team sports should employ the same modes of activity featured in the sport and aim to impose corresponding stresses on metabolic systems to those experienced during match-play. In accordance with this contention, sport-specific conditioning modes that replicate and overload physiological and kinematic conditions encountered during athletic performance are identified as being most effective for preparing players for competition (Deutsch et al., 1998).

Applying metabolic specificity thus essentially requires the format of conditioning to reflect the parameters of competition. Practically achieving this for a team sports player poses unique difficulties. Team sports do not involve continuous locomotion at a constant exercise intensity. Setting training paces to exert proportionate stresses upon energy systems for the desired modes of activity featured in a particular team sport therefore represents more of a challenge.

ADAPTATIONS TO ENDURANCE TRAINING

Depending on the nature of metabolic conditioning performed – i.e. the format, intensity, duration etc. – several adaptations may result. These potential changes can be broadly categorized as central versus peripheral adaptations:

- Central adaptations originate in central cardiorespiratory organs (heart and lungs) and central nervous system.
- Peripheral adaptations concern structural, cellular, and molecular changes associated with the working muscles.

Central adaptations to metabolic conditioning

- Heart:
  - Increase in size and capacity of the heart.
  - Improved regulation of heart rate (HR) – marked by lowered HR for a given absolute work intensity.
  - Increased diastolic filling and ‘contractility’ (elasticity and strength of cardiac wall):
    - leading to increased stroke volume and cardiac output.
- Lungs:
  - Slight increases in lung ***vital capacity*** (maximal volume of air that can exhaled).
  - Lowered rate of respiration at rest and at a given absolute submaximal work intensity.
  - Increased ***pulmonary ventilation*** (movement of air in and out of the lungs) during maximal exercise.
  - More efficient gas transfer between lungs and pulmonary blood vessels:
    - greater oxygen extraction from lungs into the blood.
  - Improved regulation of oxygen uptake kinetics:
    - reduced time lag at the onset of exercise before oxygen uptake reaches required levels;
    - more rapid adjustments to changes in workload during exercise (Jones and Carter, 2000).

- Central Nervous System:
  - Improved co-ordination and efficiency of movement.

Peripheral adaptations to metabolic conditioning

- Increased capillarization – greater number and changed architecture of blood vessels supplying muscle fibres; resulting in improved blood supply and transport of nutrients and oxygen to muscle cells.
- Changes in muscle fibre subtypes – particularly conversion of Type IIb (fast-twitch, glycolytic) to Type IIa (fast-twitch, oxidative, glycolytic).
- Increase in number and capacity of *mitochondria* (site of oxidative energy production within muscle cells).
- Increase in *myoglobin* (oxygen binding molecule within muscle cell).
- Increase in activity of enzymes for oxidative metabolism.
- Increase in activity of enzymes for glycolytic metabolism.
- Increased glycogen availability within muscle cells (energy substrate for glycolytic metabolism).
- Increased fat stores within muscle cell – preferentially situated close to mitochondria.
- Preferential increase in the proportion of energy supplied by fat metabolism (sparing glycogen reserves).
- Improved lactate handling.
- Increased muscle buffering capacity (ability to neutralize hydrogen ions within muscle cell and resist shift in muscle pH).

METABOLIC CONDITIONING AND TEAM SPORTS PERFORMANCE

It is reported that measures of fitness exhibited by soccer players are significantly related to distance covered in a game (Reilly, 1994). Level of fitness also shows significant correlation to the number of high-intensity efforts players attempt (Helgerud et al., 2001). Hence, metabolic conditioning exerts a pronounced influence not only on players' work rate, but also their involvement in the game.

A player's ability to retain their capacity to perform high-intensity efforts at the key moment is often crucial in deciding the result of a match (Drust et al., 1998; Reilly, 1997). This can be via a positive influence: making a break or evading a tackle, keeping up with play to be available in support at the critical instant, or being able to chase back in defence to make a crucial intervention. Likewise, it can be telling in a negative sense – such as missing a tackle or interception, failing to support a team-mate in possession of the ball leading to an attack breaking down, or being unable to cover in defence at the critical moment.

Metabolic demands of team sports

Characteristically, physical exertion during team sports is of an intermittent nature, comprising sprints and other modes of high-intensity effort. These bouts of intense activity are interspersed with periods of variable duration engaged in lower intensity locomotion, during which active recovery and removal of lactate can take place (Hoff, 2005). Metabolic demands thus alternate between energy provision for bouts of high-intensity work, and replenishing energy sources and restoring homeostasis during the intervals in between (Balsom et al., 1992).

The intermittent nature of match-play activity in team sports is illustrated by studies such as that of McInnes and colleagues (McInnes et al., 1995), which identified 997±183 movements during the course of a basketball match, with transitions between modes of activity on average every two seconds. A study examining rugby union football has similarly reported 560 discrete activities during a 70-minute age-grade match (Deutsch et al., 1998). Bangsbo (Bangsbo et al., 1991) likewise recorded 1,197 changes in activity during a 90-minute professional soccer match.

This intermittent exertion which is characteristic of team sports has implications for bioenergetics and conditioning. The frequent changes in direction and velocity of movement require inertia to be repeatedly overcome and involve accelerations and decelerations which constitute a considerable added metabolic demand (McInnes et al., 1995; Wilkins et al., 1991). Intermittent running performed under controlled conditions on a treadmill is associated with greater physiological strain (higher ratings of perceived exertion and ventilatory responses) than exercise of the same average intensity performed continuously (Drust et al., 2000). This in turn necessitates a greater relative contribution of anaerobic metabolism to energy provision. Similarly, the diverse modes of locomotion in multiple directions that players engage in require movement efficiency and running economy for a wide variety of game-related movements.

Importance of anaerobic capacity for team sports athletes

A key aspect of metabolic conditioning is developing ‘anaerobic capacity’. Developing this parameter of athletic performance is a primary objective of conditioning for team sports in order to ensure players are able to sustain power output and sprint performance for the duration of playing time. The ability to perform intermittent maximal intensity efforts is largely dependent on the relative capacity to recover from the previous work bouts (Balsom et al., 1992). Peripheral adaptations that support this include lactate handling, acid/base buffering, and high-energy phosphate (phosphocreatine and ATP) resynthesis (Balsom et al., 1992; Bell et al., 1997).

Anaerobic capacity can be functionally assessed by the player’s ability to sustain repeated high-intensity bouts of exertion with given rest intervals. A ‘fatigue index’ score is generally used to measure this parameter, expressed as percentage drop-off in sprint times or power output with progression of a fixed number of intervals (Hoffman et al., 1999; Quarrie et al., 1995). Despite the importance of this aspect of conditioning, it has been highlighted recently that there is a lack of data pertaining to anaerobic capacity of team sports players, especially those competing at elite level (Duthie et al., 2003).

Specificity effects are demonstrated when training to develop this quality. Despite marked concurrent improvements in aerobic performance measures, the conditioning stimulus must exceed a threshold intensity in order to have a measurable effect on anaerobic capacity (Tabata et al., 1996). This is most often achieved using an intermittent or interval format, whereby high-intensity phases are interspersed with active or passive rest periods.

Aerobic contribution to energy provision for team sports

Previously it has been suggested that the role of aerobic metabolism during team sports play is limited to rest periods during stoppages between periods of activity (Duthie et al., 2003). Some authors have inferred that aerobic fitness is of lesser relative importance, based upon the comparatively lower aerobic power scores reported for players in some team sports, particularly in rugby union football and basketball (Duthie et al., 2003; Hoffman et al., 1999).

However, repeated sprint exercise of the type featured during matches does involve a significant aerobic contribution to energy production (Bogdanis et al., 1996). Oxidative metabolism contributes a major portion of the energy during subsequent sets following the first sprint. A study investigating repeated maximal 30-second bouts reported that the aerobic contribution increased from 31 per cent in the first 30-s sprint in a set to almost 50 per cent in the second, even with 4 minutes recovery between sprints (Bogdanis et al., 1996). This appears to offset losses in power output resulting from reduced capacity for anaerobic energy production. A relationship has been identified between oxidative capacity of muscle and ability to resynthesize phosphocreatine (PCr) – the key energy source for brief maximal efforts (Bogdanis et al., 1996). Running velocity at a reference lactate threshold value (a measure of aerobic endurance) also shows strong relationships to PCr resynthesis. Accordingly, it has been identified that PCr resynthesis capabilities can be improved by endurance training (Bogdanis et al., 1996).

Developing aerobic fitness also improves the ability of players to mobilize fat as an energy source during games, which spares the player's finite glycogen stores (Hoff, 2005). This is significant in sports such as soccer where glycogen depletion during the second half of matches results in decreased work capacity – reflected in decreased distances covered and reduced high-intensity activity (Hoff, 2005).

Lactate threshold

Training can enhance the relative work intensity athletes are able to maintain without lactate accumulation, independent of changes in aerobic power

(VO_2max). This parameter is typically measured in terms of running velocity at a reference threshold value (e.g. 4mM) of BLa (Jones and Carter, 2000).

The relative work output an athlete can sustain may be more relevant to endurance for many intermittent team sports than absolute aerobic power (Hoff, 2005). This may explain the relatively modest VO_2max scores of team sports players (Wilmore and Costill, 1999). Hoffman and colleagues (Hoffman et al., 1999) showed that basketball players' fatigue index scores from a game-related anaerobic test showed no relation to their VO_2max scores. Similarly, VO_2max is reported to be unrelated to metabolic recovery measures during an intermittent exercise bout in endurance trained athletes (Bell et al., 1997).

Efficiency and economy of movement

Exercise economy is identified as a key component of cardiorespiratory fitness (Jones and Carter, 2000). Improvements in the efficiency of locomotion and movement during athletic performance can therefore influence aerobic endurance levels during competition. From this point of view, neuromuscular control and motor patterns used in training would appear to be of crucial importance in terms of the carry-over of metabolic conditioning to performance.

FACTORS DETERMINING CONDITIONING RESPONSES

The nature of the conditioning response is dependent upon the work intensity and volume/duration of training performed. Some changes, such as growth of size and capacity of the heart and increases in lung vital capacity, are only apparent in athletes who have completed high volumes of endurance training over a period of years. Other training adaptations are much more responsive to training.

Changes in high-intensity performance and anaerobic capacity

The efficacy of conditioning in developing anaerobic capacity is intensity dependent – i.e. it requires training at intensities that exceed lactate threshold or 'maximum lactate steady state' intensity. By definition, the conditioning performed must elevate lactate levels in order to stimulate lactate handling and buffering mechanisms (Billat et al., 2001b). Training at moderate exercise intensity will elicit performance changes and adaptations in aerobic fitness but will not produce such changes in lactate clearance and muscle buffering capabilities (Tabata et al., 1996; Tabata et al., 1997). A recent study reported that when matched for volume, short-term (5 weeks) training at an intensity just above lactate threshold elicits superior improvements in buffering capacity than training at an intensity just below the athletes' measured lactate threshold (Edge et al., 2006).

Improvements in lactate threshold

Either continuous or intermittent exercise at suitable threshold intensity is shown to be similarly effective in developing running velocity at a given BLa (Jones and Carter, 2000). These specific adaptations are attributed to peripheral adaptations associated with improvements in lactate handling. These include increased capilliarization of muscle fibres (Jones and Carter, 2000) improved acid/base buffering, and possible up-regulation of lactate transporters (Billat 2003). Improvements in buffering capacity in particular are reported to be highly dependent upon the exercise intensity employed in training (Edge et al., 2006).

Changes in 'aerobic' capacity

There are some data to suggest that the higher the work intensity of training the lower the duration or volume required to produce improvements in performance and changes in oxidative capacity.

For example, a study by Gibala and colleagues (2006) reported that a two-week high-intensity and low volume cycling training intervention produced comparable improvements in cycling time trial performance (over both short and long distances) and similar changes measured muscle oxidative capacity to another training group that completed traditional moderate-intensity high volume training. The high-intensity conditioning consisted of 4–6 sets of all-out sprints with 4 minutes recovery between sets, whereas the other training group performed 90–120 minute bouts of continuous cycling conditioning (Gibala et al., 2006). The similar improvements elicited by the high-intensity conditioning group was despite total training time and volume being only a fraction of that completed by the moderate intensity high volume training group.

It is suggested that part of this potency of high-intensity conditioning is due to its recruitment of a larger pool of muscle fibre during the conditioning activity – such as greater use of larger high-threshold Type II muscle fibres. Conditioning performed at lower intensities does not recruit these motor units. Furthermore, for well-trained athletes it is suggested that training at or above a work intensity that demands maximal oxygen consumption (VO_2max) is likely to be required in order to produce any further improvements in endurance performance (e.g. VO_2max scores) (Laursen and Jenkins, 2002; Midgley et al., 2006).

Changes in movement efficiency or work economy

Training responses with respect to work economy and movement efficiency are observed to be dependent upon the exercise mode used in conditioning and also specific to the velocity at which the athlete typically trains (Jones and Carter, 2000). Exercise mode specificity of changes in endurance performance is related to neuromuscular aspects that underpin work economy. For example, a study of elite triathletes reported that the running and cycling training completed by these athletes was unrelated to their swim performance (Millet et al., 2002a). Likewise, performance improvements on a swimming test measure following swim training were not reflected in the triathletes' treadmill running test scores. In trained non-athletes, cross training (swimming) is likewise shown to be inferior to running training in improving running performance parameters (Foster et al., 1997).

It follows that metabolic conditioning for team sports should similarly replicate the type of locomotion and movements encountered during competition to develop this exercise economy component of endurance. As such, development of movement efficiency should necessarily include the unorthodox forms of locomotion performed during sideways, backwards, and tracking movements (Reilly, 1994).

Improvements in work economy are also specific to the velocity at which conditioning is performed. For example, in runners the improvements observed in running economy are greatest at the running velocity at which the athlete habitually trains (Jones and Carter, 2000). From this it appears that conditioning performed should reflect the movement velocities encountered during match-play in order to develop work economy at these specific velocities.

Strength training appears to have a role to play in improving movement efficiency (Hoff, 2005). Maximal strength training has proved to be effective in reducing oxygen cost at a given workload with endurance athletes, indicating improved work economy (Hoff, 2005). Exercise selection is again likely to be decisive in eliciting gains in strength and work economy for the particular movements required during a match in a given team sport. The potential for strength training to impact of upon endurance performance is discussed in greater detail in Chapter 3.

TRAINING STRATEGIES TO DEVELOP DIFFERENT ASPECTS OF METABOLIC CONDITIONING

Long slow distance training

Continuous training is necessarily performed at moderate exercise intensities: long slow distance training is therefore typically constant pace at low-moderate work intensity performed over an extended distance or duration. In untrained and moderately trained individuals the moderate training intensities involved are effective in improving endurance performance and maximal oxygen uptake (VO_2max). However, training at submaximal intensity – although effective in untrained or moderately trained subjects – is unlikely to stimulate improvements in well-trained athletes when used in isolation (Laursen and Jenkins, 2002). It is suggested that well-trained endurance athletes require higher training intensities to produce further gains in performance and enhancement in VO_2max (Midgley et al., 2006). These levels of intensity – in the range of 95–100 per cent of the velocity attained at VO_2max – are not sustainable for the work duration associated with long slow distance training. Consequently this approach to training (in isolation) is unlikely to be effective in well-trained athletes and moreover not time-efficient or particularly appropriate for the type of metabolic conditioning required by team sports players.

Threshold training

Threshold training involves continuous work at the pace associated with lactate threshold or maximum lactate steady state (MLSS). By definition, this form of training aims to set conditioning at an intensity which is at the upper limit for what can be sustained for a prolonged period. It follows that this form of conditioning requires that this intensity must first be identified for the individual athlete by appropriate testing. Further monitoring will similarly be required in order to adjust conditioning intensity with changes in the athlete's lactate threshold or work intensity associated with MLSS. Practically, testing and continued monitoring for each individual player upon which this approach relies is likely to be problematic for large squads of players.

Interval versus continuous format for conditioning

By definition, continuous work over an extended period is limited to submaximal work intensities – higher work rates cannot be sustained over these longer periods. Interval conditioning therefore provides a framework to allow higher work intensities to be performed over repeated bouts – with the intention that the accumulated total time spent at these higher intensities is longer than would be possible if working continuously (Billat 2001a).

Aerobic interval training

Aerobic interval training is defined as conditioning that involves repeated bouts of work of an intensity at or above lactate threshold or MLSS; these repeated work bouts are interspersed with recovery periods of a prescribed duration (Billat 2001a). Rest intervals between work bouts can comprise active (light intensity work) or passive recovery – active recovery is recommended to assist clearance of lactate and enhance oxidative recovery.

What separates aerobic interval training from anaerobic interval training is that the intensity, length, and format of work:rest ensures that aerobic metabolism remains the primary energy source (Billat 2001a). Appropriate recovery interval length is that which provides sufficient physiological stimulus to develop aerobic–anaerobic endurance whilst avoiding accumulation of excessive lactate and compromised work output (Vuorimaa and Karvonen, 1988). Endurance athletes often select the intensity of work bouts based upon specific race velocities for their event (Billat 2001a). Training of this type elevates the relative exercise intensity the athlete is able to sustain for extended periods – hence fulfils the criteria for 'threshold training' described previously.

High-intensity interval exercise is shown to elicit significant concurrent improvement in both aerobic power (VO_2max) and a selection of anaerobic capacity and intermittent exercise performance measures (Gaiga and Docherty, 1995; Tabata et al., 1996). There are some data to suggest that aerobic interval training also promotes oxidative metabolism of fats and spare glycogen – in comparison to the same exercise performed as a continuous bout (Billat 2001a). The preferential use of fats as an energy substrate and sparing of finite stores of glycogen (carbohydrate) is an important adaptation in improving endurance capacity. Specifically, increased fat utilization and sparing of glycogen is likely to prolong the duration over which the player is able to perform at higher work intensities. If work bouts are conducted at paces that correspond to those occurring during competition this form of training will also favour improvements in running economy and work efficiency at competition velocities (Jones and Carter, 2000).

Anaerobic interval training and repeated sprint conditioning

What separates anaerobic interval training from aerobic interval training is that higher work intensities are involved: work intervals are conducted at velocities above that associated with VO_2max – i.e. closer to sprinting velocities (Billat 2001b). The other factor that distinguishes anaerobic interval training is that relatively longer recovery durations are used in order to allow more complete restoration of PCr stores within the muscle. The longer pauses also enable the athlete to work for a greater accumulated time at high intensity during the session (Billat 2001b).

Investigations of interval (multiple sprint) training protocols have found that aerobic and anaerobic systems are taxed to a different relative extent depending on the format of training. The key factors are the intensity of work bouts, and the relative length of work and recovery phases employed (Tabata et al., 1997). Short work bouts (≈20 seconds) of high intensity with extensive rest intervals (≈2 minutes) provide a predominantly anaerobic training stimulus (Tabata et al., 1997). Conversely, lengthy work bouts (up to 5 minutes) of moderate intensity interspersed with brief rest periods has a largely aerobic training effect (Wilmore and Costill, 1999). It appears that optimal combinations of high-intensity work bouts and brief rest intervals do exist that simultaneously tax both aerobic and anaerobic systems almost maximally (Tabata et al., 1996; Tabata et al., 1997).

When close to maximal work intensities are used, this form of training is more accurately defined as repeated sprint training (Billat 2001b). These protocols commonly use recovery intervals as long as 4 minutes between work bouts (Bodganis et al., 1996). Depending on conditions (work intensity and nature of recovery), rest intervals of this length allow almost complete restoration of PCr stores within the muscle; this enables the contribution of the phosphagen system to energy production to be maintained over consecutive sprints (Billat 2001b). The contribution of oxidative metabolism also increases with each work bout, despite the near-maximal work intensities and extended recovery periods used in these protocols (Bodganis et al., 1996).

SPECIFIC METABOLIC CONDITIONING MODES FOR TEAM SPORTS

By their intermittent nature, team sports would appear to be most amenable to aerobic and anaerobic interval conditioning. Importantly, interval-based conditioning also enables both aerobic and anaerobic capacity to be developed simultaneously (Laursen and Jenkins, 2002). Thus, this would appear to be not only the most sport-specific approach, but also more time-efficient – this is an important consideration in view of the volume of technical/tactical practices and other training athletes in these sports are required to perform.

High-intensity interval and repeated sprint conditioning

High-intensity interval training is shown to improve cardiorespiratory fitness parameters and measures of performance in team sports athletes (Helgerud et al., 2001). A range of conditioning modes have been used successfully, including hill running (Helgerud et al., 2001) and high-intensity game-related drills (McMillan et al., 2005). One such study reported increases in aerobic power, lactate threshold, and running economy observed in junior elite soccer players following training that were also reflected in concurrent improvements in performance measures. Significant increases were observed in distance covered in a match, average work intensity in both halves of play, number of sprints, and frequency of involvement in play (Helgerud et al., 2001).

Some authors have suggested that repeated sprint conditioning over short distances using work:rest ratios recommended to optimize PCr resynthesis may be a suitable approach for developing the capacities required by team sports players (Little and Williams, 2007). Proponents of this approach have suggested that the sprint distances and work:rest ratios recommended also correspond quite closely to those reported for various field team sports. A study has investigated a range of repeated sprint protocols with reference to the physiological responses of soccer (Little and Williams, 2007). Variations of two protocols were used: 15 sets of 40m sprints with either 1:4 or 1:6 work:rest ratio; and 40 sets of 15m sprints, again with either 1:4 or 1:6 work:rest ratio. Based upon physiological responses recorded, the authors of the study suggested that the 40×15m sprints with 1:6 work:rest ratio would be most applicable to soccer (Little and Williams, 2007). With both 15m and 40m sprint distances the decrement in sprint times when 1:4 work:rest ratios were employed was concluded to be too great for use with soccer players. However, the authors did also suggest that the 15×40m sprints with 1:4 work:rest might have application as an overload training stimulus for soccer players (Little and Williams, 2007).

Tactical metabolic training approach

The 'special endurance' approach to conditioning models training intensities upon the workloads and the 'effort distribution' observed during competition (Plisk, 2000). In the case of sports featuring intermittent activity, the way conditioning is structured can be defined in terms of work:rest ratios observed from competition (Plisk, 2000). The process of identifying relevant parameters from competitive play to apply to players' metabolic conditioning has been termed 'tactical modelling' (Plisk and Gambetta, 1997). The tactical metabolic training (TMT) approach to conditioning is essentially an extension of the high-intensity intervals/repeated sprint conditioning approach – the difference being that the intensity of work intervals and work:rest ratios employed are directly based upon those observed during competitive matches.

Such an approach gives recognition to the interrelationship between energy systems during competition, as energy systems are trained in combination in a way that aims to reflect the bioenergetics of competition (Plisk and Gambetta, 1997; Plisk, 2000). Proposed advantages of this TMT format include greater time efficiency, as skill elements can be incorporated into metabolic conditioning (Plisk and Gambetta, 1997). This is favourable from a coaching point of view as it allows game-related skills to be executed in simulated game conditions. The game-oriented nature of TMT is also postulated to be advantageous in that it is likely to engender greater motivation and enhanced training compliance among athletes (Plisk and Gambetta, 1997).

The special conditioning TMT approach for team sports was originally developed in American football. This sport is highly structured with the ball being live for only brief periods until the player in possession of the ball is tackled or the ball goes out of play, at which time there are extended stoppages until play restarts. More continuous team sports featuring more variable patterns of activity pose greater challenges to application of this approach to conditioning design. Objectively quantifying competition demands tend to demand extensive time-motion analysis and physiological data. If these data are available for the sport in question, TMT methods can be used by structuring conditioning drills around typical work:rest ratios reported (Plisk, 2000; Plisk and Gambetta, 1997). Successful application of the TMT approach has previously been described for collegiate basketball (Taylor, 2004).

Methodological considerations for profiling demands of team sports competition

Attempts to quantify demands of team sports as a basis upon which to model sport-specific conditioning practices commonly use time–motion based analysis of players' movements during match-play. Distance covered during the course of a match is often recorded as a global measure of energy expenditure and physiological demand (Reilly, 1994). However, it is notoriously difficult to evaluate physiological stresses associated with intermittent sports by such indirect estimation (Gamble, 2004a; Reilly, 1994; Reilly, 1997).

Time–motion analysis does provide a means to document the types of activity players engage in during a match (Duthie et al., 2003; McInnes et al., 1995). However, intermittent sports have been shown to have energetic demands far in excess of those that would be predicted from covering the same distance continuously (Drust et al., 2000). Effectively, the patterns of transitions between movement phases are of similar importance to the individual component activities themselves.

Studies show that unorthodox (sideways and backwards) modes of locomotion feature prominently in team sports, with certain playing positions having a particular emphasis on these modes of locomotion (Duthie et al., 2003; McInnes et al., 1995; Reilly, 1994; Rienzi et al., 1999). These movements involve energy demands in excess of conventional running (Reilly, 1997). This added physiological cost rises disproportionately with increases in speed of movement (Reilly, 1994). Game-related activities similarly impose considerably higher energy expenditure than running (Reilly, 1994; Reilly, 1997).

Both of these factors compound the underestimation of the physiological cost of match-play for team sports from indirect observation and time–motion analysis. Estimations based on individual component activities in isolation will significantly underestimate physiological stresses imposed on players, and can thereby give a false indication of the metabolic pathways implicated in real game situations.

It follows that accurate assessment of exertion levels requires players to be directly monitored during game-play. The consensus is that assessment of energetic demands in team sports should include sampling of markers of physiological stress under performance conditions (Duthie et al., 2003; McInnes et al., 1995; Reilly, 1994; Reilly, 1997).

Despite technological advances, gas analysis apparatus will inevitably restrict players' movements and interfere with match-play, and certainly would not be safe for contact sports. In view of this, studies to assess energy expenditure typically use HR or BLa as the physiological marker (Reilly, 1994).

The main argument against BLa as an index of exertion levels during competitive matches is the dynamic nature of lactate as a metabolite (Bangsbo et al., 1991). BLa levels are essentially determined by relative rates of production, release, uptake, and removal. Consequently, single blood samples merely give a snap-shot of the activity performed during the interval immediately prior to when the sample was taken. Concentrations of BLa are commonly used to indicate contribution of anaerobic glycolysis to energy production (Coutts et al., 2003). However, beyond establishing that anaerobic metabolism plays a role in match-play exertion for a given sport, sporadic determination of BLa is of little value in profiling activity or intensity patterns throughout a match (Impellizzeri et al., 2005). Theoretically, serial measurements of BLa may better reflect shifts in intensity of exertion throughout a game, but the frequency of sampling required would be unfeasible during a competitive match.

Assessments of the demands of game-play have thus tended to favour HR monitoring as the sole reliable and practical indicator of physiological strain or energy expenditure (Boyle et al., 1994). Combining both HR monitoring and time–motion analysis of accompanying match footage can offer greater insights into demands of competition in team sports.

Quantifying physiological demands of match-play in collision sports

The element of violent bodily contact with opposing players and the playing surface has tended to preclude direct measurement of physiological responses during game-play in collision sports (Duthie et al., 2003). A consequence of this failure to objectively define the specific demands of match-play is that training specificity has frequently been neglected in the design of conditioning regimes for players at all levels in these collision sports.

Recent attempts that have been made to implement HR monitoring during match-play in contact sports such as rugby union and rugby league have been limited to youth and semi-professional playing grades (Coutts et al., 2003; Deutsch et al., 1998). The relevance of these data may be questionable for senior players at elite level.

Sources of variability when evaluating demands of sports performance

The strength and style of play of the opposition will inevitably influence the nature, frequency, duration, and density with respect to time of activities players are required to perform (Duthie et al., 2003; Woolford and Angove, 1991). These aspects will similarly be affected by the officiating styles and environmental conditions (Duthie et al., 2003). The referee has a major bearing on the format the game takes in terms of number of stoppages and duration of phases of play, particularly in highly technical sports such as rugby union, ice hockey, and American football. Similarly, environmental conditions will influence tactics and the errors committed by both sides, which will in turn influence the pattern and mode of activity players will be engaged in. Thus, there is significant variation not only within a match but also between consecutive games (Duthie et al., 2003).

Notwithstanding the difficulties outlined in gathering data pertaining to the global demands of match-play as they relate to a team, individual roles of particular playing positions within a team are also quite diverse (Duthie et al., 2003). Precise roles of the respective playing positions therefore vary between teams, depending on their particular structured game-plan, and associated demands imposed upon players in different positions.

A significant volume of data would therefore appear to be required to overcome the inherent variability within and between games to establish an accurate assessment of demands during competition that are representative for a particular team. This demand is multiplied several-fold if the aim is to gather a complete picture of the associated demands for individual playing positions within that team.

In the absence of comprehensive data for a given sport, the key aspects of competition can still be incorporated into the design of conditioning. For example, conditioning drills should simulate game-related movements and modes of locomotion – including lateral and backwards motion (Plisk and Gambetta, 1997). Appropriate constraints associated with the particular sport may also be replicated in the training environment during conditioning activities where possible, such as opposing players and dimensions of the playing area (Handford et al., 1997). However, alternative methods of sport-specific conditioning for team sports should also be explored.

Skill-based conditioning games approach

As outlined, there are significant methodological issues that compound the inherent difficulty in collecting data upon which to quantify demands associated with team sports, particularly collision sports. The complexities and inherent variability of team sports render efforts to design conditioning drills to simulate match conditions all the more difficult (Gabbett, 2002). Furthermore, strength and conditioning specialists seek to not merely simulate typical match-play demands, but rather impose overload in terms of the intensity, frequency, duration, and density of specific activities demanded in match-play (Gamble, 2007b). An alternative approach to provide appropriate overload is to operate at the extremes of frequency, duration, and intensity of activity levels a player could expect to experience during a competitive match.

A conditioning format that meets these criteria involves the use of skill-based conditioning games. These comprise purpose-designed games featuring modified playing areas and rules, which allow training intensity to be manipulated (Hoff et al., 2002; Rampinini et al., 2007). A multitude of skill-based conditioning games with different rules can be adapted from other ball games, such as team handball, netball, Australian Rules football, and American football – whilst still using the same regulation ball and similar skill set to that featured in the sport the athlete is training for (Gamble, 2007b).

Depending on the choice of conditioning game, it is possible to elicit different levels of training intensity. Factors identified as influencing training intensity with conditioning games include pitch dimensions, players per side, and presence of coaching/instruction (Rampinini et al., 2007). Different games and parameters can thus be employed to provide variety in training and manipulate intensity. Typically the highest training intensity is elicited by having fewer players in a team, playing on a larger playing surface, restricting the time the ball is out of play, and having coaches present to provide instruction and encouragement (Hoff et al., 2002; Jeffreys, 2004; Rampinini et al., 2007). However, there does tend to be an optimal size of playing area that requires greatest exertion without allowing the player in possession too much time and space (Jeffreys, 2004).

Skill-based conditioning games are by definition less structured and conducted in a more open and random setting, which is in contrast to the discrete conditioning drills or simulated plays that are often used with the

TMT format. Due to the intermittent nature of conditioning games and the fact that reaction to game-related cues is incorporated, this approach to metabolic conditioning encompasses both movement and context specificity. Likewise, the fact that decision-making and game skills can also be developed makes conditioning games highly time-efficient as these technical and tactical elements can be developed concurrently (Gamble, 2004a; Jeffreys, 2004). The skill and competition elements that are the key features of skill-based conditioning games are suggested to promote enhanced effort despite apparently lower perceived exertion ratings by participating players (Gabbett, 2006). As such, the skill-based conditioning games approach is likely to engender greater compliance, making this form of conditioning conducive to continued use over an extended period (Gamble, 2007b; Jeffreys, 2004). The presence of a coach to provide verbal encouragement and instruction when conditioning games are being conducted also appears to enhance the consistency of players' work rates over time (Rampinini et al., 2007).

Hoff and colleagues (Hoff et al., 2002) concluded that small-sided games fulfilled the necessary criteria to be an effective means of interval training for soccer players, on the basis of HR and respiratory responses recorded during training. In support of this, a preseason conditioning programme exclusively employing conditioning games was shown to positively influence cardiorespiratory responses to a standardized shuttle test with elite-level rugby union football players (Gamble, 2004a). The skill-based conditioning games training format has similarly been used in rugby league football and produced equivalent gains on measures of aerobic fitness following a preseason training period to a control group that performed interval running conditioning (Gabbett, 2006). The application of skill-based conditioning games is not restricted to field-based team sports; this approach also shows potential use for court-based team sports such as volleyball and basketball. A study of junior elite volleyball players showed that the skill-based conditioning game studied involved comparable time in specified intensity zones (defined as ranges of players' percentage HR max) as those recorded when the players were engaged in competitive matches (Gabbett, 2008). Such data provide support for the use of skill-based conditioning games to prepare volleyball players for the physiological demands of competition.

The skill element that is a feature of conditioning games has been suggested to offer concurrent sports skills development – particularly skill execution under conditions of fatigue (Gabbett, 2006; Gamble, 2007b). A study of elite junior volleyball players reported that skill-based conditioning games conferred some improvement in scores for certain sport skill measures, although they did not produce the degree of improvement on the same range of measures as a training group that engaged in specific skill practices (Gabbett, 2008). Accordingly, this form of conditioning will complement players' skill work, but should not replace dedicated skill practice. This form of metabolic conditioning also appears to be associated with lower injury incidence rates, in comparison to other forms of training (Gabbett, 2002). In the study by Gabbett (2002) the reduced rate of injury reported with rugby league players when engaged in skill-based conditioning games contrasted with traditional conditioning (without any skill element), which featured by far the highest incidence of injury.

It is conceivable that improved motor control may be an underlying factor in the decreased injury when performing sports movements, as opposed to traditional running conditioning (Gamble, 2004a).

Training using such an inherently unstructured format as conditioning games requires some objective marker to evaluate the work rates of individual players (Gamble, 2007b). HR monitoring is extensively used as the most effective and practical means to objectively monitor intensity during a training session (Potteiger and Evans, 1995), and quantify training loads in the athlete's weekly training log (Gilman and Wells, 1993). The use of HR to monitor exercise intensity has also been validated against direct measurement of ventilatory responses during small-sided conditioning games in soccer players (Hoff et al., 2002). Monitoring of players' HR therefore would appear a crucial adjunct to the skill-based conditioning games approach, in order to quantify training intensity in the conditioning game setting (Gamble, 2007b).

CONCLUSIONS AND TRAINING RECOMMENDATIONS

- Owing to the intermittent and unpredictable nature of team sports, they are conducive to structuring metabolic conditioning using prescribed distances with target training paces, as is the case for more continuous endurance sports.
- High-intensity interval and repeated sprint conditioning appear to be the training approaches best suited for concurrent development of aerobic and anaerobic capacities in order to prepare players for the intermittent nature of exertion that is characteristic of team sports.
- TMT methods offer a means for high-intensity interval training in a way that may better reflect physiological conditions and movement patterns experienced during competition; and incorporating skill elements into TMT design may also benefit motivation and training compliance.
- To implement the TMT approach properly requires a considerable amount of physiological and time–motion data from competitive matches, which may not be available for some sports.
- Skill-based conditioning games also represent a sport-specific mode of training for team sports; this approach also offers advantages in terms of time-efficiency, motivation, and training compliance.
- For most team sports, high-intensity interval training, repeated sprint conditioning, TMT and skill-based conditioning games can be employed at various times during the training year:
    - During the off-season, the use of conditioning games may be restricted, for example, due to NCAA regulations that may not permit their use on the basis that they may be deemed to represent skill or tactical training – hence high-intensity interval training or TMT would be the predominant mode of conditioning at this time.

- Repeated sprint conditioning can be implemented during particular phases of training for specific development of speed-endurance particularly for those playing positions that have a special requirement for this capacity.
- During the playing season, coaches may favour the use of conditioning games on the basis of their time-efficiency and opportunity to incorporate skill and decision-making elements (Jeffreys, 2004).

CHAPTER 5

TRAINING FOR POWER

INTRODUCTION

Training specificity is evident when training to develop 'explosive power' or speed-strength. It has been identified that the neuromuscular firing patterns observed during strength-oriented and explosive movements are grossly different (Ives and Shelley, 2003). Neuromuscular firing patterns and intramuscular co-ordination demands are factors that differentiate training methods which are effective for developing explosive power from other forms of strength training (Young, 2006).

Speed-strength training modes are a special category of training exercises that fulfil the conditions necessary, in terms of intramuscular and intermuscular co-ordination, to develop explosive power production. Speed-strength training modes have a demonstrated capacity to impact specifically upon explosive performance (e.g. jump-and-reach height) in the absence of any changes in other strength properties such as maximum strength (Newton et al., 1999; Winchester et al., 2008).

Several discrete elements of the neuromuscular system have been isolated, all of which influence power output (Newton and Kraemer, 1994; Newton and Dugan, 2002). Each of these qualities contributing to explosive power development requires a specific training stimulus. These individual neuromuscular components involved in expression of explosive power can, however, be considered trainable and developing each of these components either in isolation or in combination can favourably impact upon expression of power (Newton and Kraemer, 1994).

Aside from considerations regarding neuromuscular firing patterns and intramuscular co-ordination, in much the same way as strength training exercises, power training methods also demonstrate mechanical specificity. Speed-strength training therefore must likewise satisfy kinetic, kinematic, and biomechanical criteria that are specific to the athletic or sport skill movement in order to be most effective.

Approaching training for power or 'speed-strength'

There have historically been two major schools of thought regarding training methods to develop explosive muscular power. Some proponents have suggested it is sufficient to solely develop force-development capabilities (i.e. strength) and then transfer the gains in strength by subsequent practice with the particular athletic activity (Kraemer, 1997). Such an approach essentially accounts for the force element in the force × velocity equation for power. However, explosive power is a learned motor skill of the neuromuscular system and is identified as a capacity that is distinct from maximal force production (Ives and Shelley, 2003). Although maximal power output is dependent upon strength to a varying extent depending on the resistance involved (Stone et al., 2003a), expression of sport-specific power has elements that are independent of the basic force-generating capacity of the musculature. This is illustrated by the dissociation of maximum (1-RM) strength and explosive power scores in elite athletes (McBride et al., 1999; Delecluse et al., 1995).

The efficacy of specific training to develop power is demonstrated by the observed improvements in measures of explosive power performance with short-term speed-strength training interventions in the absence of any maximal strength gains (Newton et al., 1999; Winchester et al., 2008). Likewise, Olympic lifts have been found to increase concentric power (squat jump height) in elite strength athletes (champion weightlifters) (Hakkinen et al., 1987). This is similarly significant, as traditional heavy resistance training modes are relatively ineffective in developing lower body power (vertical jump height) in trained power athletes, despite significant concurrent gains in 1-RM strength (Baker, 1996).

Such considerations led to the genesis of a multidimensional construct for explosive muscular power. Several discrete elements of the neuromuscular system have been isolated, all of which influence power output (Newton and Kraemer, 1994; Newton and Dugan, 2002). Each of these individual components of the neuromuscular system that contribute to expression of power can be considered trainable. 'Mixed methods' training strategies propose employing a range of training modalities to specifically train each neuromuscular capacity implicated in the expression of explosive power (Newton and Kraemer, 1994). These factors, targeted via appropriate training, have the potential to individually contribute to the development of explosive power capabilities. Developing these components in combination can further have a cumulative impact upon the athlete's ability to develop explosive power.

Evidence as to the efficacy of mixed methods training is seen by the superior results elicited by combination training in comparison to either high force or high power training (Harris et al., 2000). Greater gains are reported with strength trained team sports players (collegiate American Football players) on a wider range of performance measures with a combination of both high-force and high-velocity 'power' training. Performed individually, high force training effects are limited to gains in maximal strength (1-RM) and heavy load speed-strength (hang pull 1-RM) measures, with no impact on dynamic athletic measures. Conversely, the high-velocity 'power' training resulted in gains in dynamic measures, with no impact on heavy load capabilities (Harris et al., 2000). Interestingly, combination training not only yielded the benefits associated with both single training modes, but also produced gains on measures (ten yard shuttle agility run and average vertical jump power) not seen with either high-force or high-velocity training alone (Harris et al., 2000). Adaptation to high force or high velocity training performed in isolation by strength trained athletes is reflected in performance measures that are restricted to the region of the force/velocity curve that characterized the training. Furthermore, combined methods are observed to be most effective in developing vertical jump height (the standard measure of lower body power production) (Baker, 1996). Superior performance effects on a broader spectrum of the force/velocity curve with combined training were attributed to exploiting different avenues of explosive performance development simultaneously (Harris et al., 2000).

FACTORS IN THE EXPRESSION OF EXPLOSIVE MUSCULAR POWER

The individual elements that have been implicated in the expression of explosive muscular power will be discussed in turn.

Rate of force development

Rate of force development (RFD) describes the ability to develop force within a limited time frame. This component represents the slope of the force/time curve for a muscular action (Newton and Dugan, 2002). Rate coding is a major factor influencing RFD; specifically, the maximal firing rates of motor units within the window for force development allowed by the movement (Behm, 1995). Accordingly RFD is associated with the ability to achieve rapid acceleration for a given movement (Stone, 1993). The time interval for force development in many athletic movements is very brief – typically within 300ms (Newton and Kraemer, 1994). On this basis, some authors identify RFD as possibly the most important capacity influencing athletic performance (Wilson et al., 1995).

It follows that the time taken to develop force featured in the training exercise must be similarly brief to train the neuromuscular system to develop maximal force across these shorter time frames. In accordance with this is the observation that the closer the time interval of a given dynamic strength measure to the contact time observed for athletic movements, the greater the correlation to performance (Young et al., 1995). Traditional heavy strength training would appear to be unsuitable for developing this RFD component;

a heavy barbell squat, for example, can take around 1.5–2 seconds to complete the concentric portion of the movement (Baker, 2001a). Conversely, motor unit firing rates are appreciably higher during the short window for force development associated with maximal ballistic concentric actions (Hedrick, 1993; Behm, 1995). Under certain conditions, improvements in isometric RFD have been noted following isometric training in non-athlete subjects (Behm and Sale, 1993); however, the relevance to athletic performance of both isometric training (Morrisey et al., 1995) and isometric measures of RFD (Wilson et al., 1995) have been questioned.

Slow-velocity strength

Slow-velocity (1-RM) strength is required at the initiation of any explosive movement to overcome inertia when system velocity is zero or slow (Stone, 1993). Maximum strength therefore has a major influence on the initial rate at which force is developed early in the movement (Stone et al., 2003). For locomotion and jumping movements in particular, even in the absence of external resistance, there is a significant inertia component. Accordingly, maximum strength relative to body mass is a key element in the expression of power for gross motor actions involved in a variety of athletic movements (Peterson et al., 2006). High correlations are observed between 1-RM strength and power output even for unloaded jumps. Furthermore, slow-velocity strength development influences the mechanical power output a player is able to generate in higher resistance regions of the load versus power curve (Stone et al., 2003a). For players in contact sports, in particular, the ability to generate power against external resistance is an important factor, which similarly relies heavily upon high levels of force output and therefore maximum strength.

High-velocity strength

High-velocity strength, or speed-strength, is the ability to exert force at high contraction velocities. Increases in maximum strength are of limited relevance if the athlete is unable to express this greater force at the movement velocity encountered in competition (Hedrick, 1993). The neuromuscular basis for improvements in force development at higher velocity regions of the force-velocity curve are neural adaptations in the capability to preferentially recruit high-threshold motor units (Stone, 1993; Cronin, 2001a) and the capacity of these motor units to fire rapidly for short intervals (Hedrick, 1993). Such adaptations in intramuscular co-ordination appear to result in specific improvements at the higher movement velocity region of the force/velocity curve (Stone, 1993). Improvements in high-velocity strength may also be mechanical in origin: adaptations in the contractile properties of muscle fibres that lead to increased maximal shortening velocity and peak power have been shown to be elicited by appropriate training (Malisoux et al., 2006).

Stretch-shortening cycle capabilities

The stretch-shortening cycle ('SSC') comprises series of elastic contractile and connective tissue elements and neural potentiation that include reflexes at local spinal level. Authors increasingly distinguish between 'fast SSC' (100–200ms) and 'slow SSC' (300–500ms) movements based upon the duration of ground contact or force application. SSC performance characteristics are found to be independent of maximal muscle strength in highly trained athletes (Plisk, 2000). SSC performance in part depends on the capacity of the musculoskeletal complex to store and use elastic tension (Yessis, 1994; Newton et al., 1997). This can be modified by increasing muscle activation and tension during the interval immediately prior to ground contact. Such modification in descending neural input to the muscles from higher motor centres is responsible in part for the improvement in fast SSC performance following appropriate plyometric training. Another of the underlying neural mechanisms responsible for additional augmentation of power output immediately following pre-stretch is associated with the 'stretch reflex'. This is a peripheral reflex at local spinal level that acts to stimulate the stretched muscle to contract, in an attempt to return the muscle to its previous length (Potach and Chu, 2000). This stretch reflex-mediated neural drive is superimposed upon voluntary drive to the agonist muscles, which leads to augmentation of power output in the subsequent concentric phase (Newton et al., 1997).

Neuromuscular skill

The final component of explosive power is neuromuscular skill. In much the same way as sport-specific strength, a player's effectiveness is limited to the extent that they are able to express the elements of explosive power described above during the execution of game-related activities and sport skills at the decisive time in match situations (Smith, 2003). This encompasses both intermuscular and intramuscular co-ordination (Newton and Kraemer, 1994). Broadly, intramuscular co-ordination comprises the recruitment and firing of motor units of muscle groups involved in the movement. Intramuscular co-ordination thus encompasses descending neural drive from the motor cortex and excitatory and inhibitory inputs originating from local spinal level (Cronin et al., 2001). Increasing motor unit recruitment, descending neural drive, and net excitatory input to the motor units involved in an athletic or sports skill movement will have a favourable effect on force and power output. Intermuscular co-ordination concerns the coordinated action of muscles that are involved in producing athletic or sports skill movements (Young, 2006). As such, this entails interaction between the agonist, synergist, and antagonist muscle groups employed during the particular movement. For example, one important aspect of intermuscular co-ordination is reduced co-contraction of agonist and antagonist muscle groups (Newton and Kraemer, 1994). It follows that adaptations in intermuscular co-ordination will be closely related and highly specific to the particular movement(s) featured in training (Young, 2006). Increasing force or power output of a single muscle group in isolation could conceivably impair athletic performance if the increased single muscle function is not achieved in co-ordination with other muscle groups acting on the kinetic chain of joints involved in a movement

SPEED-STRENGTH TRAINING MODES FOR DEVELOPMENT OF EXPLOSIVE MUSCULAR POWER

Heavy resistance training is a key element in developing the necessary strength and eliciting both morphological and neural adaptations that will enable a player to generate high levels of muscular power. Players therefore require optimal levels of strength, developed via appropriate heavy resistance strength training, as a precursor to engaging in training to specifically develop power. The specific approach that may be taken to strength training has been covered in a previous chapter. There does, however, remain a need for specific speed-strength training to follow this initial strength development in order to optimize players' ability to express explosive muscular power. Accordingly, the addition of speed-strength training has been shown to produce gains beyond those elicited by heavy resistance training alone (Newton et al., 1999; Baker, 1996; Delecluse et al., 1995).

In the case of gross muscle actions, speed-strength exercises have been identified as the optimal means to target the elements of explosive power production described. As implied by their title, speed-strength exercises combine both high force (the product of mass and acceleration) and high velocity (Hydock, 2001). Speed-strength exercises are characterized by maximal rates of force development (Hedrick, 1993) throughout the movement range of motion (Stone, 1993). These power development oriented exercises have thus been termed 'full acceleration' exercises by some authors (Baker, 2003).

Potential adaptations to speed-strength training include improvements in contractile elements – such as increased maximum shortening velocity and power output of muscle fibres (Malisoux et al., 2006). Speed-strength training is also associated with preferential hypertrophy of high-threshold Type II muscle fibres (Stone, 1993). Intent is key to the neural adaptations associated with speed-strength training (Behm and Sale, 1993). Due to their explosive nature, speed-strength exercises are more suited to evoke explosive intent. In the case of conventional strength training lifts such as the bench press, aside from mechanical considerations, athletes also must be coached to make a conscious effort to lift with explosive intent to optimize training responses on explosive power scores (Jones et al., 1999). Velocity gains following training are reportedly reduced by half when subjects are left to self-select lifting speed (Jones et al., 1999).

Ballistic resistance training

Ballistic resistance exercises represent one of the major speed-strength training modalities for developing concentric power capabilities. This form of training is unique in that the load is released or projected into free space at the end of the movement. It is this characteristic that makes ballistic resistance training superior to conventional strength training exercises in developing elements of explosive muscular power (Cronin et al., 2003). Specifically, ballistic resistance exercises allow power to be generated throughout the full range of motion, as there is no requirement to brake the motion of the load to bring it to a halt at the end of the movement. As the acceleration phase is not terminated before the end of the range of motion (ROM) for the exercise, this in turn allows higher velocities to be produced with the result that a higher peak velocity (hence peak power) can be attained later in the movement (Newton et al., 1996). Accordingly, Cronin and colleagues identified projection (i.e. release) of the load as the most crucial factor influencing expression of peak power (Cronin et al., 2003; Cronin et al., 2001b). This is reflected in greater average and peak velocities with upper body movements for a range of loads (30–60 per cent 1-RM) under conditions where the load is projected into free space (Cronin et al., 2003).

Jump squats have been identified as an effective training modality for developing measures of lower body explosive power (vertical jump height) in elite power athletes (Newton et al., 1999; Wilson et al., 1993; Baker, 1996). Short-term (5 weeks) jump squat training was also reported to produce significant improvements in high force speed-strength measures (power clean 1-RM) in collegiate American football players (Hoffman et al., 2005). Such changes in speed-strength and vertical jump performance appear to be relatively independent of changes in 1-RM strength and peak force measures or changes in muscle morphology. A recent study examining performance effects and underlying mechanisms for training adaptations with jump squat training in recreational athletes reported significant gains in peak power, rate of force development, and peak velocity (Winchester et al., 2008). However, there were no significant changes in peak force, 1-RM squat, or muscle fibre type expression accompanying these improvements in speed-strength measures. Due to the bilateral and vertical nature of the jump squat exercises, it is perhaps unsurprising that less success has been reported with this training mode in improving sprinting performance. A 10-week study employing jump squats improved jump height measures, isokinetic knee extension scores, and 6-second cycle performance without any significant improvement in 30-m sprint (Wilson et al., 1993).

The obvious upper-body equivalent to the jump squat is the bench throw. Accordingly, this mode of training has been shown to elicit significant upper-body power gains (Lyttle et al., 1996). It is suggested that the greater velocity and movement pattern specificity of ballistic training is more likely to stimulate functional high-velocity adaptations (Cronin et al., 2003) than traditional resistance training. Accordingly, bench throw training is shown to elicit significant improvements in functional performance in elite baseball players (McEvoy and Newton, 1998). A practical consideration with this ballistic training mode is that it requires costly apparatus to safely restrict the barbell to vertical-only movement and to brake the descent of the bar once it is released. One alternative is to substitute the ballistic push-up exercise; this circumvents the need for expensive specialized equipment to catch an external load as the athlete's own body mass is the load that is projected into free space. When compared to standard modified push-ups (supported on the knees), ballistic modified push-up training (hands leaving the floor at the top of the movement) was reported to elicit significantly greater improvement in ballistic power, as assessed by medicine ball throw distance, and similar gains in strength (chest press 1-RM) scores in female subjects (Vossen et al., 2000).

It has been contended that ballistic training with 'P_{max}' loads that maximize mechanical power output is the optimal means of developing explosive muscular power (Wilson et al., 1993; Baker et al., 2001a; Baker et al., 2001b). These methods have proven effective in developing power output and scores for dynamic athletic performance (Wilson et al., 1993). However, from a methodological point of view identifying players' individual P_{max} loads often leads to variable results. P_{max} appears to be affected by numerous factors including the movement in question – upper body versus lower body, joint angles and contraction type involved – and the relative strength of subjects tested (Baker 2001c; Harris et al., 2007), which in turn is influenced by strength training history. From this it appears the particular P_{max} value is both specific to the population and the movement involved in a given training exercise (Harris et al., 2007).

Similarly, the practical significance of this P_{max} load has been called into question by a number of authors. In view of the multidimensional nature of explosive muscular power developed, discussed earlier in the chapter, it seems counterintuitive that training a single percentage 1-RM load would be the optimal way to develop speed-strength capabilities (Cronin and Sleivert, 2005). Data from elite senior team sports athletes (rugby union players) also show that power output at different loads either side of the P_{max} load value in fact differ very little for a given training movement (machine jump squats) (Harris et al., 2007). In addition, employing P_{max} training modes in isolation tends to neglect the principles of specificity. Although a particular training load may be optimal for developing mechanical power output for a given movement, if the loading bears no relation to the resistances the athlete faces during competition, then the degree of transfer to performance appears questionable. It is similarly unlikely that training solely at P_{max} resistance will provide optimal training responses at both extremes of the force/velocity curve, as suggested by some proponents. Lower body intensive movements in particular are heavily dependent on maximum strength – reflected in the strong relationships between 1-RM strength and loaded vertical jump scores even with light resistance (Stone et al., 2003a). A bandwidth of loads around this conceptual P_{max} load therefore appears necessary: some authors suggest using a range of training loads from 30–70 per cent 1-RM (Cronin and Sleivert, 2005).

Conventional strength training modes are unsuitable for speed-strength training. Attempting to use traditional strength training exercises in an explosive fashion (lifting the load as rapidly as possible, keeping hold of the barbell at the termination of the movement) has been shown to be counterproductive (Newton et al., 1996).

Lifting lighter ‘maximal power’ loads (45 per cent 1-RM) in this manner results in a significant deceleration component, which can be up to 40 per cent of the range of motion (Newton et al., 1996). As a result, in the case of the bench press, beyond the initial 10 per cent of the range of motion at the initiation of the concentric movement, both force and velocity are less than the corresponding values for the ballistic bench throw at equivalent loads (Newton et al., 1996). This is accompanied by a loss of motor activity in agonist muscles, reflected in reduced EMG recorded for the bench press versus bench throw movement at these loads (Newton et al., 1996). Antagonist co-contraction is likewise increased when explosively performing the bench press exercise, particularly with light loads (Cronin et al., 2001). As a result, the training stimulus is compromised for the affected portion of the movement (Cronin et al., 2001b). Furthermore, efforts to lift a submaximal resistance with maximal acceleration results in the barbell gathering considerable kinetic energy, which will ultimately have to be absorbed by the muscles and joints at the end of its range of motion (Newton and Kraemer 1994). Attempting to use conventional strength training exercises in this manner therefore engenders the risk of injury.

Underlying neural adaptations influencing high-velocity strength include both intramuscular and intermuscular co-ordination. Intramuscular co-ordination aspects include improved recruitment and firing of high threshold motor units at the high contraction velocities associated with the ballistic training movement (Stone, 1993; Hedrick, 1993). Maximal ballistic muscle actions involve appreciably higher motor unit firing rates than those observed with conventional strength training (Behm, 1995; Hedrick, 1993). It follows that repeated exposure will favour developments in the ability for motor units to fire rapidly during the short interval for force development allowed by the ballistic action. Ballistic contractions appear to be part pre-programmed by higher motor centres in anticipation of how the ballistic action is expected to occur, with some modification of motor unit activation based upon sensory feedback during the movement (Behm, 1995). As such, power output for a ballistic action exhibits learning effects with repeated exposure to the specific training movement (Ives and Shelley, 2003). Intermuscular co-ordination and antagonist co-contraction is likewise largely pre-programmed, and is believed to be a protective mechanism acting to maintain joint integrity in anticipation of the forces and limb accelerations during the ballistic action (Behm, 1995). Fine-tuning of antagonist input with repeated exposure to the ballistic training movement may occur to reduce co-contraction to increase net concentric force output. The acceleration/deceleration profiles associated with bench throw training have been suggested to more closely resemble sporting activities (Cronin et al., 2003). This being the case, similar advantages in terms of improving performance via enhanced intermuscular co-ordination may be conferred by ballistic training.

The contribution of the player’s own body mass should be considered in order to accurately calculate loads for ballistic resistance exercises such as jump squat and ballistic push-up which involve the body being projected into free space (Cronin and Sleivert, 2005). Practically, there will also tend to be a trade-off between the degree of external loading used versus lifting form and the explosiveness with which the player is able to execute the movement. Qualitative assessment of both posture and lifting technique as well as velocity and height achieved should therefore also be used to guide loading when players perform ballistic resistance exercises.

Olympic weightlifting training modes

Olympic lifts are classified as speed-strength exercises (Stone, 1993), on the basis that they feature both a force (strength) and speed component (Hydock, 2001). These lifts are unique in that the resistance is accelerated up the natural line of the body and gravity acts to decelerate the load, which means the neuromuscular system does not have to intervene to brake the motion of the barbell (Kraemer, 1997). Elevating the athlete's own centre of mass represents a significant component of the work done when performing Olympic lifts (Garhammer, 1993). In contrast to ballistic resistance training modes in which the load is released at the end of the movement, with Olympic weightlifting movements the external load (typically a barbell) is held throughout: in the event that the barbell is still travelling upwards at the termination of the concentric phase, the lifter's feet merely comes off the floor. Average mechanical power output values reported for the Olympic lifts are 3000W for the barbell snatch and 2950W for the clean, which are nearly three times greater than that of back squat or deadlift (approximately 1100W) (Stone, 1993; Garhammer, 1993). Peak power output recorded during the 'second pull' phase can be five times greater (5500W) (Stone, 1993). Peak propulsion forces for these lifts are similarly comparable to those during jumping movements (Stone, 1993).

The unique nature of Olympic lifts allows heavy loads to be handled in an explosive fashion (McBride et al., 1999). This enables high levels of high-force 'speed strength' and RFD elements to be developed simultaneously. A reflection of the combination of heavy loads and high velocity of movement featured in Olympic lift training is that Olympic weightlifters exhibit equivalent strength scores and superior dynamic power scores to powerlifters (McBride et al., 1999). That said, Olympic weightlifters do also perform classic strength oriented lifts in their training, which contributes to their strength development.

Most Olympic lifts – particularly the pulling lifts – develop neural and contractile elements involved predominantly with concentric performance (Hakkinen et al., 1987), as opposed to SCC components. Observations of a year's weightlifting training in elite weightlifters registered significant improvements in unloaded and loaded squat jump height in the absence of any significant change in countermovement jump height (indicative of 'slow SSC' performance) with equivalent loads (Hakkinen et al., 1987). Similarly, these athletes also exhibit very small differences between squat jump and countermovement jump scores, indicating limited SSC augmentation of jumping performance (Baker, 1996).

Underlying mechanisms for the gains in concentric power output are generally ascribed to improvements in RFD and high-velocity strength (Stone, 1993; Garhammer, 1993; McBride et al., 1999; Souza et al., 2002). Increased peak RFD has been reported following Olympic lift training with concurrent gains in Olympic lift (snatch) 1-RM and performance test (shot put distance) scores (Stone et al., 2003b). In turn, intermuscular and intramuscular co-ordination elements are implicated in these adaptations (Newton and Kraemer, 1994; Hedrick, 1993). Intermuscular co-ordination effects are observed in preferential recruitment of high threshold (high force) motor units, and reductions in co-contraction of antagonist muscles. Developments in intramuscular co-ordination are manifested in enhanced capability of individual motor units to fire rapidly for short intervals (Hedrick, 1993), which underpins improvements in RFD (Behm, 1995). Other adaptations in intramuscular co-ordination include neuromuscular learning effects associated with rapid muscular contractions (Morrissey et al., 1995). Such learned 'neural strategies' include overriding inhibitory input and an anticipatory priming of motor units during the interval immediately prior to initiating the movement (Baker et al., 2001).

Olympic lifts are identified as combining strength, power, and neuromuscular co-ordination elements in a way that favours transfer to athletic activities, such as vertical jump performance (Kraemer et al., 2002). Peak propulsion forces relative to body mass generated during the power clean lift are shown to be similar to those exerted during jumping movements (Stone, 1993). Likewise, Olympic lifting movements involve a comparable time interval for force production, typically between 100 and 200 milliseconds for the second pull phase (Garhammer, 1993). On the basis of their biomechanical similarity and comparable time frames for concentric force production, Olympic lifts are routinely used in athletes' physical preparation as a means to replicate sport-specific movements (Souza et al., 2002).

Olympic lifters are reported to generate greater velocity and power than powerlifters when performing countermovement jumps with or without added loading (McBride et al., 1999). Similarly, Olympic lifters exhibit superior strength (1-RM squat) in comparison to sprinters (McBride et al., 1999). From these data it could be inferred that Olympic lift training is similarly effective in sprint training and more effective than powerlifting training in developing dynamic power, and more effective than sprint training in developing maximal strength. Similarly, of particular relevance to contact team sports is the observation that Olympic lifters perform better than sprinters in dynamic movements against resistance (McBride et al., 1999). The superior performance exhibited by Olympic lifters in this capacity suggests that the heavy load speed-strength training provided by Olympic lifting has the potential to develop this ability to generate power against resistance. Such observations point to the potential benefits of heavy load speed-strength training and specifically the use of Olympic lifts in rugby football and other contact sports. However, controlled prospective studies are required to draw definitive conclusions.

The kinetic and kinematic specificity of Olympic lifts with regard to the vertical jump movement are suggested to develop speed-strength in a way that transfers it more readily to jumping performance (Baker, 1996). A study of semi-professional rugby league football players also reported that players' scores on hang power clean relative to body mass discriminated between those who showed superior performance on vertical jump and 20m sprint, as well as speed strength measures with a loaded jump squat (Hori et al., 2008). A previous study with similar subjects reported hang power clean scores relative to body mass to be significant predictors of acceleration (10m) and short distance (40m) sprint scores in rugby league players (Baker and Nance, 1999b). In accordance with this, a study using non-athlete subjects reported that short-term (8 weeks) training using Olympic lifts in combination with heavy resistance training improved both squat jump and countermovement jump, and 10m sprint – although 30m performance was unchanged (Tricoli et al., 2005).

However, another training study with collegiate football players that included derivatives of the Olympic lifts (mid-thigh pull and push press) failed to show improvements in 30-metre sprint scores – although improvements in jump height and performance on a stair climb power test were seen (Harris et al., 2000). A more recent study also examining collegiate football players compared Olympic lift training to powerlifting training and likewise showed no changes in 40-yard sprint or T-test change of direction performance in either group (Hoffman et al., 2004). Therefore although Olympic weightlifting training is consistently shown to improve vertical jump performance there is some uncertainty as to whether bilateral speed-strength training of this type will transfer to sprinting performance (Young, 2006). Change of direction performance also appears to be both independent of hang power clean test scores (Hori et al., 2008) and similarly unresponsive to training involving standard weightlifting movements (Hoffman et al., 2004; Tricoli et al., 2005). This may be a consequence of the bilateral nature and predominantly vertical force production that is characteristic of the classical weightlifting movements. That said, single-leg and split variations of the Olympic lift movements do exist that may transfer more readily to a broader range of athletic and sports skill movements.

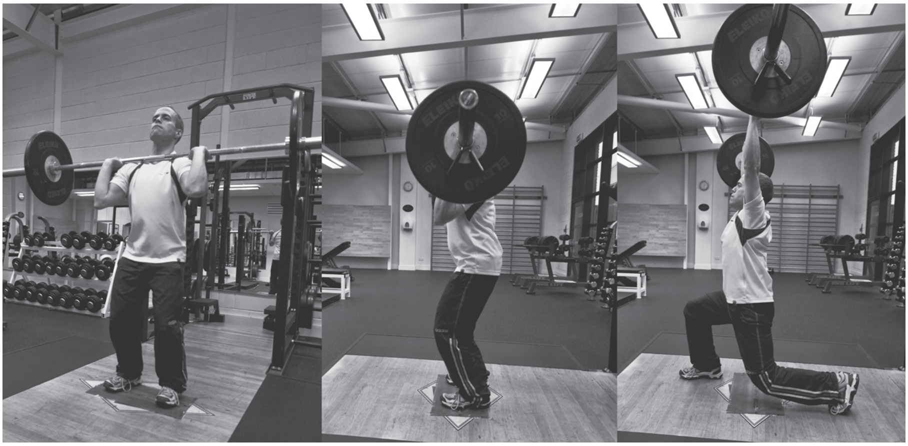

Figure 5.1 Barbell split jerk.

The clean pull variation has the same biomechanical characteristics of the power clean lift (minus the catch phase) and comprises the maximal power second pull portion of the lift (Souza et al., 2002). Likewise, the snatch pull also features the second pull phase, and power outputs during the second pull for the snatch and clean are found to be very similar (Garhammer, 1993). Purely in terms of concentric power production, the 'catch' phases that characterize the classical Olympic snatch and clean lifts are of little consequence (Hydock, 2001). Limitations imposed by technique flaws in the catch phase when employing the classical Olympic lifts can potentially restrict the load players are able to handle (Hydock, 2001). The pull variations of the Olympic lifts allow higher loads (≈110–120 per cent) to be handled relative to the classical clean and snatch lifts, which tend to be more limited by deficiencies in lifting technique (Hydock, 2001). The pull variations of these lifts are a good option for introducing Olympic lifts into players' training for speed-strength development and to allow technique for the key pull phase to be developed. Furthermore, these lifts will allow relatively higher loads to be handled than would be the case for the full clean or snatch lifts, particularly for those players who are technically less proficient. For both these reasons it is suggested that the pull variations of the Olympic lifts might be the best option when the player initially moves into speed-strength oriented training phases in their training macrocycle. In subsequent training cycles during late preseason and throughout the playing season more technical progressions of these lifts can then be introduced to progress neuromuscular demands and facilitate transfer to performance. Such progressions may include the full power clean and power snatch (featuring the catch element), power clean and power snatch executed from the hang position, split variations of the power clean and jerk, and finally single-leg variations of the clean and snatch from the hang position.

The relative load used is shown to influence the power output with which a lift is executed. Taking the hang power clean as an example, peak and average power output varied with loads from 50 to 90 per cent of subjects' recorded 1-RM for the hang power clean (Kawamori et al., 2005). One characteristic that makes Olympic weightlifting movements unique is that the relative loading at which mechanical power is optimized is relatively higher than that for other strength and speed-strength training exercises, including ballistic resistance

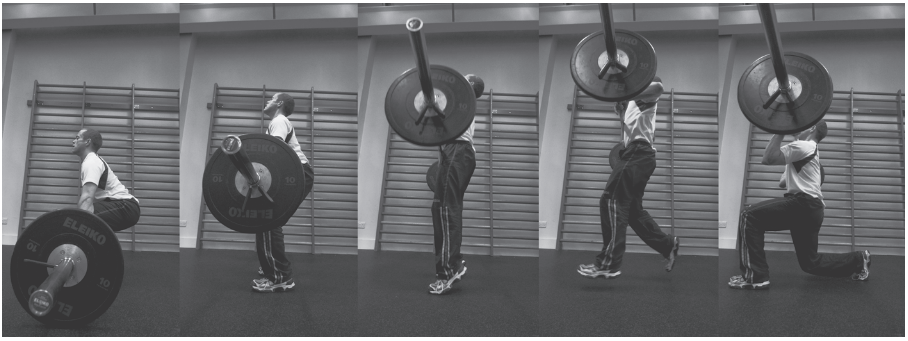

Figure 5.2 Barbell stop split clean.

training modes. Peak and average power output were reported to be maximized at the 70 per cent 1-RM load for the hang power clean (Kawamori et al., 2005). However, peak power output values did not vary dramatically across a range of loads from 50 to 90 per cent 1-RM. Selection of training loads will depend partly upon the team sport in question. For example, relatively lighter loads may be appropriate for sports such as volleyball and basketball. Conversely, relatively higher loading towards the 90 per cent 1-RM value might be preferred for collision sports, such as rugby football and American football given the need to overcome external resistance provided by opposing players in these sports. In either case, a range of loads may be used during the course of periodized strength and speed-strength oriented training cycles.

It has been postulated that repeated exposure to high propulsion forces associated with Olympic lift training leads to adaptation in non-contractile structures in the joints concerned (Stone, 1993). This being the case, the use of Olympic lifts by players in contact team sports may confer an ancillary benefit, in terms of injury prevention. In view of the high degree of biomechanical specificity mentioned, it follows that loading joints during training in a manner consistent with what occurs during high-power activities encountered during match-play should make players less susceptible to injury (Stone, 1993). Conversely, Olympic lifts also offer the ancillary benefit of lesser impact forces to those experienced with other ballistic speed-strength training modes when landing (e.g. jump squats) (Stone, 1993).

Plyometric training

Plyometrics are a special class of speed-strength training exercises that emphasize both SSC and reactive speed-strength aspects – hence involve a considerable eccentric component (Matavulj et al., 2001). Plyometrics confer similar benefits to ballistic training during the concentric phase of speed-strength movements, albeit reportedly to a lesser extent (Wilson et al., 1993). However, the major benefit of this training mode is that targeted plyometric training can develop the capacity to harness mechanical and reflex potentiation during preparatory countermovement and ground contact phases of SSC movements. Accordingly, the addition of plyometric training to the physical preparation of trained elite junior athletes was shown to elicit significant improvements in vertical jump performance in these athletes (Matavulj et al., 2001). A meta-analysis of the research literature has reported that both slow SSC (countermovement jump) and fast SSC (drop jump) plyometric training modes produce significant improvement in vertical jump performance (Markovic, 2007).

The SSC training stimulus provided by plyometric training has shown to elicit improvements in shortening velocity and peak power output of single Type II muscle fibres (Malisoux et al., 2006). In addition to such mechanical adaptations in contractile tissues, mechanisms for the improved SSC performance with repeated exposure to plyometric training also appear to be of neural origin – including changes to descending neural input from higher motor control centres. One aspect of the neural activation in response to plyometric exercise is the pre-activation of agonist muscles during preparatory and eccentric phases of both slow SSC (e.g. countermovement jump) and fast SSC (e.g. drop jump) movements (McBride et al., 2008). This pre-activation of agonist muscles increases the stiffness of the muscle-tendon complex, which in turn enhances the storage and return of elastic energy during eccentric and concentric phases respectively. Another postulated effect of this descending input is to modulate locally mediated inhibition of stretch reflex neural pathways (via golgi tendon organ) immediately prior to and during the pre-stretch phase. Plyometric training is thus suggested to effect 'disinhibition' of stretch reflex-mediated neural drive during the countermovement, which is postulated to augment power output in the subsequent concentric phase (Newton and Kraemer, 1994).

The described adaptations elicited by plyometric appear to be manifested in enhanced force and RFD capabilities of the hip extensors and knee extensors (Matavulj et al., 2001). Plyometric training in the form of depth jumps can also evoke improvements in eccentric RFD with short-term progressive training at increasing drop heights (Wilson et al., 1996). This improvement in rate of eccentric force production is suggested to enhance storage of elastic energy in the musculo-tendinous unit, which underpins observed improvements in SSC performance in response to progressive plyometric training (Wilson et al., 1996).

Whether the augmented neural activation to agonist muscles during plyometric exercise translates into increased jump height or distance depends on the net balance between the augmented concentric energy production versus the amount of energy absorbed during the eccentric phase (McBride et al., 2008). In the case of a countermovement jump the augmented concentric phase output will usually exceed the additional eccentric work involved – hence countermovement jump height is typically greater than squat jump height. Drop jump height may or may not be greater than countermovement jump

Figure 5.3 Alternate leg box skips.

height, depending on the reactive speed-strength and fast SSC capabilities of the player (McBride et al., 2008). Plotting players' jump height for squat jump, countermovement jump, and drop jumps executed from a range of drop heights offers a means to profile their SSC abilities. Above a certain ideal drop height for the player, there is a withdrawal of neural pre-activation, which is reflected in a steep decline in jump height achieved when this critical drop height is exceeded. This appears to be a protective response which is modifiable with training. Exposure to plyometric training and drop jump training in particular does shift players' drop height versus jump height curves, so that jump height across a range of drop heights increases and the threshold drop height above which jumping performance declines is elevated.

One of the most notable applications of plyometric training is for sprinting. Sprinting is essentially a cyclic unilateral movement that comprises repeated stretch shortening cycles (Delecluse, 1997). Thereby, there is considerable series elastic component (SEC) contribution to power output and energy production, which becomes greater as velocity of locomotion increases (Delecluse, 1997). Drop jumps would be relatively poor choices for improving sprinting speed, given that they are typically performed bilaterally and feature force production in a vertical direction (Young, 2006). According a 10-week training period using drop jumps produced no significant gains in 30m sprint scores despite significant improvements in countermovement jump (Wilson et al., 1993). Similarly, the interval for force production during sprinting (dictated by foot contact time) is less than half that for vertical jumping, and much shorter than that allowed by speed-strength training modes (Mero and Komi, 1994). This may be a factor in the frequent failure of speed-strength training studies to produce significant effects in sprint performance over longer distances (30–40m), despite concurrent improvements in vertical power measures and acceleration (10m sprint) parameters (Wilson et al., 1993; Lyttle et al., 1996; Harris et al., 2000). From a specificity viewpoint, cyclic unilateral horizontal bounding and jumping plyometric exercises (in a horizontal direction) would appear the most appropriate training modes to develop sprint capabilities (Young, 2006). Bounding, in particular, features comparable horizontal propulsion forces, foot contact position and contact times, and muscle activation to those recorded during sprinting (Mero and Komi, 1994). Accordingly, a study that employed plyometric training which included unilateral jumping and bounding exercises in a horizontal direction did report increases in acceleration (10m sprint time) and overall 100m sprint scores (Delecluse et al., 1995).

Despite the extensive use of plyometric training in particular for lower-body-dominated athletic training, there is a lack of systematic investigation to determine the optimal load for plyometric exercises (Wilson et al., 1993). Standard methods for upper- and lower-body plyometric training are likewise yet to be established empirically (Vossen et al., 2000). In the absence of such data, body weight is typically used as resistance due to convenience. This may contribute to the lesser improvements in concentric performance with conventional plyometric training exercises. However, it may conversely be that it is counterproductive to add loading to plyometric movements on the basis that this may lead to a protective inhibitory effect upon neural activation – as has been noted with depth jumps when added load is applied.

Figure 5.4 Alternate leg split bounds.

It has been noted previously that specific upper-body power training is underprescribed by strength coaches (Baker and Nance, 1999a). The majority of plyometric exercises featured in training and research are typically lower-body intensive (McEvoy and Newton, 1998), with training to develop SSC capabilities in upper-body movements receiving little attention in the literature (Newton et al., 1997). The few upper-body targeted plyometric exercises that are implemented typically employ weighted medicine balls to provide resistance. The training stimulus provided by such weighted implements represents a far smaller external loading compared to the corresponding lower-body plyometric exercises. Practically, to project a medicine ball or any other weighted implement, heavy enough to provide the requisite external loading (46–63 per cent 1-RM), from a supine position is untenable without the use of specialized equipment. Accordingly, drop medicine ball throws failed to produce the enhancement in rate of eccentric force development conferred by lower-body plyometric depth jump training (Wilson et al., 1996). Variations of a ballistic push-up show potential use as equivalent upper-body plyometric training modes. For example, a ballistic push-up executed with countermovement might be used to develop slow SSC capabilities, whereas a drop ballistic push-up initiated from raised blocks could serve as fast SSC plyometric training.

Complex training

Complex training, or contrast loading, is a method often used in conjunction with ballistic or plyometric exercises. Contrast loading incorporates a heavier load strength oriented exercise prior to performing a full acceleration (typically ballistic) exercise (Young et al., 1998; Baker, 2003). This approach attempts to harness transient mechanical and neural effects of the preceding heavy load to augment power output when the speed-strength exercise is subsequently performed (Baker, 2003). This phenomenon is termed post-activation potentiation (Chiu et al., 2003). Essentially, following activity there are two residual effects: one is fatigue; the other post-activation potentiation (Kilduff et al., 2007). It is the net effect of these two opposing effects that determine the acute performance response at a given time point following the initial activity. Attempts to manipulate these transient effects therefore aim to minimize fatigue whilst harnessing potentiation effects (Kilduff et al., 2007).

Two major aspects of optimizing performance enhancement and minimizing detrimental fatigue effects are the load and volume used with the preceding primer set and the rest interval employed between primer set and the target activity (Kilduff et al., 2007). Both isometric (Paasuke et al., 2007) and dynamic heavy resistance modes have been successfully employed to produce post-activation potentiation effects – typically studies have used the back squat exercise with near-maximal resistance (Chiu et al., 2003). However, short-term performance enhancement has also been reported with an intervening set at a heavier resistance with the same ballistic exercise (jump squats) (Baker, 2001). Theoretically employing a speed-strength exercise as the preload set should be beneficial from the point of view of minimizing residual fatigue effects.

Studies examining rest intervals have typically employed heavy load barbell squat and bench press as the preceding resistance exercises for lower-body and upper-body movement respectively. It has been reported that recovery time in the range of 8–12 minutes appears optimal for observing performance enhancement (Kilduff et al., 2007). However, this may vary according to both the contraction mode featured in the preload set and the training history of the individual player (Paasuke et al., 2007).

To date, acute contrast loading effects have been most widely documented with lower-body exercises, typically with jump squats as the target ballistic activity. Acute potentiation of dynamic lower-body performance has been observed with standing long jump, vertical jump, and jump squat scores when performed immediately following a heavy load set with a strength-oriented lower-body exercise (Young et al., 1998; Baker, 2003). Data for upper-body complex training has been more equivocal. It has recently been elucidated that a lesser load (≈65 per cent bench press 1-RM) for the primer exercise set appears to be more effective in producing enhanced power output in the subsequent target upper-body power activity (Baker, 2003). This was identified as the reason why previous studies featuring heavier upper-body contrast loads (85–90 per cent bench press 1-RM) did not observe any acute performance augmentation effect (Baker, 2003). However, a recent study featuring professional rugby union players did report significant, albeit modest, increases in peak power output for ballistic bench throws at different time points following a bench press 3RM 'preload' set (Kilduff et al., 2007).

Tension-sensitive contractile and neural mechanisms have been identified as underlying the acute performance effects observed with contrast loading (Baker, 2003; Chiu et al., 2003). Mechanical factors are suggested to involve transient changes in stiffness of series elastic components within the musculotendinous unit. One of the biochemical changes identified as underlying such contractile effects is phosphorylation of regulatory myosin light chains initiated by calcium release during the initial muscle action (Chiu et al., 2003). This process renders the actin–myosin complex more sensitive to further calcium release during subsequent muscle contraction – hence its proposed role in post-activation potentiation (Paasuke et al., 2007). The various postulated neural mechanisms principally involve acute changes in autogenic regulatory inputs to motor units involved in the movement (Kilduff et al., 2007). Part of the modification of peripheral pathways involved is likely to originate from descending input from higher motor centres. The probable mediating factors at the level of the motor unit are the Golgi tendon organ (GTO) and Renshaw cell. The net peripheral effects are suggested to comprise reduced inhibitory input to the agonist muscles and increased reciprocal inhibition of antagonist motor units (Baker, 2003). These mechanical and neural effects are transient and are reported to dissipate approximately 20 minutes after performing the initial high-intensity preload set (Kilduff et al., 2007).

Due to the paucity of data regarding contrast loading, chronic effects associated with the use of complex training have to date received little research attention (Paasuke et al., 2007). As a result, possible mechanisms for any performance improvement elicited by the long-term use of complex training are yet to be determined. The application of these methods also appears dependent upon the training status of the individual. Significant positive correlation is reported between lower-body strength and the degree of potentiation, which suggests that the mechanisms underlying acute performance augmentation play an increasing role with advances in training status (Young et al., 1998). In accordance with this, it was reported that performance enhancement consistent with post-activation potentiation was observed in athlete subjects whereas the recreationally trained subjects studied did not show such a response (Chiu et al., 2003). Another study identified that power athletes appear to exhibit differing responses to endurance athletes with respect to post-activation potentiation (Paasuke et al., 2007). Both the magnitude and the time course of post-activation potentiation may therefore differ according to players' training background.

Co-ordination training

As is the case with other aspects of physical preparation, specific power training modes are only effective to the extent that muscular power developed through training transfers to performance of a particular athletic movement or sport skill (Harris, 2000). Power output for a given action exhibits learning effects with repeated exposure to the specific training movement (Ives and Shelley, 2003). In the case of fine motor skills, the training stimulus must feature a high degree of specificity to simulate the movement patterns and velocity encountered in competition in order to elicit improvements in power output for the particular skill movement (Kraemer et al., 2002). Similarly, this requirement for movement specificity to produce improvements in sport skill power output is likely to be particularly evident with experienced athletes (Newton and Kraemer, 1994). The concept of co-ordination training has been introduced to describe training modes that satisfy these criteria. Specifically, co-ordination training modes should allow co-ordination of agonist, synergist, and antagonist force output for the pattern and velocity of movement featured in the particular athletic activity (Newton and Kraemer, 1994).

The term 'co-ordination training' describes training modes that feature co-ordination of force output of agonist, synergist, and antagonist muscle groups in a way that closely replicates the movement patterns and velocity of an athletic activity (Newton and Kraemer, 1994). A very high degree of specificity of loading does, however, appear to be required. Despite the greater similarity noted for the force/time curve for the bench throw movement with regard to sport-specific movements, bench throw training was found not to offer any advantage to conventional bench press training in developing netball pass velocity in female players, despite the apparent greater biomechanical specificity (Cronin et al., 2001). The authors concluded that the movement velocity involved in the bench throw was too dissimilar to the netball chest pass movement to evoke superior gains in chest pass velocity in relation to conventional bench press training. Likewise, the divergence in motor patterns involved in two-handed overhead and chest pass medicine ball throws are apparently too great to stimulate a training effect for baseball throwing velocity, even in junior players with no resistance training experience (Newton and McEvoy, 1994). Accordingly, successful co-ordination training modes typically apply resistance directly to the specific skill movement (Escamilla et al., 2000; van den Tillar, 2004). For example, pulleys have been used with some success for the over-arm throwing movement (Escamilla et al., 2000).

With reference to throwing sports, a variety of underweight and overweight balls have been employed as a means to provide overload in the form of velocity and force, respectively (van den Tillar, 2004). It follows that the training implement employed for ballistic resistance training should be of the same dimensions as that used in the particular sport. The benefits of underweight ball training interventions have been reported previously by a number of studies examining over-arm throwing sports (van den Tillar, 2004). Likewise, combination training featuring both overweight and underweight (over-arm) ball throws has repeatedly proven to be successful. However, results of studies featuring overweight ball training interventions in over-arm throwing sports players have been more variable (Escamilla et al., 2000; van den Tillar, 2004).

The rationale behind the use of weighted implements when carrying out game-related motor skills is that the resistance training stimulus is provided during the actual target movement. The greater specificity of this loading method in terms of kinetic and kinematic similarity favours carry-over of strength training effects to the sports activity. Thus, as sports skill-specific neuromuscular firing patterns are employed throughout, this form of training may offer superior training for the muscles involved, in relation to traditional resistance exercises. In accordance with this contention, studies have shown training employing overweight balls has the potential to significantly increase over-arm throwing velocity with regulation balls (DeRenne et al., 1994; DeRenne et al., 1990). Crucially, throwing accuracy also appears to be maintained at the enhanced throwing velocities post-training (Escamilla et al., 2000).

The precise mechanisms for increases in throwing velocity with modified (heavy and light) ball training are yet to be elucidated. The increases in velocity for the passing skill observed in the current study are likely to be mediated by neural factors, on the basis that the relative loading offered by the heavy ball is probably insufficient to elicit morphological changes. These underlying neural factors likely include improvements in rate of force development (RFD). This RFD parameter is dependent on the rate at which the musculature is activated (Stone et al., 2003), and increases can be attributed primarily to enhanced motor firing in the brief time interval for force production allowed by the sports skill (Behm, 1995). Gains in high velocity strength in the specific musculature involved in the passing movement may also have been a factor. Authors of a previous over-arm throwing study hypothesized that improvements in the ability to selectively recruit high threshold motor units may play a role (DeRenne et al., 1994). It is likewise possible that improved intermuscular co-ordination of agonist, synergist, and antagonist muscle firing may also contribute to gains in throwing velocity.

In the case of fine motor skills, it has been proposed that if the contrast in load is too great then disruption of the precise motor patterns of the sports skill would occur, thereby nullifying any benefits of training (Baker, 2001). Previously, the data of DeRenne et al (DeRenne et al., 1994) indicated that a load variation of ±20 per cent regulation weight was successful for under and overweight training interventions, which is consistent with previous data for athletic throwing events (Escamilla et al., 2000). Other over-arm throwing studies have reported success with balls that are 100 per cent overweight (van den Tillar, 2004). The over-arm warm-up study by van Huss et al., (Van Huss et al., 1962) that successfully showed acute enhancement of throwing velocity, employed 11oz balls, which were 120 per cent heavier than regulation ball weight. However, over-arm training studies employing overweight balls of this degree of difference (>100 per cent regulation weight) have typically not reported improvements in throwing velocity (van den Tillar, 2004). In the study by Straub (Straub, 1968), subjects threw balls that were progressively increased in weight each week, culminating with 17oz balls (240 per cent heavier than regulation) in the final week of the study, and no improvement in velocity was noted. That said, as noted previously, the low skill level of the high school students examined may have been a confounding factor in this study.

CONCLUSIONS AND TRAINING RECOMMENDATIONS

Power is clearly multidimensional: it follows that training to develop this quality should likewise feature multiple forms of training to account for the different factors that contribute to the ability to express explosive muscular power. Selection of training exercises will depend upon the training history of the individual player (Baker and Newton, 2005). The degree to which particular forms of training will be effective in developing explosive power capabilities is influenced by the level of adaptation that has already taken place in each different factor that underpins expression of power. For example, a key consideration is the strength base of the athlete (Baker and Newton, 2005). Implementation of speed-strength training modes specifically into players' training should also follow the principles of periodization: planned variation has been identified as an important factor in optimizing gains in speed-strength performance over time. An undulating periodization format, featuring alterations in training intensity both between workouts and successive training weeks, has been employed successfully in short-term (8 week) speed-strength training studies (Winchester et al., 2008). Similarly, the format of each set performed with speed-strength training exercise can be manipulated to provide variation and enhance the quality with which each repetition is performed (Haff et al., 2008). One such approach involves the use of 'cluster' or 'rest-pause' sets: this format incorporates a brief rest period between individual repetitions within the set. Some authors have found that lifting velocity is better maintained for consecutive repetitions when sets with a speed-strength lift (barbell clean pull) are performed in a cluster set format (Haff et al., 2003). Implementing this approach may therefore optimize the speed-strength training stimulus provided, particularly in terms of neural aspects (Haff et al., 2008). Similarly, varying the set format at different times in the training cycle according to the goals of the training phase is another tool strength and conditioning which specialists may use when periodizing players' speed-strength training.

CHAPTER 6

AGILITY AND SPEED TRAINING

INTRODUCTION

Speed and agility in team sports are said to comprise complex psychomotor skills (Verkhoshansky, 1996). Accordingly, training to develop speed and agility would appear to demand a high degree of neuromuscular specificity. There are, likewise, issues of biomechanical specificity that must be considered when designing speed and agility training for a particular team sport. Furthermore, perceptual components that underpin sports speed and agility should be accounted for, which include anticipation and decision-making. Again, these will be specific to the sport and playing position.

Speed training comprises various elements. Maximum strength is implicated in the need to overcome inertia during initial acceleration. Speed-strength and stretch-shortening cycle abilities are required every time the foot touches down to propel the body forward. Speed capabilities are also heavily dependent upon anaerobic metabolic power. All of these components must be trained in a way that is specific to the form of locomotion (e.g. running or skating) and movement velocities that feature in the sport in order to assure transfer to performance.

A categorical definition of agility has recently been offered: ‘rapid whole-body movement with change of velocity or direction in response to a stimulus’ (Sheppard and Young, 2006). In the context of team sports, agility therefore comprises not only change of direction abilities but also perception and decision-making. The limited common variance frequently reported between change of direction and speed tests indicate that change of direction performance is relatively independent of straight-line speed performance (Little and Williams, 2005; Young et al., 2001b). The multidirectional acceleration and deceleration involved in change of direction movements, which in turn underpin agility performance, are therefore specific qualities and should be trained as such (Jeffreys, 2006).

Due to the variable nature of match-play, high-velocity movements may be initiated from a variety of starting positions. Multidirectional acceleration from both standing and moving starts must therefore be catered for in sport-specific agility and speed-training design. Exhibition of both speed and agility in team sports occurs in response to game situations (Young et al., 2001b); perception–action coupling and decision-making elements therefore also come into play. According the earlier definition of agility, sports speed could be viewed as an agility task, despite the absence of any change of direction element (Sheppard and Young, 2006). From this viewpoint, practice-related strategies that are specific to the sport have application in speed and agility training.

SPORT-SPECIFIC SPEED AND AGILITY

Sprinting technique of team sports players appears to differ from that of track athletes (Young et al., 1995). It is also suggested that the acceleration phase for team sports athletes may be shorter so that they acquire top speed within a shorter distance in relation to track sprinters (Baker and Nance, 1999). Studies of both track and field athletes and team sports players report that measures of acceleration performance are not closely correlated to maximum sprinting speed (Young et al., 1995; Cronin and Hansen, 2005). This would appear to reflect that these abilities involve different patterns of muscle recruitment and motor firing.

In the context of some team sports, acceleration and short-distance speed may be of more relevance than top speed attained over longer distances (Cronin and Hansen, 2005). The distances covered at high-velocity locomotion are typically short and this generally coincides with direct involvement in attacking or defensive play. Team sports played on a restricted playing area (basketball, volleyball) and some playing positions within other field team sports will rarely engage in high-velocity locomotion over distances sufficient to attain maximum speed (McInnes et al., 1995). Hence, training for maximum speed would appear to be a secondary priority for these players given that they will rarely express these capabilities on the field of play (Young et al., 2001a). Conversely, the larger playing field team sports (rugby, soccer) combined with the fact players may already be in motion when they start sprinting can allow certain playing positions to attain near maximal speeds in some instances (Little and Williams, 2005). For these playing positions in field team sports, development of maximal speed over longer distances therefore remains a key training goal.

Off-line and change-of-direction movements in a variety of directions are frequently performed during competitive play in all team sports. In the same way that straight-line acceleration and short-distance speed are important for forward locomotion, acceleration during lateral motion is likewise crucial for team sports players (Twist and Benicky, 1996). In addition to the capacity to accelerate in a variety of directions, the ability to decelerate is fundamental in successful execution of change-of-direction movements. Team sports agility comprises not only these change-of-direction abilities, but also the capability to anticipate, read, and react to game-specific cues in the environment (Sheppard and Young, 2006; Young and Farrow, 2006).

Specificity of speed versus agility development

Players' straight-line sprinting scores and tests of agility performance typically show only limited statistical relationship. In a study of professional soccer (Little and Williams, 2005), players' scores on acceleration, maximum speed, and change-of-direction tests showed low coefficients of determination. The authors concluded that speed and agility are distinct abilities that are relatively independent of each other (Little and Williams, 2005). Furthermore, correlations between measures of these abilities reportedly decrease markedly when any sport skill component is incorporated in the agility tests (Young et al., 2001b). This reflects the dissimilarity of movement mechanics between straight-line running and the locomotion employed during change-of-direction tasks (Sheppard and Young, 2006; Young et al., 2001b). Major differences include stride mechanics and the requirement for deceleration and lateral acceleration – including hip abduction and generation of medial–lateral ground reaction forces (McLean et al., 2004).

The specificity of training effects is reinforced by the very limited transfer to change-of-direction performance reported following a 6-week period of straight-line sprint training (Young et al., 2001b). In this study, as the complexity of the agility test increased (greater number of changes in direction and more acute angles of cutting), the degree of improvement following the straight-line sprint training became less. The converse also appears to be true of agility training. Following 6 weeks agility training, performance improved in a selection of tests with varying numbers of changes in direction – however, no improvement was seen on a straight-line test (Young et al., 2001b). Again, the greatest carry-over was observed on the tests with similar change-of-direction complexity and angles of cutting to that featured in the agility training employed (Young et al., 2001b). As these change-of-direction abilities which underpin agility performance would appear to be independent of straight-line sprinting ability, it follows that they must be developed via specific training (Jeffreys, 2006).

The role of the strength and conditioning coach in agility and speed development

Theoretically, taking specificity of training to its logical conclusion, it could be stated that the only way to train in a truly functional or sport-specific manner is to perform the competitive sport or athletic event (Siff, 2002). With this perspective, some authorities suggest that sports speed and agility can only be developed via competitive play or team practices under the supervision of the sports coach. However, this does neglect the element of overload necessary to elicit improved performance (Gamble, 2006). The abilities that underpin agility and speed for team sports can be developed via targeted neuromuscular training (Myer et al., 2005; Yaggie and Campbell, 2006; Young et al., 2001b). In so doing, it should be possible to improve players' agility and speed expressed during competitive play.

Indeed it may be necessary to undertake such neuromuscular training in order to develop lower-limb neuromuscular control and establish sound movement mechanics, in order to help prevent potentially injurious lower-limb alignment and loading (Myer et al., 2005). This is likely to be the case in young athletes and female athletes particularly – given the neuromuscular control deficits that have been reported in studies examining these populations (Barber-Westin et al., 2005; Quatman et al., 2006). The strength and conditioning professional is likely to be the individual most able to not only recognize aberrant movement mechanics but also implement appropriate training interventions to address such neuromuscular control issues. Hence, the strength and conditioning coach would appear to have an important role to play in developing agility and speed capabilities of team sports players.

DEVELOPMENT OF COMPONENTS OF 'SPORTS SPEED'

A number of different elements contribute to speed performance during competition. Each component can be viewed as an avenue for development through which overall speed expression may be improved. It follows that each element should be addressed via dedicated training in order to maximize overall speed development. A multidimensional approach to developing sports speed therefore appears the most appropriate – in much the same way as the mixed methods approach for developing power (Newton and Kraemer, 1994) described in Chapter 5.

Speed-strength

Maximum strength and speed-strength ('explosive power') are key factors from the point of view of overcoming the player's own inertia particularly when initiating high-velocity movements. By increasing the force-generating capacity of the muscles involved, it is possible to improve players' acceleration and speed when engaging in high-velocity locomotion during a game (Cronin and Hansen; 2006, Hoff, 2005). One aspect of achieving this is through the use of appropriate strength training incorporating specific movements (Verkhoshansky, 1996).

Different strength qualities appear to predominate in different phases of a sprint (Young et al., 1995). Maximum strength, relative to body mass, is suggested to be relatively more important for the initial acceleration phase (Young et al., 2001a). Concentric speed-strength capabilities appear to be important for both initial acceleration (Young et al., 1995) and speed over longer distances (Young et al., 2001a). As the player attains higher velocity and foot contact time becomes shorter, reactive strength is suggested to play an increasing role (Young et al., 2001a). Fast stretch-shortening cycle abilities similarly play an important role during maximal sprinting.

Correlation studies report that measures of speed-strength are closely related to speed capabilities of team sports players. In one study of semi-professional and full-time professional rugby league players, only scores on loaded jump squat and vertical jump (squat jump and countermovement jump) differentiated between 'fast' and 'slow' groups within the players studied (Cronin and Hansen, 2005). In another study of professional rugby league football, higher force speed-strength measures (higher load jump squats and 3RM hang clean) showed strongest relationships to speed performance in the players studied (Baker and Nance, 1999). A more recent study reported that players' scores on hang power clean successfully differentiated those with differing sprinting ability (fast versus slow groups) in a sample of professional Australian Rule football players (Hori et al., 2008).

The muscles that extend the hip and knee and plantarflex the ankle are a common focus for strength training to improve speed performance due to their involvement in propulsion during sprinting (Deane et al., 2005; Delecluse, 1997). Olympic weightlifting exercises and ballistic exercises such as jump squats are suggested to favour lower-limb speed-strength gains at appropriate hip and knee angles for running (Cronin and Hansen, 2006). Short-term training employing Olympic-style lifts was shown to elicit improvement in 10m speed in physically active male college students with strength training experience (Tricoli et al., 2005). This is supported by the correlations between hang clean and jump squat 3RM with 10m and 40m sprint scores of rugby league players (Baker and Nance, 1999).

However, despite the importance of speed-strength of the locomotor muscles inferred from the correlation studies mentioned previously, very few strength and speed-strength training studies consistently report improvements in speed measures. One reason suggested for this finding is that speed-strength training studies use ballistic exercises and/or Olympic-style lifts that are typically bilateral and involve predominantly vertical force production (Young, 2006). This raises obvious issues concerning biomechanical and kinematic specificity given that sprinting involves cyclic unilateral motion and features primarily horizontal force production. Based upon this contention, two suggestions can be made: the first is that progression to unilateral and split variations of the Olympic-style lifts and ballistic speed-strength exercises may be necessary to translate gains in speed-strength to sprinting performance. The second is that horizontal speed-strength and plyometric movements – such as unilateral bounding exercises – may develop speed strength and reactive strength in a way that offers greater transfer to speed performance (Young, 2006).

Speed-strength training for the hip flexors is another mode of training employed to develop speed performance, and is designed to enhance recovery during the swing phase (Deane et al., 2005). Despite being a frequently used mode of training by track athletes, it has been identified that speed-strength training for the hip flexors is not commonly used in team sports athletes' training (Deane et al., 2005). A 12-week programme of hip flexor training with resistance tubing was shown to improve 10-yard sprint times as well as 40-yard times (mainly due to the improvement over 10 yards), and it also improved short distance shuttle run times (Deane et al., 2005). However, the subjects featured in the study were untrained recreationally active college students, so this mode of training requires further investigation to demonstrate its effectiveness in trained team sports players. In addition, hip flexor training has the potential to impose injurious loading on the spine, and therefore should be implemented with caution (McGill, 2006).

Straight-line acceleration

Acceleration capabilities are partly determined by force-generating capacity (Verkhoshansky, 1996) and so the speed-strength methods described above would appear to have a role in their development. However, technical and neuromuscular aspects also play a key role and offer another means for developing players' acceleration (Cronin and Hansen, 2006). The acceleration phase is characterized by different posture in relation to sprinting at top speed – specifically a pronounced forward lean and greater degree of knee flexion (Delecluse, 1997; Cronin and Hansen, 2006). As such, there is different muscular involvement including relatively greater quadriceps activity during the initial stages when a player is accelerating. Similarly, there is less stretch-shortening cycle contribution due to the longer ground contact time when athletes are accelerating (Delecluse, 1997).

First-step quickness (0–5m split sprint time) and acceleration (10-m speed) have been identified as distinct capabilities of 30-m speed in sports players (Cronin and Hansen, 2005). Whilst first-step quickness and acceleration measures correlate closely to each other ($r = 0.92$) in team sports players (professional and semi-professional rugby league players), the relationship with maximal speed scores was much weaker in these players (Cronin and Hansen, 2005). Similarly, weak association was found between 10-m acceleration and 40-m speed scores in another sample of professional rugby league football players (Baker and Nance, 1999b). It follows that these capabilities must not only be assessed independently but also that developing each of these qualities will require a different training stimulus to speed over longer distances (Cronin and Hansen, 2005).

From a kinetic and kinematic specificity viewpoint, training methods to develop acceleration should aim to replicate the characteristic stride mechanics of the acceleration phase – such as greater trunk flexion, longer stance times and propulsive phase, and increased knee extensor involvement (Cronin and Hansen, 2006). Falling starts are a good means to promote the required forward lean during acceleration. Another important consideration is the conditions from which acceleration and first-step quickness are initiated (Young et al., 2001a). Players may be static or in motion (in a variety of directions) when they accelerate to intercept the trajectory of a ball or become involved in play. Players must therefore be capable of executing acceleration and developing short-distance speed from a variety of starting conditions

(Cronin and Hansen, 2006). For similar reasons, starts from crouching, three-point stance, or prone postures can be used to reflect game conditions.

One approach employed to specifically develop acceleration involves the use of resisted sprinting methods (Cronin and Hansen, 2006). This may be achieved simply by using an inclined surface. The kinematic changes associated with uphill sprinting – including greater trunk flexion and reduced distance between centre of gravity and foot strike – serve to lengthen the propulsive phase during foot contact (Paradisis and Cooke, 2001). Such changes would appear to replicate the specific mechanics associated with the acceleration phase (Cronin and Hansen, 2006), including pronounced forward lean and greater knee extensor involvement (Delecluse, 1997).

Towing weighted sleds or tyres can similarly be used to provide resistance for short-distance straight-line sprinting. Applying resistance in this way is suggested to demand greater stabilization of trunk and pelvis, and should therefore promote development of lumbopelvic stability during the sprinting action (Cronin and Hansen, 2006). Towing tends to produce similar kinematic changes to those described with uphill sprinting (greater trunk lean, hip flexion, and ground contact time) (Lockie et al., 2003), which may be beneficial to developing acceleration. Heavier towing loads appear to interfere with sprinting mechanics to a greater degree (Lockie et al., 2003). For this reason, lighter loads (approx 10 per cent body mass) are typically recommended – however, the friction provided by the running surface is another contributing factor that is harder to quantify (Cronin and Hansen, 2006). An alternative and possibly more practical approach is to assess the degree to which a given load impacts upon performance (sprint times). The guideline suggested is that if sprint times are affected by more than 10 per cent, the loading is too great and should be adjusted (Cronin and Hansen, 2006).

Adding weight to the athlete is another means by which coaches have increased resistance during speed training (Cronin and Hansen, 2006). Weighted vests provide a different form of overload by imposing greater vertical (rather than horizontal) forces. Although step length and step frequency are reduced and stance times are increased, joint kinematics are not significantly different when sprinting with weighted vests, which lends support to the biomechanical specificity of this training mode (Cronin and Hansen, 2006).

Neuromuscular co-ordination

Sprinting is a highly complex skilled movement involving high degrees of activation of multiple muscle groups (Ross et al., 2001). Speed is also categorized as a relatively closed skill, with predictable and planned motor patterns that can be reinforced via training (Young et al., 2001b). The relative sequencing of muscle activation and resulting movement mechanics are observed to change with sprint training (Ross et al., 2001). It follows that dedicated neuromuscular training to develop the requisite intermuscular co-ordination is therefore critical in improving athletes' ability to optimally execute the movement patterns involved in high-velocity locomotion during competition. Technical and kinematic aspects of speed expression over the first few steps appear to differ from maximum speed sprinting over longer distances (Delecluse, 1997). Given the importance of speed over short distances in team sports, it follows that dedicated training for this acceleration phase is likewise warranted.

A key aspect of improving sprint running velocity is maximizing the propulsive ground reaction force at each foot contact and limiting touchdown time (Hunter et al., 2005). Propulsive impulse generated by the athlete during touchdown, relative to their body mass, is the single biggest predictor of sprinting velocity over short distances (≈16m) (Hunter et al., 2005). Coordinating torque-generation at the hip and knee and the orientation of the foot prior to and during touchdown is a complex neuromuscular skill – it follows that this should require dedicated training in order to develop it. Accordingly, high-velocity training aimed at enhancing motor unit recruitment (intramuscular co-ordination) and intermuscular co-ordination has been shown to elicit improvements in speed performance (Delecluse et al., 1995).

Particular technical aspects of straight-line sprinting can also be coached and reinforced by appropriate technique drills (Cissik, 2005). By their nature, such drills are self-paced and carried out at submaximal speed. This allows a particular aspect of sprinting mechanics to be emphasized, but obviously such drills have marked differences to the mechanics and velocities featured in sprinting. Therefore, ultimately, in order to allow carry-over to performance, these technique drills must be progressed to actual sprinting (Cissik, 2005). For much the same reasons of specificity, sprint practice by team sports athletes must be undertaken at maximal velocity, and conducted over distances that they encounter during competitive matches. Furthermore, for sports that involve carrying or dribbling a ball, high-speed locomotion involving the ball should also be considered when designing speed-training sessions (Sheppard and Young, 2006).

Stretch-shortening cycle

The ability of the team sports athlete to utilize SSC components is a key avenue for developing their ability to move quickly on the field of play (Ross et al., 2001). Different phases of a sprint rely on slow (300–500ms) and fast (100–200ms) SSC properties to different degrees, depending on duration of foot contact. Slow SSC performance will be required during the longer foot contacts featured during acceleration. Fast SSC then predominates as foot contacts become shorter as the player attains higher velocities. Measures of fast SSC performance are significantly related to sprint performance over 30m, and over longer distances (100m and beyond) in trained athletes (Hennessy and Kilty, 2001). In fact, drop jump for height was shown to be the single biggest predictor of sprint performance in the elite female sprint athletes studied.

Specific sprint drills and bounding exercises are the tools typically employed to develop SSC performance. To account for specificity in order to improve transfer of training, it is important that the force–time characteristics of exercises used reflect those experienced during high-velocity actions on the field of play (Mero and Komi, 1994). Particularly important when developing SSC performance is the ground contact time involved in particular exercises. Excessive braking forces and a compromised propulsion phase occur in particular with stepping and hopping bounding exercises, which reduce the SSC training stimulus and limit their effectiveness in evoking neuromuscular adaptations (Mero and Komi, 1994). A factor in this is that stepping and hopping bounding exercises involve initial contact with the heel, rather than mid-foot as occurs in maximal running – which is again unfavourable from a biomechanical specificity viewpoint. Maximal bounding that features initial contact at the mid-foot and shortened ground contact times avoids these problems and so is likely to favour SSC and neuromuscular adaptations (Mero and Komi, 1994). In support of this contention, short-term plyometric training that featured unilateral and horizontal bounding exercises was reported to be successful in improving 10m (acceleration) and 100m (maximum speed) sprint times, albeit in non-athlete subjects (Delecluse et al., 1995).

Summary

A number of individual qualities contribute to the expression of speed qualities. Speed-strength development appears important in enabling players to overcome their own inertia when initiating high-velocity movements; however, split and unilateral progressions of ballistic and Olympic-style exercises may offer superior transfer to speed performance. In addition to improving force-generating capacity via speed-strength training, acceleration abilities can also be developed by employing specific acceleration training modes. Whether developing acceleration or maximal speed, neuromuscular aspects – in particular intermuscular co-ordination – can be developed via specific technical training, which will necessarily include actual sprinting over appropriate distances. Plyometric training can develop SSC components that contribute to speed performance – specifically, slow SSC during acceleration and fast SSC for maximal speed; such training should have appropriate emphasis on unilateral and horizontal bounding exercises. In view of the multifactorial nature of speed expression, an integrated approach to players' speed training that accounts for each of the aspects described would appear to be the best route to optimal development of overall speed performance.

DEVELOPING AGILITY FOR TEAM SPORTS

In much the same way as speed expression, agility in the context of team sports is multifactorial, with many different components that may contribute to a player's agility performance. There are also additional aspects to consider in the case of agility performance – such as the need to decelerate and accelerate in various directions. Fundamentally, team sports agility likewise comprises reaction to game-related cues, 'perception–action coupling' and decision-making elements (Sheppard and Young, 2006). There are two major schools of thought regarding 'sports agility' development (Bloomfield et al., 2007). One approach involves relatively closed skill practice of movement mechanics, often using specialized commercially available equipment such as ladders, mini hurdles, and resistance belts. Others advocate a more open skill approach in which agility movements are conducted in a training environment that is less structured and thereby closer to match conditions (Bloomfield et al., 2007).

Postural control and balance

Lumbopelvic stability and neuromuscular control aspects that include whole-body proprioception and balance all contribute to the ability to change direction efficiently. The player's awareness of and ability to control the position of their centre of mass is critical in allowing them to efficiently perform agility movements (Yaggie and Campbell, 2006). Players' ability to retain lumbopelvic stability and strong trunk posture would seem to be crucial to maintain proper lower limb mechanics and efficient transfer of force from the ground upwards to generate change-of-direction movement (Kibler et al., 2006). Dynamic balance capacities would also appear to be important to improve the ability to dissipate impact forces involved in deceleration and change-of-direction movements (Myer et al., 2006).

The athletic or 'ready' position is the starting posture for most sports movements, which should be instructed early in any player's development. This posture is characterized by a forward lean of the torso, with hips and knees flexed and the athlete's weight supported on the balls of their feet, which are hip-width apart (Twist and Benicky, 1996). This is obviously an 'ideal' posture – practically, players will be forced to execute movement from a variety of positions as demanded by circumstances during a match, often involving unilateral base of support and less-balanced body positions.

Whatever the starting posture from which movements are initiated, acceleration, deceleration, and changes in direction require appropriate postural adjustments (Young and Farrow, 2006). For example, during a lateral cutting manoeuvre the player typically leans into the new direction of movement as they cut with their outside foot. One function of such adjustments is to allow the player to maintain their balance by keeping their centre of gravity within their base of support (Yaggie and Campbell, 2006). Another key aspect of postural control is controlling the position and orientation of the trunk with respect to the pelvis (Kibler et al., 2006). Similarly, optimal execution of movement requires the player to maintain tension through a stable torso in order to transmit forces generated through the ground to effectively transfer these ground reaction forces into movement (Young and Farrow, 2006). As such, stabilization and strength through the lumbopelvic region would appear critical in optimal function of the kinetic chain (from base of support to extremities) involved during athletic movements in general and change-of-direction movement in particular (Kibler et al., 2006).

In order to facilitate transfer to athletic function in general, and change-of-direction performance capacity specifically, development of lumbopelvic stability should be undertaken in a weight-bearing stance and using training modes that integrate the full kinetic chain involved in the relevant movements in the sport. Performing such exercises on labile surfaces such as balance disks or domed devices may be used to increase the challenge. Perturbation in the form of external resistance provided by cables or free weights may also be used to elicit stabilization demands similar to those that occur in the sport. Planned change-of-direction movements allow the athlete to anticipate, which allows these postural adjustments to be made much more easily. In the case of unanticipated cutting movements that are executed in response to an external cue, these postural adjustments are harder to make, which in turn affects loading on lower limb joints (Besier et al., 2001). Unplanned postural adjustments therefore would appear to be an element that should be incorporated into players' training (Besier et al., 2001; Craig, 2004).

One area that shows potential for not only improving lower limb biomechanics but also improving agility performance is postural balance training consisting of single-leg support tasks. Following short-term training of this type using a balance training device, performance in a shuttle-run test incorporating change-of-direction movements was significantly improved (Yaggie and Campbell, 2006). The subjects in the study were only recreationally active, so the application to elite players is unclear; however, further study of performance effects in athletic populations appears warranted. An extension of these methods that have perhaps more apparent relevance to change-of-direction and agility performance is dynamic stabilization training. Such training involves drills to develop transition from motion to a static position and often employs domed devices and balance disc equipment. These abilities have obvious application to the deceleration phase that commonly precedes the initiation of change-of-direction movements. One aspect of dynamic stabilization training is that it develops the ability to dissipate landing forces (Myer et al., 2006). Such capacities are likely to be important for safe and efficient execution of the deceleration involved when change-of-direction movements are initiated.

Change-of-direction movement mechanics

Specific change-of-direction training has been shown to carry over to change-of-direction performance tests – particularly those involving similar cutting angles (Young et al., 2001b). The neuromuscular control capacities involved in dissipating ground reaction forces and maintaining lower-limb alignment when landing and changing direction are not only important for execution of agility movements; these factors are also identified as influencing injury risk (Quatman et al., 2006). Neuromuscular training that emphasizes these elements has been found to improve biomechanical ACL injury risk factors and neuromuscular performance in female team sports players (Myer et al., 2005). From both injury prevention and performance enhancement perspectives it follows that neuromuscular training employing change-of-direction movements should be employed during players' physical preparation. This is particularly relevant for youth sports players and female players at all stages of physical development, as these groups are reported to exhibit neuromuscular control deficits identified as risk factors for non-contact lower-limb injury (Barber-Westin et al., 2005; Quatman et al., 2006).

Drills that integrate specific lateral and cutting movements allow technique to be developed and specific neuromuscular patterns to be reinforced (Craig, 2004). This approach is analogous to the programmed conditioning methods for agility development described by Bloomfield and colleagues (2007). Initially, simple cones may be used to mark changes of directions. It has been identified that the specialized equipment commonly used in conjunction with programmed 'agility' conditioning methods are in fact not crucial to the success of these training modes. Drills involving specialized equipment can be readily substituted for equivalent drills that develop similar movement skills without any significant impairment of performance improvements observed following training (Bloomfield et al., 2007). For example, in place of ladders, the line markings on the pitch or court can be used to guide footwork drills – in fact, this approach may be preferable as players will be less inclined to look at the floor when executing these drills without a ladder.

This can be progressed to using static poles or standing players to simulate a defender. A recent study found that the presence of even a static dummy 'defender' had a marked influence upon sidestep cutting mechanics (McLean et al., 2004). The simulated defender (a model skeleton) caused the players to perform more forceful cutting movements (greater ground reaction forces), accompanied by more hip flexion and abduction as well as greater (flexion and valgus) angles at the knee (McLean et al., 2004). These self-paced drills can be progressed by incorporating game-related skill movements (Twist and Benicky, 1996).

A further progression is to initiate cutting movements in response to a particular external cue. Movement mechanics and joint kinematics during preplanned and unanticipated cutting movements are significantly different (Besier et al., 2001). It follows that unanticipated cutting must be addressed in training, in order for neuromuscular control and co-ordination abilities to carry over to agility movements executed in match situations. This need for perception–action coupling and decision-making elements is explored further in a later section.

Arm action is an often overlooked component of agility that can have a pronounced effect on the athlete's efficiency of movement when changing direction (Brown and Vescovi, 2003). A key aspect during the sidestep cutting action (manoeuvre commonly used to evade an opponent) is driving the inside arm in the opposite direction to assist driving the inside leg towards the new direction of movement as the player executes the 'cut' with their outside foot. After this first stride is the new direction, similar backward arm drive by the opposite (outside) arm then assists in rotating the body and bringing the outside leg through to drive towards the new direction of movement. In both the initial cutting stride and second stride, it is important that the arm drive is kept tight to the body, in order to reduce unwanted inertia and direct the acceleration forces in the desired direction (Brown and Vescovi, 2003). These elements must be

Figure 6.1 Barbell lateral step up.

addressed by specific movement practice in much the same way as any other movement skill.

For sports that involve carrying a ball (American football, rugby football) or holding an implement (field hockey, lacrosse, ice hockey), there are indications that skill sports athletes exhibit enhanced agility when holding the implement of their sport (Kraemer and Gomez, 2001). This is something that must be considered when designing agility in these sports. With progression of training, it follows that drills can become more sport specific by incorporating a ball or sports implement in the drill (Jeffreys, 2006; Sheppard and Young, 2006).

Lateral acceleration

Lateral movements are a characteristic aspect of movement during team sports performance. In particular, evasive manoeuvres that occur in competitive play are frequently initiated with a lateral step (Twist and Benicky, 1996). Similarly, the sidestep cutting action (rapid change-of-direction to evade a defensive opponent) involves hip abduction and generation of medial–lateral ground reaction forces to create lateral propulsion (McLean et al., 2004). Speed-strength development in these different planes of motion would therefore appear important to develop lateral acceleration in much the same way as sagittal plane speed-strength exercises are employed to improve straight-line acceleration (Hedrick, 1999).

It is reported that standard bilateral strength and power measures (squat, loaded and unloaded vertical jump) typically are not shown to be strongly related to change-of-direction performance (Sheppard and Young, 2006).

Figure 6.2 Cable resisted cross-over lateral lunge.

Hang power clean scores of Australian Rules football players were similarly unrelated to these players' scores on a change-of-direction measure (Hori et al., 2008). The bilateral and predominantly sagittal plane movement that characterizes exercises typically used for speed-strength development therefore appear inadequate for developing the requisite strength capabilities for change-of-direction movements. Strength (both concentric and eccentric), speed-strength, and reactive strength qualities required for change-of-direction movements may be better developed via appropriate unilateral strength and plyometric training exercises (Twist and Benicky, 1996). Similarly, such training should necessarily feature force-generation and propulsion movements in the relevant planes of motion. This is an area that warrants further research.

Deceleration and reactive strength

By the nature of team sports, players are frequently required to decelerate sharply, as they respond to the movement of team-mates, opponents, and the ball (Lakomy and Hayden, 2004). A player's ability to decelerate is important in executing change-of-direction movement (Griffiths, 2005), as they must first brake their forward momentum before propelling the body into the new direction of movement (McLean et al., 2004). Despite this, deceleration is not commonly addressed during training for team sports (Lakomy and Hayden, 2004; Griffiths, 2005). Targeted neuromuscular training to develop technical aspects of deceleration is therefore an area that may warrant investigation for team sports players.

Reactive strength describes the ability to reverse eccentric into concentric muscle actions (Young and Farrow, 2006). This particular strength quality has

Figure 6.3 Alternate leg lateral box skips.

relevance to change-of-direction activities, as the leg performing the cutting action first exerts eccentric force to brake the player's own momentum before performing the concentric action that accelerates the athlete in the new direction of movement (McLean et al., 2004). As such, reactive strength capabilities also underpin the player's ability to decelerate effectively – and then make an effective transition to concentric force production.

Depending on the duration of ground contact during these movements, slow SSC elements will also contribute to performance. Slow SSC elements (300–500ms) are likely to be more important than fast SSC (100–200ms) due to the relatively longer foot contacts involved in change-of-direction movements in comparison to sprinting. Reactive strength measures (e.g. drop jump test scores) do appear to have stronger statistical relationship with change-of-direction performance than concentric strength measures, which typically show no significant relation to change-of-direction ability (Sheppard and Young, 2006). For this reason, it is suggested that specific training to develop these muscular properties such as bilateral and unilateral drop jump training have the potential to improve change-of-direction abilities (Young and Farrow, 2006). Such training to develop reactive strength should also feature single-leg plyometric drills that involve reversing direction and incorporate lateral movement in order to account for the relevant movements involved in change of direction.

Perceptual aspects

There is an important distinction between change-of-direction abilities during movements that are pre-planned (e.g. manoeuvring around fixed obstacles) and sport-specific agility executed in response to game-specific cues (movement of the ball, opponents, or team-mates) (Sheppard and Young, 2006; Young and Farrow, 2006). During the initial stages of training to develop agility, change-of-direction movements that feature in agility performance can be developed by repetition of specific movement skill drills that are self-paced and negotiate fixed obstacles (cones, slalom poles, etc.). This change-of-direction training is essentially closed skill practice as movements are pre-planned and do not require any reaction or decision-making (Sheppard and Young, 2006).

However, the defining characteristic of agility is that change of direction or velocity occurs in response to an external stimulus (Sheppard and Young, 2006). As such, in order to develop agility, planned change-of-direction movements executed in a static practice environment must be progressed to open skill conditions (i.e. requiring response to a stimulus) (Craig, 2004). Requiring the athlete to initiate movements and changes in direction in response to external cues provides specific agility training as opposed to pre-planned change-of-direction movement (Young and Farrow, 2006). Such training is important to improve reaction time and ability to interpret cues from the environment in order to make postural adjustments and improve movement execution. These abilities also have implications in terms of injury prevention: loads sustained at the knee are reported to be significantly increased during unanticipated cutting movements (Besier et al., 2001). Appropriate dynamic neuromuscular training emphasizing postural control and correct lower-limb alignment during unanticipated cutting manoeuvres (e.g. against a 'live' opponent) therefore appears necessary in order to protect against non-contact knee injury (Besier et al., 2001).

How this transition to specific agility development can be practically achieved is by progressively removing the player's ability to anticipate movement responses (Besier et al., 2001). This progression can be viewed as a continuum of motor learning drills with closed movement skill practice at one extreme and an entirely random open skill environment at the opposite end of the spectrum. Between these two extremes, strength and conditioning specialists can implement a continuum of drills that expose the player to a progressively increasing perceptual challenge. Examples of progressions include self-paced to maximal execution speed; progressing from fixed obstacles to initiating pre-planned movement on command; simple reaction (single response) to complex reaction (multiple movement responses); and finally incorporating decision-making and read–react drills against a 'live' opponent.

With advances in agility training, appropriate constraints associated with the particular sport should also be replicated in the training environment, such as opposing players and dimensions of the playing area (Handford et al., 1997). Similarly, making the cues in read-and-react drills game-related and incorporating decision-making that is specific to the sport may further help translate change-of-direction speed into sport-specific agility (Handford et al., 1997; Plisk, 2000; Young et al., 2001b). In designing these open skill 'read-and-react' drills, sport-specific cues and movement responses must first be identified for the sport and playing position (Jeffreys, 2006). These abilities to anticipate and process cues from the game environment to make decisions quickly are identified as a key factor in the faster movement times of more skilled players (Young and Farrow, 2006). However, at the open skill end of the spectrum it may be argued that such advanced cognitive skill acquisition is better suited to the domain of technical/tactical practice and competitive play, under the instruction of the sports coach.

Summary

In much the same way as straight-line speed development, multiple components contribute to agility performance in team sports. Again, each of the components described would appear to require dedicated training to fully exploit these factors in improving overall agility performance. Postural control, neuromuscular skill, lateral acceleration, deceleration, and reactive strength qualities are all implicated in successful execution of the change-of-direction movements involved in agility performance. Addressing perceptual-aspects including stimulus–response and decision-making elements that characterize agility movements represents an additional challenge that must be accounted for in order to specifically develop agility. Essentially, addressing all these elements will comprise both approaches typically adopted for sports agility development (Bloomfield et al., 2007) – including aspects of closed skill practice and ultimately progression to an open skill practice environment.

CONCLUSIONS AND TRAINING RECOMMENDATIONS

Speed development

All team sports have a considerable requirement for first step speed and acceleration. Development of underlying speed-strength components can be addressed by appropriate strength and power training methods. Training for sports speed development should necessarily concentrate on speed development over the shorter distances typically seen in team sports. The need for speed over longer distances can be determined by qualitative assessment of the sport and playing position (Cissik, 2005).

Neuromuscular co-ordination and technical aspects of speed performance can be developed via dedicated training. Where necessary, appropriate sprinting technique drills can be used to develop neural aspects. Suitable bounding exercises may be implemented to develop speed-strength and SSC components. Training should ultimately progress to actual sprinting, over similar velocities to those encountered by the player during matches (Cissik, 2005). Initiating sprints from a variety of positions and directions, and in response to game-related cues, can also be implemented to facilitate transfer to on-field performance.

Adequate rest should be allowed when training to develop sprinting mechanics and neuromuscular elements that underpin sports speed, to facilitate motor skill acquisition and avoid disruption of movement mechanics by fatigue (Merlau, 2005). At an advanced stage of speed development, rest intervals may be manipulated in order to develop speed-endurance. However, this should only be attempted once sound movement mechanics have been established and players have completed sufficient speed development work to tolerate this advanced form of training.

Developing change of direction and agility performance

A first step when designing agility training is observing the characteristic movement patterns for the sport and playing position (Jeffreys, 2006). The majority of team sports have fundamental movements in common. Once identified, the ability to perform the component movements that comprise sport-specific change-of-direction actions can be developed by addressing the underlying neuromuscular qualities that underpin their successful execution.

This should comprise appropriate development of postural stability, including specific development of lumbopelvic stability and strength incorporating relevant (weight-bearing) postures and stabilization challenges, as well as neuromuscular training to develop balance and dynamic stabilization. Development of reactive strength for requisite movements should be undertaken via plyometric training modes, including bilateral and unilateral drop jump training and progression to bounding drills that involve reversing direction and multiplanar movement. Lateral acceleration and deceleration abilities should similarly be developed via appropriate movement skill training, alongside appropriate speed-strength training and plyometrics.

Motor skill development for the movement mechanics involved in component change-of-direction movements can be undertaken initially via closed skill practice in a self-paced manner using static markers and obstacles. Complexity of self-paced change-of-direction movement drills can be progressed by incorporating sport skills. Once the discrete movement skills that underpin change-of-direction abilities have been developed, a continuum of drills can be introduced that involve execution of change-of-direction movements under unanticipated conditions and feature response to cues – progressing from simple to complex reaction tasks. Finally, sport-specific agility can be developed by more open skill practice that is increasingly game-related:

- initiating agility movements in response to game-specific cues;
- progressively increasing decision-making requirement.

CHAPTER 7

LUMBOPELVIC 'CORE' STABILITY

INTRODUCTION

The profile of core stability training has risen massively in recent years, with growing use by both athletes and recreational trainers (Carter et al., 2006; Liemohn et al., 2005). Core work has become an integral part of training for all athletes with the aim of improving performance, and core exercises are commonly prescribed for therapeutic training applications (Brown, 2006).

Core stability is described in the sports medicine literature as 'the product of motor control and muscular capacity of the lumbo-pelvic-hip complex' (Leetun et al., 2004). In musculoskeletal terms, this comprises the spine, pelvis, and hip joints, and proximal lower limb – in addition to all associated musculature (Kibler et al., 2006). In reality, the term 'core training' has become an all-purpose label for any exercise that addresses some aspect of *lumbopelvic stability*.

Training the 'core' is therefore considerably more complex than the global term core training implies. As mentioned, 'core training' could refer to any mode of exercise that addresses any one of the various different musculoskeletal structures and neuromuscular components involved in providing lumbopelvic stability (Gamble, 2007a). Conversely, the combination of muscles that provide lumbopelvic stability in a particular posture or movement is shown to vary, depending on a variety of factors (Juker et al., 1998). The player's base of support and their orientation in three-dimensional space as well as the forces acting upon the player during a given movement will all determine the particular combination of muscles that act to stabilize the player.

This ambiguity is likely behind the confusion regarding the effectiveness of 'core training' for different health and performance goals (Stanton et al., 2004; Tse et al., 2005). Training for lumbopelvic stability is typically undertaken with one of two objectives: improving performance or injury prevention

(Kibler et al., 2006). The efficacy of 'core training' modes for injury prevention is documented; however, support for the role of training for lumbopelvic stability for performance enhancement has proved more elusive. Much of the confusion is due to lack of clarity about what constituted the 'core training' employed in a given study, and thus what aspect of lumbopelvic stability was in fact addressed. The training employed in studies also often does not reflect the postural or movement demands associated with the practice and competition environment in which lumbopelvic stability is manifested by players.

IMPORTANCE OF TRAINING FOR LUMBOPELVIC STABILITY

The spine depends heavily upon active stability provided by various muscles (Cholewicki and McGill, 1996). This is illustrated by the finding that when stripped of muscle and left to rely upon passive (bone and ligament) support, the human spine will collapse under 20lb (≈9kg) of load (Barr et al., 2005). Obviously this does not occur in healthy individuals, and it is the muscular components that contribute to lumbopelvic stability which take up the slack.

It has been demonstrated that submaximal levels of muscle activation are usually adequate to provide effective spine stabilization (Cholewicki and McGill, 1996). Continuous submaximal muscle activation therefore appears to be crucial in maintaining spine stability for most daily tasks (McGill, 2004). Stability provided by the muscles of the lumbopelvic region is also identified as critical for whole-body dynamic balance (Anderson and Behm, 2005). The combination of muscles that act to provide stability varies with posture, the direction of movement and magnitude of loading on the spine (Juker et al., 1998). Hence, a wide variety of muscles contribute to different degrees according to the demands of the situation.

Most of the muscles that move and stabilize the limbs attach proximally to the lumbopelvic region and the 'core' is described as the 'anatomical base for motion' (Kibler et al., 2006). The lumbar spine is the site through which various compressive and shearing forces are transmitted between lower and upper body (Cholewicki and McGill, 1996; Stephenson and Swank, 2004). A strong and stable lumbopelvic region facilitates efficient transfer of forces from the ground to produce movement and/or generate torque at the extremities (Behm et al., 2005; Cissik, 2002; McGill, 2004).

Lumbopelvic stability and injury

Muscles that prevent excessive spine motion at segmental level and help maintain desired pelvis and lumbar spine posture reduce the stresses placed upon the lumbar spine and thereby protect against injury (Daneels et al., 2001; McGill, 2004). The muscles that provide active lumbopelvic stability also serve to spare the spine and resist external forces under conditions of higher loading (McGill, 2004).

Accordingly, low or unbalanced scores on various tests of trunk muscle function indicative of poor lumbopelvic stability are frequently identified as risk factors for injury (McGill, 2004). Scores of trunk muscle endurance in particular are consistently shown to correlate with incidence of low back pain or injury (McGill, 2004).

Lumbopelvic instability can be both the cause and result of injury (McGill, 2004). Conversely, impaired passive stability and disrupted motor patterns (compromising active stabilization) are commonly observed following injury (McGill, 2004; Montgomery and Haak, 1999). It follows that addressing these issues via appropriate training will offer a protective effect in terms of both guarding against initial injury and reducing subsequent incidence in those with a history of previous injury.

A role for training the various areas contributing to lumbopelvic stability in reducing incidence of injury is supported by the majority of studies (Barr et al., 2005; Cusi et al., 2001; Hides et al., 2001; Tse et al., 2005). Lumbopelvic exercise training incorporating a Swiss ball is proven to improve measures of spine stability – specifically extensor and side bridge endurance times – in sedentary individuals (Carter et al., 2006). As mentioned previously, these measures are associated with lowered incidence of low back pain and injury (McGill, 2004).

The importance of this preventative function is underlined by the observation that the lower back is commonly reported as the third most common site of injury in sports, after the ankle and knee (Nadler et al., 2000). Low back pain and injury is commonplace among both recreational and competitive athletes and can severely impair the athlete's ability to train and compete (Montgomery and Haak, 1999). This type of injury is particularly prevalent in female athletes – a study of injury incidence in NCAA collegiate athletes for the 1997–1998 season indicated almost twice the number of lower back injuries in females, compared to male athletes (Nadler et al., 2002).

Lumbopelvic stability issues can affect all lower extremity joints by disrupting the integrated function of the *kinetic chain* of joints between the planted foot and the lumbar spine, where forces are transmitted upwards (Leetun et al., 2004; Nadler et al., 2000). Most movements in sports are *closed kinetic chain,* being executed with one or both feet planted. Consequently, lumbopelvic stability has the potential to affect the function and injury risk at all lower extremity joints – in particular knee and ankle (Leetun et al., 2004).

Lumbopelvic stability and performance

The lumbopelvic region will inevitably be a vital link in the kinetic chains (incorporating joints from base of support to extremities) involved in all athletic movements (Kibler et al., 2006). From this viewpoint, stabilization of the joint segments involved and efficient force transmission through the lumbopelvic region would appear critical to athletic function. It follows that appropriate development of lumbopelvic stability and strength should be reflected in enhanced athletic and sports performance. Despite this, such a link between core training interventions and improvements in measures of athletic performance is yet to be established in the research literature (Stanton et al., 2004; Tse et al., 2005). However, this may simply be due to lack of consistency in terms of what constituted core training in the studies, and the nature of exercises employed (Gamble, 2007a). Coaches continue to widely prescribe 'core' training with the specific aim of improving sports performance.

Movements in athletic events and team sports occur in multiple directions. As a result players must possess lumbopelvic stability in all three planes of motion (Leetun et al., 2004). Furthermore, these capabilities are required under both static and dynamic conditions during competition. In order to maintain whole-body stability whilst sustaining and/or generating external forces, athletes require both strength and endurance for these muscles (Barr et al., 2005). Besides providing a stable base for motion at the distal segments (i.e. the limbs), the 'core' can also be the origin from which rotational torques are generated and transferred to the extremities (Kibler et al., 2006).

COMPONENTS OF LUMBOPELVIC STABILITY

The core muscles are generally described to include abdominal and low back musculature (Stephenson and Swank, 2004). Lumbopelvic stability in effect comprises different functional components: deep muscles that stabilize the lumbar spine; the abdominal musculature; the posterior muscles of the lower and middle back; and hip muscles that help support and stabilize the pelvis. In addition, neural co-ordination and motor control play a key role (Barr et al., 2005).

The contribution of different muscle groups to lumbopelvic stability is dynamic, and varies according to the movement and postural demands of the given activity (Juker et al., 1998). Furthermore, weakness or impairment at any point in the integrated system of support can lead to damage to structural tissues (ligament and joint capsule), causing injury and pain (Barr et al., 2005). Hence, any one or two muscles cannot be viewed as relatively more important to lumbopelvic stability (Brown, 2006).

Deep lumbar spine stabilizer muscles

The deep lumbar spine stabilizers consist of muscles that originate from or insert directly onto the lumbar vertebrae (Anderson and Behm, 2005; Barr et al., 2005). These muscles are in a unique position to provide rigidity to the lumbar spine at segmental level. The small cross-sectional area of many of these muscles limits the amount of torque they can generate, so their role is more concerned with providing local support and corrective action (McGill, 2004). In doing so, these muscles act to maintain the integrity of the lumbar spine in opposition to internal forces generated during movement performed both with and without external loading. For such reasons, these muscles are termed 'postural' muscles, or collectively as the local stabilizing system (Carter et al., 2006; Liemohn et al., 2005).

The importance of these muscles can be inferred from the finding that these muscles are atrophied in individuals with chronic lower back pain (Barr et al., 2005; Daneels et al., 2001). These deep muscles also play a key role in kinaesthetic awareness and proprioception (Barr et al., 2005). This is reflected in the density of proprioceptors in these muscles, particularly rotatores (McGill, 2004). An associated benefit of specific training for these muscles therefore is improved neuromuscular function and postural control.

Exercises to specifically develop these deep muscles typically consist of a sequence of static postures, each held for a brief period. A study assessing multifidus cross-sectional area following training highlighted that this isometric muscle contraction element appears to be key in developing these local stabilizer muscles (Daneels et al., 2001).

Abdominal muscles

The abdominal muscles are taken to comprise rectus abdominis and the muscles of the abdominal wall – external and internal obliques and transverse abdominis (Kibler et al., 2006). Collectively, these larger and more superficial muscles act as a rigid cylinder around the lumbar spine. Whereas the deep lumbar spine stabilizer muscles are implicated with handling internal forces, the abdominal muscles serve a key role in handling external loads and bracing the lumbar spine during dynamic movements (Barr et al., 2005; Juker et al., 1998). The individual abdominal muscles act in a load- and velocity-specific manner to provide stability by bracing the trunk during rapid actions, such as athletic activities (Barr et al., 2005). These muscles thus serve an important function for team sports – allowing players to handle heavy loads in training and competition, in addition to providing stability and mobility to the trunk during sports movements.

In athletes with impaired deep lumbar muscle strength or function, these superficial abdominal muscles may try to compensate (Barr et al., 2005). These muscles are not mechanically able to stabilize the lumbar spine as effectively, so attempting to perform this stabilizing role actually compromises their effectiveness. Excessive co-contraction of the superficial abdominal musculature may interfere with normal movement and restrict breathing (Barr et al., 2005). For these reasons, some authors advocate neuromuscular training to selectively isolate and recruit the deep lumbar stabilizer muscles for athletes with overactive abdominal muscles (Pool-Goudzwaard et al., 1998).

Muscles of the lower and middle back

These muscles include the large extensor muscles longissismus and iliocostalis. Both these muscles have thoracic and lumbar components. The thoracic portions of these muscles generate the most extensor torque due to their long moment arm, whereas the lumbar parts generate posterior shear forces to stabilize anterior shear on the lumbar spine (McGill, 2004).

This group of large posterior muscles is completed by quadratus lumborum and latissimus dorsi. Quadratus lumborum primarily acts not only to provide stability in the frontal plane but also appears to serve an isometric stabilizing role for a variety of movements (Kibler et al., 2006). Studies assessing muscle activation and spine stability report that quadratus lumborum is observed to increase tension in response to increasing loads and stability demands (McGill, 2004). Latissimus dorsi is included with these large posterior muscles on the basis that it provides tension to the lumbodorsal fascia that forms the posterior aspect of the stabilizing 'corset' described in a later section (McGill, 2004).

Hip muscles

The hip musculature has a major role in all dynamic activities, and particularly those performed in an upright stance (Nadler et al., 2000). The hips and pelvis act as the anatomical base of support for the trunk. Similarly, one of the functions of the hip muscles of the supporting leg is to stabilize the trunk and upper body (Kibler et al., 2006). These muscles are implicated in various phases of the gait cycle, for example, helping to stabilize the pelvis and provide assistance to the supporting leg during the swing phase (Nadler et al., 2000). In fact in all dynamic movements, the hip extensors and rotators particularly

Figure 7.1 Alternate arm cable lat pulldown.

play a part in efficient transmission of forces from the ground upwards. The hip flexors – which include psoas (Juker et al., 1998) – play a crucial role in rapid and efficient action of the recovery leg during sprinting, which is identified as a determining factor in sprint performance.

The importance of the hip muscles' role in stabilizing the lower limb joints during dynamic movements is seen in that the function of these muscles impacts upon lower limb injury incidence, particularly in female athletes (Leetun et al., 2004). Inadequate hip muscle function combined with anatomical differences can predispose female players to excessive motion in the lower limb joints, placing these joints in positions where they are at risk of non-contact injury. Tests scores for isometric hip abduction and external rotation strength are found to be significant predictors of subsequent lower limb injury during the competitive season in collegiate athletes (Leetun et al., 2004).

Side-to-side imbalances in hip muscle strength are commonly observed in athletes. Right-handed athletes typically exhibit greater strength in their opposite (left) hip extensors (Nadler et al., 2000). This may well be due to the use of the left leg as the supporting leg during these right leg dominant sports activities, such as kicking. Likewise, right-hand dominant athletes will tend to take-off from their left leg when jumping. Both these instances place greater demands upon the leg hip extensor muscles. Conversely, right hip abductor strength is generally greater in right-handed athletes (Nadler et al., 2000). This can be explained by phenomena such as the dominant right hip abductor involvement of fine motor skills, for example the kicking action.

Impaired function of the hip extensors and hip abductors are observed in athletes suffering from lower back pain (Nadler et al., 2002). Muscle strength imbalances in these muscles are also implicated in lower back injury, particularly in female athletes (Nadler et al., 2002). Correcting hip abductor strength imbalances by a core strengthening programme shows the potential to reduce subsequent lower back pain incidence, particularly in female athletes (Nadler et al., 2002). Specific training to address these factors therefore can help to guard against incidence of injury and lower back pain.

The hip rotators are often overlooked in physical preparation. This is despite the recent finding that isometric hip external rotation strength was the single best predictor of lower back and lower extremity injury incidence in collegiate athletes (Leetun et al., 2004). Inflexible or weak hip rotators can predispose the athlete to poor pelvic alignment (Regan, 2000). Excessive lumbar spine motion can also occur in an attempt to compensate for impaired hip rotator function. Both of these factors can lead to pain and incidence of lumbar spine injury (Regan, 2000). It follows that these muscles must also be specifically addressed in training.

Thoracolumbar fascia

The larger trunk muscles and muscles of the abdominal wall attach to the passive structures of the thoracolumbar fascia to form a loop around the abdomen (Kibler et al., 2006). The abdominal fascia makes up the front of this hoop structure, with the abdominal muscles forming the sides, and the lumbodorsal fascia at the back (McGill, 2004). The proximal muscles of the upper limb (including pectoralis major anteriorly and latissimus dorsi posteriorly) and lower limb (in particular gluteus maximus) also attach to the thoracolumbar fascia – providing a link between lower and upper limbs (Kibler et al., 2006). Together, these muscles and passive structures serve as a stabilizing corset, with the attaching upper- and lower-limb muscles providing additional stiffness to the 'corset' when activated (McGill, 2004).

Neuromuscular control and co-ordination

Neural control is critical in the activation and co-ordination of each of the supporting muscles described above (Barr et al., 2005). A key aspect of this is the coordinated firing of local deep lumbar stabilizer muscles and activation of the large superficial muscles when handling external loads (Cholewicki and McGill, 1996). Another key element is proprioception and kinaesthetic awareness of the orientation of the pelvis, which directly impacts upon lumbar spine posture. Poor control of the position of the pelvis can put the lumbar spine under undue stress (Cissik, 2002).

Lumbopelvic stability in gross movements is underpinned by the firing of various core muscles in preparation for movement (Barr et al., 2005; Leetun et al., 2004). Hereby, the muscles providing the base of support are activated before the muscles involved in the particular movement (Anderson and Behm, 2005). The role of these anticipatory postural adjustments is to maintain the body's centre of gravity within its base of support in order to minimize any loss of balance (Anderson and Behm, 2005). This also serves to prevent unwanted trunk motion and provide a stable base of support during movement.

The neuromuscular system must govern function of stabilizing muscles not only in anticipation of expected direction and magnitude of forces, but also in reaction to sudden movement or loading (Barr et al., 2005). In this way, postural control, whole-body balance, and proprioception are also heavily involved in neural control of lumbopelvic stability.

A reflection of the importance of neuromuscular control is that individuals with chronic lower back pain exhibit impaired neuromuscular feedback and delayed muscle reaction, which is accompanied by reduced capacity to sense the orientation of their spine and pelvis (Barr et al., 2005; Rogers, 2006). These factors are responsible for the poor performance of these individuals in balance and movement response tasks (Barr et al., 2005). However, these deficits in neuromuscular control can be reversed by appropriate training interventions (Barr et al., 2005).

Summary

Lumbopelvic stability is multidimensional; functionally it can be considered to comprise three subsystems: deep postural muscles that provide local stability; the 'corset' of connective tissue structures and larger more superficial muscles that brace the core during higher force movement; and the hip muscles that act to provide stable base of support for the pelvis and trunk during weight-bearing movement. The diverse nature of the integrated system of support described above calls for an integrated approach to training that addresses each of the respective components that contribute to lumbopelvic stability (Rogers, 2006). Clinical approaches that commonly focus on one specific area or muscle group (typically, transverse abdominis or multifidus) to the exclusion of others are therefore fundamentally flawed.

McGill (2004) elucidated the fact that the diverse muscle groups that act in concert to support the lumbar spine must be in balance in order to ensure that optimal stability is provided. It follows that each of the separate components should be trained in a co-ordinated way in order to function harmoniously (McGill, 2004; Rogers, 2006). This is again contrary to clinical approaches that promote independent activation of single muscle groups in isolation by employing practices, such as 'drawing in the belly button' (abdominal hollowing), that cannot be considered functional by any definition (Brown, 2006).

PRACTICAL APPROACH TO TRAINING LUMBOPELVIC STABILITY

It is important to differentiate between lumbopelvic stability training for performance and for rehabilitation (McGill, 2002; McGill, 2004). The training goals in each case are significantly different – correspondingly, so should be the approaches taken to training. Injury and low back pain is often associated with disrupted motor control, which must be specifically addressed (McGill, 2002; McGill, 2004). Rehabilitation is a complex and diverse area, which is beyond the scope of the current article – the reader is referred to McGill (McGill, 2002; McGill, 2007). This section will instead focus on lumbopelvic stability training for improved performance in healthy athletes.

Rather than isolating particular muscle groups, there is instead a distinction between exercises that recruit deep postural muscles and more dynamic gross motor tasks that require the player to recruit the larger muscles to brace the trunk during movement. This is analogous to the differentiation between 'local stabilization system' and 'global stabilizing system', or 'postural' versus 'mobilizer' muscles (Liemohn et al., 2005; Carter et al., 2006). Approaches to core training design that include separate (isometric) stabilization exercises and dynamic core strength training have been described previously (Stephenson and Swank, 2004).

Some authors have questioned the need for dedicated training for the postural muscles that provide local stability (Willardson, 2007). This is based on the contention that these muscles will automatically be recruited simultaneously when athletes perform higher-intensity core exercises and more challenging exercises in the gym. These authors therefore argue that these deep lumbar stabilizer muscles will be concurrently developed during such training – hence do not require specific training (Willardson, 2007). However, from clinical experience undertaking musculoskeletal screening with a number of athletes from various sports, some athletes may exhibit highly developed lumbopelvic stability during more challenging tests that require bracing the trunk and yet are not able to activate consistently the deep postural musculature on command. These deep lumbar stabilizer muscles are activated in a tonic and constant fashion to support posture and provide local stability during locomotion and low-intensity movement in a way that the higher force tonic muscles that brace the trunk are not able to. It follows that the capacities of these muscles and the ability to recruit them should not be neglected in players' preparation.

The low-intensity exercises for the local stabilizers require high degrees of concentration and focused mental attention. As such they are not amenable to the high levels of activity and psychological arousal that are characteristic of a weights-room setting. Accordingly, it is recommended that these low-intensity exercises – which can and should be performed daily – might be undertaken as a stand-alone session or prior to warm-up for a workout or other training session, and conducted in a quiet controlled setting. Conversely, the more functional dynamic lumbopelvic stability exercises can be integrated into the athlete's strength-training workouts.

Daily low-intensity lumbopelvic stability exercises

As mentioned above, these exercises are proposed as comprising a stand-alone session to be performed on a daily basis by the athlete. These exercises require minimal equipment and are most suited to being performed in a quiet environment. More dynamic lumbopelvic stability training involving higher-intensity exercises targeting the larger trunk muscles in a load- and movement-specific manner are predominantly reserved for the weights room (see later section). Such a session may be undertaken early in the training day, or as a recovery session between or after technical/tactical practices or bouts of physical training. A session of this type is most beneficial when performed daily (McGill, 2004).

These exercises primarily focus on the deep lumbar stabilizers and low-intensity exercises for the hip musculature. The objective of these exercises is to develop motor control of lumbar spine stabilizers and proprioception – particularly the ability to sense lumbar spine positioning and orientation of the pelvis (Carter et al., 2006). The emphasis when performing these exercises is on maintaining a neutral spine posture and holding the pelvis stable (Carter et al., 2006).

A key element when performing these exercises is that the athlete is instructed to hold each posture for a period, whilst taking a full breath in and out. The addition of a static hold when performing dynamic strength training was found to elicit increases in cross-sectional area of multifidus in patients with chronic low back pain, which were not seen when performing the same dynamic training without a static hold (Daneels et al., 2001). This finding suggests that including an isometric contraction between concentric and eccentric phases may be necessary to develop size and function of these deep lumbar stabilizer muscles (Daneels et al., 2001).

The instruction to take a full breath during these static hold phases is designed to emphasize maintaining stabilizer muscle activation in a way that is independent of breathing patterns. The ability to maintain muscle activation during challenged breathing is a key indicator of effective versus ineffective stabilizer motor control patterns (McGill, 2004). In addition, this deep breath facilitates (partial) relaxation of the larger superficial abdominal muscles (particularly rectus abdominis), which encourages proper activation of the local lumbar stabilizers and deeper abdominal wall muscles.

Two examples of such exercises have been described in detail elsewhere. For the bird dog exercise (two-point support from kneeling quadruped stance), the reader is referred to McGill (McGill, 2004) and Rogers (Rogers, 2006). The kneeling side bridge is described in Jenkins (Jenkins, 2003) and McGill (McGill, 2004). Training of this type should also be undertaken in weight-bearing postures in order to incorporate the muscles that stabilize the hip and pelvis. In much the same way as the floor-based activities, appropriate exercises will involve holding static postures. As such, these exercises will resemble single-leg balance tasks commonly employed for developing postural balance and lower-limb stability.

A daily session that includes the exercises of the type described above should also incorporate stretching exercises to develop hip flexibility (Rogers, 2006). Tightness in the gluteal muscles and hamstrings is common among athletes with below-par lumbopelvic stability (Jenkins, 2003), so addressing this is of obvious benefit. This has been characterized as the *Crossed Pelvis Syndrome* (McGill, 2004). Good hip flexibility likewise helps spare the spine by allowing the athlete to develop high levels of hip power whilst minimizing motion at the lumbar spine (McGill, 2004). However, flexibility training should emphasize the hip muscles, as opposed to the lumbar spine. Hyper-flexibility in the lumbar region can only make this area more unstable, which may actually predispose the athlete to injury (McGill, 2004). Consequently, stretches that incorporate a neutral spine position should be favoured.

Dynamic lumbopelvic stability training

In addition to neuromuscular co-ordination and proprioception training goals, there is also a requirement for more challenging exercises to develop strength and endurance of muscles that brace the trunk and provide lumbopelvic stability during higher force and more dynamic movements (Behm et al., 2005). The recruitment of these muscles is dependent on posture and direction of movement, as well as loading conditions (Anderson and Behm, 2005; McGill, 2004). It follows that a range of exercises in different planes should be incorporated to fully address these muscles. As mentioned previously, these may be integrated into strength-training workouts in the weights room.

Progression can be implemented in exercise selection by incorporating an unstable base of support, in order to elicit greater levels of abdominal activation for particular exercises (Behm et al., 2005; Cissik, 2002; Stephenson and Swank, 2004; Vera-Garcia et al., 2000). Typically, a wobble board or Swiss ball is used for the purposes of creating a labile supporting surface (Behm et al., 2005; Vera-Garcia et al., 2000). Imposing instability in this way is shown to increase trunk muscle activation (recorded EMG) for a variety of trunk muscle exercises (Behm et al., 2005; Vera-Garcia et al., 2000).

Another consideration is that there is often a trade-off between levels of muscle activation and compressive loads imposed upon the spine (Axler and McGill, 1997; Juker et al., 1998). Again, there must necessarily be a distinction between training for performance improvement and training for low back injury rehabilitation (McGill, 2006d). These two scenarios will obviously involve different risk-to-benefit considerations in terms of exercise selection (Axler and McGill, 1997). However, in either case, identifying exercises that optimize muscle recruitment and activation whilst sparing the spine is likely to prove beneficial.

Figure 7.2 Swiss ball bridge with leg raise.

Abdominal muscles

No single exercise activates all abdominal muscles optimally (Axler and McGill, 1997; Juker et al., 1998). It follows that a selection of various different exercises is required to develop strength and endurance for the respective muscle groups that contribute to lumbopelvic stability (Axler and McGill, 1997). As discussed previously, the trunk muscles work in different combinations depending on the direction of movement, posture, and loading involved (Barr et al., 2005; McGill, 2004). Individual considerations, such as injury history and specific areas of strengths and weakness will also influence the choice of exercises.

Whether performed on a stable or unstable base, Behm et al., (2005) reported the side bridge exercise to result in the highest levels of recorded lower abdominal muscle activation (including internal obliques and transverse abdominis) out of a selection of trunk muscle exercises studied. The side bridge exercise also has the ancillary benefit of low lumbar spine compressive loading and high activation of quadratus lumborum (Axler and McGill, 1997).

Classically, exercises for the abdominal muscles have been based upon variations of sit-ups and curl-ups. Conversely, athletic tasks typically involve a fixed neutral spine position – it follows that these muscles should therefore be

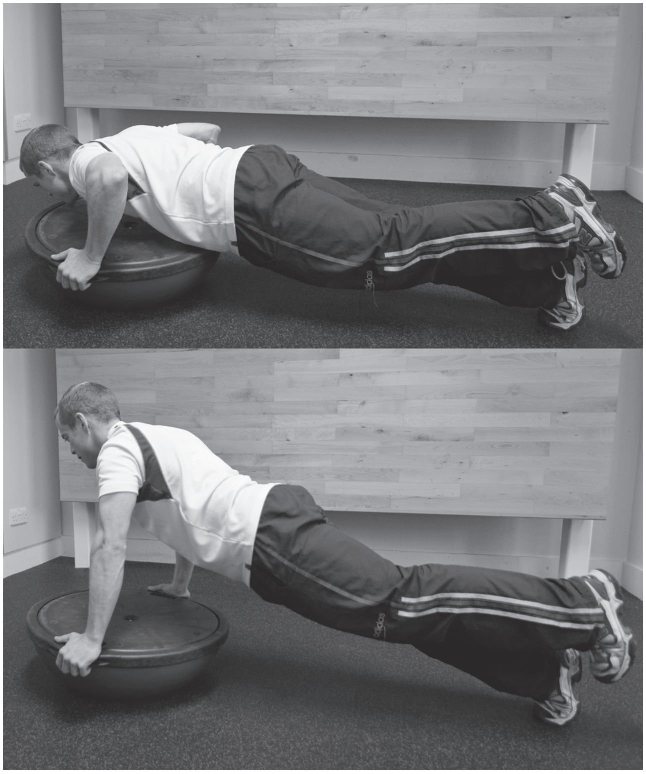

Figure 7.3 Alternate leg BOSU ball push up.

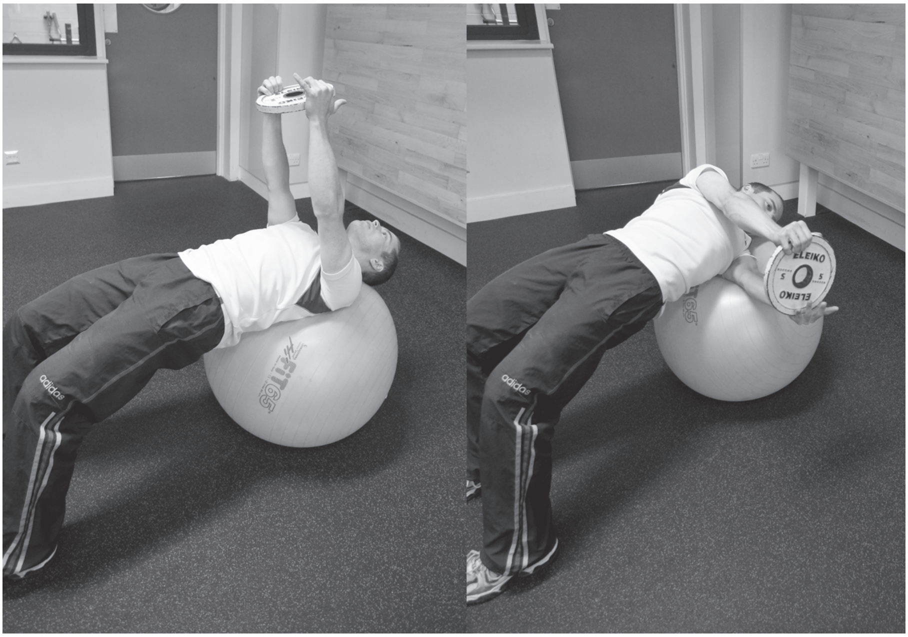

Figure 7.4 Swiss ball Russian twist.

trained under similar (isometric) conditions (McGill, 2004). Repetitive flexion of the spine under load as occurs with sit-up and curl-up exercises can also be injurious (McGill, 2002).

Twisting and turning actions are common particularly in team sports and it follows that dynamic lumbopelvic stability training should address these movements. It is suggested that initially this is best achieved with exercises on a Swiss ball, using the athlete's body weight as the primary resistance. Higher twisting torque is associated with low back injury risk – as is twisting to the extremes of range of motion (McGill, 2002). Both these situations should therefore be avoided at least in the initial stages of training, particularly for athletes with previous history of low back pain. As the athlete

Figure 7.5 Swiss ball hip rotation with push up.

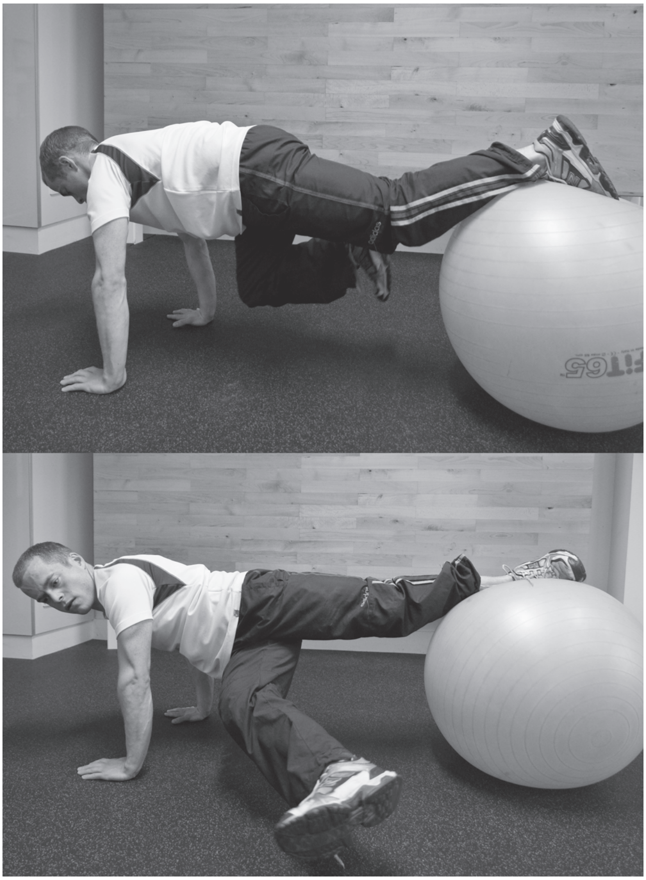

Figure 7.6 Swiss ball single-leg pivot and reach.

progresses, additional resistance using cable exercises may be progressively introduced.

Muscles of the hip and pelvis

The hip is a joint that allows movement in multiple axes. It follows that a variety of movements in different planes should be incorporated when training the hip musculature. In this way the approach to training the hip can be viewed much the same as training the shoulder rotator cuff, in terms of the variety of exercises and planes of motion that are included (Fabrocini and Mercaldo, 2003).

The hip muscles play a key role in stabilizing the pelvis during single-leg support (McGill, 2004), which characterizes the majority of movements in team sports and various track and field events. Unilateral support exercises are therefore a crucial part of any functional lumbopelvic stability training to incorporate the hip musculature (McGill, 2004). Body weight resistance

Figure 7.7 BOSU ball bridge with leg raise.

exercises can be progressed to exercises performed with resistance – free weights or cable resistance would appear to provide the most appropriate stabilization challenge. Many of the relevant hip muscles from a lumbopelvic stability standpoint cross both the hip and knee joints – it follows that exercises must be performed in a variety of postures with different degrees of hip and knee joint flexion (McGill, 2004).

Lumbopelvic stabilization during hip flexion is crucial particularly when sprinting; consequently, single-leg support exercises that incorporate resisted hip flexion are frequently used by athletes to develop sprint performance (Sheppard, 2003). However, activation of the psoas and iliacus muscle groups during hip flexion exerts large compressive forces on the spine, which are compounded when performed at high velocity (McGill, 2004). As a result, if performed with resistance, these exercises should be executed in a controlled manner rather than at high velocity. An alternative approach is to perform these exercises unloaded in different postures at faster movement speeds – allowing acceleration to provide overload to the muscles.

Figure 7.8 BOSU ball single-leg hip flexion/extension.

Neuromuscular control and coordination

The key for all of the exercises described in this chapter is for the athlete to gain an appreciation of what is occurring with their lumbo-pelvic-hip complex. Challenging the athlete's balance and postural control using appropriate exercises can facilitate developing a heightened sense of the position of their lumbar spine and orientation of their pelvis when performing various activities.

Figure 7.9 Single-leg alternate arm cable press.

The emphasis for this form of training is on maintaining neutral lumbar spine posture and whilst controlling alignment of the pelvis in both frontal and horizontal plane under different balance and load challenges. During these exercises, the athlete is simultaneously challenged to retain their balance in either bilateral or unilateral stance, by keeping their centre of mass within their base of support (ideally with weight through the heel/mid-foot of the supporting leg(s)). Hereby, these exercises develop both proprioception and whole-body stability (Shiner et al., 2006).

These exercises may be progressed to dynamic bounding-type activities similar to those used to develop dynamic stabilization for the lower limb. As such, part of the emphasis for all of these exercises should be correct lower limb alignment. The position of the pelvis (in frontal, horizontal, and sagittal planes) and trunk posture are similarly critical. Having the athlete palpate the anterior superior iliac spines (ASIS) on either side whilst performing many of these exercises facilitates developing an enhanced 'feel' for pelvic alignment and position.

Specific lumbopelvic training for sports performance

Core training for performance is defined as developing an enhanced ability to transfer force from the core to the extremities (Steyck et al., 2008). Key aspects of lumbopelvic training in the context of sports performance are developing

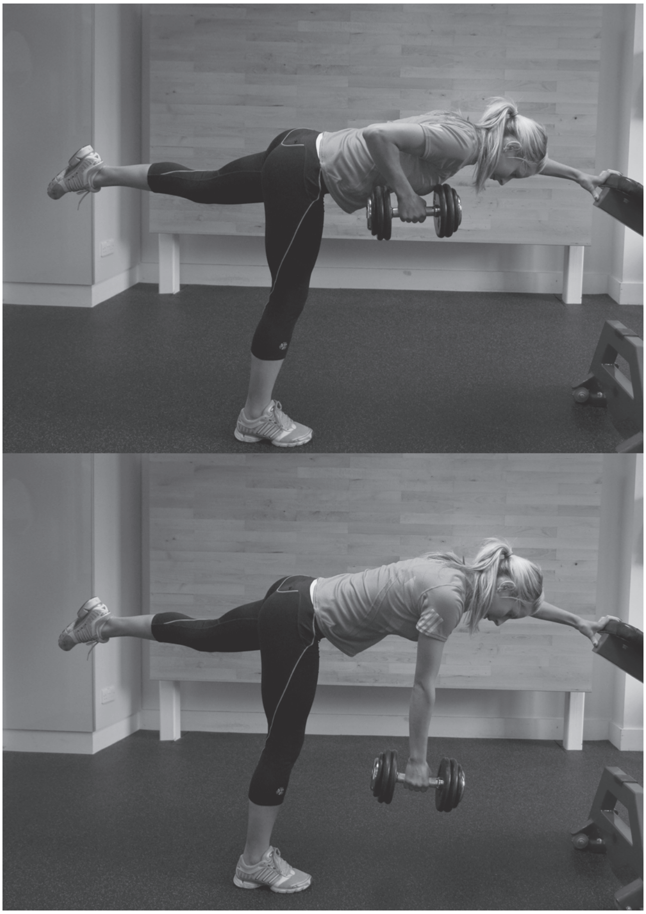

Figure 7.10 Single-leg single-arm dumbbell row.

torsional strength and the ability to maintain a neutral and stable lumbopelvic posture under various load challenges. Training of this type often involves the player assuming a fixed base of support and bracing the lumbopelvic region as the upper and lower limb muscles generate force and produce movement at the extremities (McGill, 2006f). These training modes often have a rotational force generation or torsional stabilization element (Steyck et al., 2008). A similar approach is to perform variations of fundamental movements (e.g. lunge or squat) under different loading conditions – for example, with barbell or dumbbell(s) held overhead (McGill, 2006f). The objective with either approach is for the player to maintain a stable base of support, neutral spine alignment, and strong trunk posture whilst opposing destabilizing torques (Steyck et al., 2008).

These 'core strength' training modes can incorporate external resistance in the form of cables and free weights to provide the destabilizing challenge. Alternate-limb and single-limb resistance exercises are reported to produce considerable destabilizing torques and elicit high levels of activation of muscles that stabilize the trunk (Behm et al., 2005). Hence a progression from bilateral resistance to alternate-limb and finally single-limb resistance can be employed during training. In order to facilitate transfer, it follows that such training should incorporate postures that occur during matches – including exercises performed in a split stance and from single-leg base of support (Steyck et al., 2008). Similarly, the type of external resistance applied and limb movements employed during these training modes should correspond to the movements and loading conditions encountered on the field of play. These methods represent a relatively novel approach to 'core' training – as such there is a need for prospective studies to determine their efficacy, particularly with athlete subjects.

CONCLUSIONS

A systematic approach to athletic training for the 'core' requires that the strength and conditioning specialist accounts for all the various different aspects described that underpin lumbopelvic stability. It is suggested that daily lumbopelvic stability training should be undertaken, in combination with higher-intensity dynamic exercises that can be incorporated into strength-training sessions in the weights room.

As with all training, lumbopelvic stability training should incorporate progression and specificity (Cissik, 2002; Stephenson and Swank, 2004). In the case of dynamic lumbopelvic stability training particularly, intensity of loading and exercise selection should be implemented within the context of the athlete's periodized training plan (Stephenson and Swank, 2004). Furthermore, the approach taken should reflect the needs of the individual athlete, based upon their training and injury history (Stephenson and Swank, 2004). This will necessarily include relevant screening or fitness test data – such as the relationship between flexor, extensor, and side bridge test endurance times (McGill, 2004).

Practices on competition day – such as warm-up and athletes' activity while waiting to perform – should also not be overlooked with regard to lumbopelvic function and lumbar spine health. A particular concern for non-starting players in team sports is the increase in lumbar spine stiffness observed from sitting on the bench waiting to enter into the game – reversing any positive effects of pre-match warm-up (Green et al., 2002). As such, the musculature that provides lumbopelvic stability should not be overlooked during warm-up – particularly in the case of non-starting players.

CHAPTER 8

PERIODIZATION OF TRAINING

INTRODUCTION

Training variation is increasingly acknowledged as being critical to successful training prescription (Fleck, 1999; Stone et al., 2000; Willoughby, 1993). Periodization offers a framework for planned and systematic variation of training prescription (Brown and Greenwood, 2005; Plisk and Stone, 2003; Rhea et al., 2002; Stone et al., 2000b). Accordingly, it has been established that periodized training is able to elicit improved training responses in comparison to training groups with no variation in training load (Fleck, 1999; Stone et al., 2000b; Willoughby, 1993).

The consensus is therefore that periodized training offers superior development of strength, power, body composition, and other performance variables (Fleck, 1999; Stone et al., 1999a; Stone et al., 1999b; Stone et al., 2000b; Wathen et al., 2000; Willoughby, 1993). Despite this, there are very limited research data upon which to base decisions regarding the best approach to periodization – particularly in the case of athlete populations (Fleck, 1999; Cissik et al., 2008). The choice of periodization schemes is therefore likely to be largely dictated by what is most appropriate given the amount of concurrent training involved and the competition calendar involved in the particular sport (Wathen et al., 2000).

In view of this, unique challenges are faced when attempting to apply periodization to training design in team sports. Team sports players are required to perform high volumes of technical/tactical training, team practices, and competitive matches. As a result, periodized training design requires considerable planning and skill (Gamble, 2004a). Indeed, there are numerous complications that represent an obstacle to effective application of periodized training in most team sports.

Despite these considerations, the planned variation of training provided by periodization remains vitally important for team sports athletes. The approach to periodization should be specific to the demands of the particular team sport, including the length of the competitive season and the number and frequency of fixtures involved. Selection of periodization methods for different training mesocycles throughout the year should also follow what best fits the needs of the respective phase of training (Plisk and Stone, 2003).

TRAINING VARIATION

Training variation is increasingly acknowledged as serving a key function in successful training prescription (Fleck, 1999; Stone et al., 2000a; Willoughby, 1993). According to either the general adaptation syndrome (Selye, 1956) or the more recent fitness–fatigue theory (Chiu and Barnes, 2003), sustained exposure to the same training for a given neuromuscular property fails to elicit further adaptation, and in time may lead to diminished performance (Wathen et al., 2000). One aspect of training variation is therefore avoiding plateaus in training adaptation or maladaptation (negative impact on performance resulting from unplanned over-reaching or overtraining).

Another issue when planning athletes' training is that only two or three training goals can be emphasized at any one time (Zatsiorsky and Kraemer, 2006). This is particularly with conflicting training goals that involve opposite hormonal responses (e.g. catabolic versus anabolic) and neuromuscular fatigue that interfere with training adaptation. Those sports that require a variety of training goals require that training is varied in a systematic way in order that different training goals are accounted for during different phases in the athlete's training year.

The degree of training variation required is also likely to be specific to the training experience of the individual (Plisk and Stone, 2003). More basic periodization schemes that involve less variety in training parameters are sufficient for younger athletes or those who do not have a long training history (Bompa, 2000; Kraemer and Fleck, 2005; Plisk and Stone, 2003). This is not the case for more advanced athletes.

Periodization of training

Periodization was developed with aim of manipulating the process of training adaptation, and avoiding the maladaptation phase – which could place the athlete in an overtrained state (Wathen et al., 2000; Brown and Greenwood, 2005). Periodization offers a framework for planned and systematic variation of training prescribed to vary the training stimulus at regular intervals in order to prevent plateaus in training responses (Brown and Greenwood, 2005; Plisk and Stone, 2003; Rhea et al., 2002; Stone et al., 2000a). In addition to avoiding potential negative effects of training monotony, use of periodization schemes allow planning of training prescription to prioritize particular training goals at particular times in the training year and to take advantage of superimposition of training effects from preceding cycles (Zatsiorsky and Kraemer, 2006). Essentially, preceding phases of training can be used to 'potentiate' or enhance the athlete's response to the particular training prescribed in subsequent cycles.

Accordingly, it has been established that periodized training is able to elicit improved training responses in comparison to training groups with no variation in training load (Fleck, 1999; Stone et al., 2000a; Willoughby, 1993). However, very few studies of sufficient length assessing the effects of different approaches to periodized planning have been published (Fleck, 1999). As such, there are insufficient data upon which to base decisions when selecting the best approach to periodization in order to plan athletes' training (Cissik et al., 2008).

One of the primary considerations when selecting the most appropriate periodization scheme upon which to plan the training year is the competition calendar for the particular sport (Wathen et al., 2000). Another complication when scheduling athletes' training is the interaction of concurrent training and technical/tactical practices performed in the sport. In addition to scheduling concerns, the number and variety of training goals demanded in the sport are another key consideration.

Approaching periodization

When planning athletes' training, it is customary to divide the 'macrocycle' (training year or biennial or quadrennial cycle in the case of Olympic sports) into smaller blocks called 'mesocycles' (Zatsiorsky and Kraemer, 2006). Within each *mesocycle* are smaller blocks of time known as *microcycles*, which typically comprise a week or 2-week block. Periodization of training should consider planned variation and scheduling at levels from macrocyle, to mesocycle and microcycle. For example, planning at the level of the macrocycle must consider the key dates in the competition season. Planning at microcycle level concerns not only structuring individual sessions to meet the goals of a particular phase of the training mesocycle but also scheduling the training week to account for the respective demands of competitive matches, different training sessions, and technical/tactical practices. Scheduling each training microcycle also requires consideration of negative interaction between conflicting forms of training – for example, aerobic conditioning and strength/power training.

The classic 'linear' format for training periodization is characterized by gradual increases in training intensity between successive mesocycles, with simultaneous reductions in training volumes. This progression culminates in a competition cycle, which is scheduled to coincide with one or more major competitions in the calendar and designed to allow the athlete to arrive at these competitions in peak physical condition (Wathen et al., 2000). Hence, there is considerable variation in training prescription between consecutive phases in the training year, but not typically within each training microcycle.

An alternative approach is termed non-linear or 'undulating' periodization. These schemes involve weekly variations in intensity and volume within a training microcycle, in addition to variation between mesocycles (Wathen et al., 2000). As such, non-linear models provide a greater degree of variation (both within and between training cycles). These schemes were developed for athletes competing in sports with an extended competition season. Therefore the undulating non-linear approach aims to keep the athlete close to their peak for multiple competitions spanning a prolonged period. The weekly variation between workouts in the undulating periodization model also allows for multiple training goals to be addressed simultaneously (Zatsiorsky and Kraemer, 2006).

Periodizing intensity, volume, and content of training prescribed

In the traditional periodization models, the training year or macrocyle is divided into an initial general preparation phase 'GPP', followed by special preparation phase(s) 'SPP' and culminating in the competition phase. The GPP is typically preceded by a period of active rest following the previous competition season and each phase within the training cycle may be separated and subdivided with 'transition' cycles (Wathen et al., 2000). The training goals for each cycle classically follow a particular sequence (Zatsiorsky and Kraemer, 2006). The goals during the general preparation are typically hypertrophy/strength-endurance and base metabolic conditioning to provide a foundation for the subsequent training phases in the year. Training goals then sequentially progress during the special preparation phase from general strength to strength/power and there is a shift to more intensive metabolic conditioning. The training goals that predominate during the competition phase will depend upon the sport; however, strength training is typically oriented towards power and power-endurance and metabolic conditioning becoming highly specific to the bioenergetics of the sport.

In accordance with the training goals for the respective phases of training, the early cycles in the training macrocycle during the general preparation phase are characterized by higher training volumes and lower intensities (Wathen et al., 2000). Classically, as the training year progresses through the special preparation phase and into the competition phase, training intensity is increased with corresponding decreases in training volume. Whether a linear or undulating approach is taken to periodization intensity and volume will broadly show this diverging pattern (intensity progressively increasing and volume progressively decreasing) over the course of the training macrocycle. Another factor that comes into play during competition cycles is tapering of training frequency and volume for critical phases in the competition calendar to allow residual fatigue effects to subside in order that training effects can be fully expressed in the athlete's competition performance (Zatsiorsky and Kraemer, 2006).

Periodic changes in exercise selection and conditioning modes are important in order to systematically change the training stimulus and thereby facilitate continued training adaptation (Zatsiorsky and Kraemer, 2006). The classical model for periodized planning is for training modes to feature a progressive shift from 'general' training modes during general preparation cycles to increasingly 'specific' training modes particularly as the athlete approaches key phases in the competition period. Accordingly, the general preparation phase is classically characterized by general strength-training exercises and relatively non-specific metabolic conditioning modes including cross training. The special preparation phase in turn features a gradual progression towards the sport-specific strength-training exercise selection and metabolic conditioning modes that characterize the competition phase. This sequential shift towards the most specific strength-training movements and conditioning modes is designed to translate the general or 'non-specific' strength qualities and conditioning base developed during earlier training cycles into sport-specific strength and fitness as the athlete enters the competition phase (Zatsiorsky and Kraemer, 2006).

Use of periodization in professional team sports

Strength and conditioning coaches working in a multitude of team sports at various levels report adopting a periodized approach to their programme design. The use of periodization was indicated by the vast majority of Division One collegiate strength and conditioning coaches in the United States responding to a survey of their methods (Durell et al., 2003). Similar surveys of professional North American team sports reported comparable use of periodized training design (Ebben and Blackard, 2001; Ebben et al., 2004; Ebben et al., 2005; Simenz et al., 2005). These included National Basketball Association (90 per cent of respondents using periodized programmes) (Simenz et al., 2005), National Hockey League (91.3 per cent using periodization) (Ebben et al., 2004), and Major League Baseball (83.4 per cent) (Ebben et al., 2005).

National Football League coaches reported by far the lowest use of periodization models (69 per cent) (Ebben and Blackard, 2001). This may be a result of the contact nature of the sport. On the issue of training periodization, one coach was quoted as saying, 'Weight training in football is different than any other sport. When you have them healthy, (you) train them' (Ebben and Blackard, 2001). The fact that the data collection for this study was notably earlier (1997–1998) than the other respective surveys may also have played a part. This may in turn explain the relatively greater use of 'high-intensity training' methods (19 per cent) by the coaches in the sample (Ebben and Blackard, 2001), which was enjoying relative popularity at the time.

Such difficulties as injuries and residual fatigue underline the unique challenges of designing periodized programmes for team sports athletes, particularly in the case of contact sports. Despite these considerations, training variation remains vitally important for team sports athletes. This is important to alleviate the monotony that can otherwise affect compliance throughout a long season of training and competition (Wathen et al., 2000). Taking player motivation aside, it is counterproductive and even harmful to train in the same way for extended periods. Short-term training studies consistently show training programmes that incorporate periodized training variation elicit superior results

(Stone et al., 2000a; Willoughby, 1993). Solutions to these complications must therefore be sought to enable periodized training to be incorporated into an athlete's physical preparation in a given sport.

CHALLENGES AND PRACTICAL SOLUTIONS FOR PERIODIZED TEAM SPORTS TRAINING

Extended season of competition

A major obstacle for coaches working in seasonal team sports is the frequent matches and extended competition period involved. The classical periodization models for planned training variation were developed for the competitive season in track and field athletics (Plisk and Stone, 2003). As a result, the classical linear periodized format features extended training cycles, designed to progressively prepare the athlete for one or two major championships in the year (Wathen et al., 2000).

The playing season for sports like football and rugby union can span in excess of 35 weeks, particularly in Europe. If coaches were to follow the classic model, training would taper considerably for the duration of the competition phase. This is clearly counterproductive for most team sports (Baker, 1998; Hoffman and Kang, 2003). It has been identified that following such restrictive competition phase repetition schemes may lead to excessive losses in lean body mass during the season, which is unfavourable for most power sports (Allerheiligen, 2003). Given this requirement to continue regular training over many months, achieving the necessary training variation represents a sizeable challenge.

It is vital that strength training is maintained in-season to prevent significant losses in strength, power, and lean body mass (Allerheiligen, 2003; Baker, 1998). Periodization schemes for in-season training will necessarily differ from those applied during off-season and preseason training cycles. This is discussed in greater detail later in the chapter.

Multiple training goals

Team sports require several disparate training goals. These can include, but are not limited to: hypertrophy, maximum strength, explosive power, metabolic conditioning and injury prevention (Gamble, 2004b). Multiple and often conflicting training goals must therefore be addressed in the course of the training plan. In view of this, there is a need for planned variations in the training programme to systematically shift the emphasis to promote these different training effects at different points in the players' preparation.

Due to the need to maintain different neuromuscular and metabolic training goals as well as cater for technical and tactical practice, some periodization strategies may not be appropriate for a given sport. An example of a periodization scheme that appears less suited to the multiple training goals associated with many team sports is the conjugate periodization model (Plisk and Stone, 2003). This is an advanced approach that aims to exploit fitness and fatigue after effects by consecutive overload cycles, alternately stressing one motor quality (e.g. strength) for a period, then switching to overload another motor quality (e.g. speed) for the subsequent training cycle (Plisk and Stone, 2003). Two main training goals are hence typically coupled in this approach. During the overload phase for the other motor quality in the couple (strength), a low-volume maintenance programme is undertaken for the motor quality not being emphasized (speed) (Plisk and Stone, 2003). These overload cycles are alternated in series. The greater number of training goals required by many team sports than the two motor qualities typically addressed in this periodization format would obviously make the application of this approach problematic.

It has been suggested that undulating 'non-linear' periodized approaches are more viable when planning the training year for team sports (Wathen et al., 2000). The rationale for this is that such periodization strategies allow for more variation in both training intensity and volume, both within and between training cycles. As such, multiple training goals can be emphasized in each training microcycle (Zatsiorsky and Kraemer, 2006). However, at some phases of the training year, in particular the off-season and preseason, sequential approaches similar to the classical linear periodization model may still have merit. This is explored further in a later section.

Interaction of strength training and conditioning

When programming strength training, coaches must also take account of the interaction of the metabolic conditioning that is performed alongside strength and power training (Gamble, 2004b). The physical activity involved in technical/tactical sessions and team practices should also not be overlooked.

A major consideration when strength training and metabolic conditioning are undertaken concurrently is that a prior bout of high-intensity endurance exercise in the training day is shown to impair an athlete's ability to perform strength training (Kraemer et al., 1995; Leveritt and Abernethy, 1999). Post conditioning it has been reported that players are not able to complete the same number of repetitions with a given load that they are capable of without having previously performed endurance exercise (Leveritt and Abernethy, 1999).

These interference effects are associated with conflicting hormonal responses to strength versus endurance training (Kraemer et al., 1995). As a result, when strength training is performed the same day following endurance training, power development in particular is shown to be impaired (Kraemer et al., 1995). It appears that strength and power training exercises requiring greater neuromuscular control and co-ordination may be more susceptible to such interference.

The sequencing of the training day appears key to minimizing the degree to which strength and power development are compromised by concurrent metabolic conditioning work (Leveritt and Abernethy, 1999). When strength training is prioritized and performed before conditioning, these interference effects can be reduced (Leveritt and Abernethy, 1999).

Sequencing training this way is shown to optimize strength training responses of professional rugby league players, to the extent that strength and power measures can be maintained during the course of a lengthy (29 weeks) in-season period (Baker, 2001). Younger (college-aged) players can even increase strength and power scores during the playing season by adopting this approach (Baker, 2001).

Time constraints imposed by concurrent technical and tactical training

Given the time constraints imposed by the high volumes of team practices and other skill training common to all professional team sports, the time-efficiency of physical preparation is paramount. As the playing season approaches, focus inevitably shifts to tactical aspects – with a greater number of team practices to prepare for the forthcoming fixtures (Hedrick, 2002; Wathen et al., 2000). During the season, the need to maximize the effectiveness of what limited training time is available is greater still.

The issue of limited training time may be addressed by optimizing the time efficiency of the training that is performed. A useful strategy is to incorporate different elements in order to combine practice and physiological training aspects in a single session. Particularly in-season, speed development and agility work can be included in team practice sessions (Wathen et al., 2000). Similarly, plyometric work can be incorporated into strength-training sessions – for instance, by employing complex training methods.

A good example of combined physiological and technical training is the use of game-related methods for metabolic conditioning (Gamble, 2007b). The skill element involved encourages coaches to continue metabolic conditioning via the use of conditioning games when the training emphasis shifts to skills practice and game strategy (Gamble, 2004a). Continuing metabolic conditioning in this form during the playing season is likely to allow cardiorespiratory endurance to be better maintained in-season.

Impact of physical stresses from games

When planning training during competition periods, allowances will inevitably need to be made for players' recovery after each match. Particularly in the days following games, this need to allow the players' bodies to recover is likely to limit the intensity and volume of physical training they are able to perform. As such, there is the potential for the high volumes of physically demanding practice sessions and competitive games during the season to result in players losing muscle mass during the playing season (Allerheiligen, 2003).

In the case of contact sports, in particular, consideration must also be given to the physical stresses that result from violent bodily contact with opponents and the playing surface during both practices and matches. As a consequence, muscle tissue damage incurred particularly during the playing season may compromise the quantity and content of strength training that players are able to undertake, potentially to the extent that strength and power levels may be diminished over time (Hoffman and Kang, 2003).

Scheduling of training in-season and during late preseason when competitive matches are being played should take appropriate measures to tailor training sessions to the players' physical status. In the day(s) immediately following the game, strength training will necessarily be limited to light recovery workouts, implemented alongside acute recovery practices. Similarly, the strength and conditioning coach should be prepared to modify the workout scheduled for a given day in the event that a player reports to training suffering from excessive residual fatigue or with a diagnosed acute injury that will impair their ability to perform the particular session set on that day (Plisk and Stone, 2003).

CONCLUSIONS

There are currently too few studies of sufficient length to make categorical assertions regarding the superiority of one approach to periodization over another – particularly given the paucity of periodization studies featuring athlete subjects (Fleck, 1999; Cissik et al., 2008). Furthermore, such debates may be redundant – by definition, periodization concerns variation of training. As a result, it seems unlikely that a single periodized training scheme exists that will elicit optimum results when applied for extended periods. Rather, it seems probable that a range of periodization strategies implemented in combination will produce the best results throughout players' long-term training (Plisk and Stone, 2003).

Some evidence for this assertion was observed in the superior strength gains during initial stages of training in strength-trained subjects with a daily undulating periodized (DUP) model, in comparison to a linear periodization group (Rhea et al., 2002). This was attributed to the novelty of the DUP scheme for the subjects, whose previous training had been characterized by linear periodization (Rhea et al., 2002). Equally, the attenuated training response and reports of training strain in the latter part of the study period in the DUP group indicates that the continued use of this scheme in isolation may similarly be unproductive (Rhea et al., 2002).

Hence, the best approach would appear to involve strategically combining methods, implementing periodization schemes in each training mesocycle throughout the training year according to the needs of the respective phase of players' preparation (Plisk and Stone, 2003). Periods in the off-season and preseason without competitive games will undoubtedly allow different approaches to periodized training from those that will be conducive for adequate recovery when matches are scheduled.

PRACTICAL APPLICATION OF PERIODIZED TRAINING FOR A TEAM SPORTS SEASON

As discussed earlier in the chapter, the degree of variation in training loads and volumes will depend on the age and experience of the player. Elite players are capable of tolerating higher training stress – hence training intensity and volume may remain close to their upper ranges for a large part of the training year (Wathen et al., 2000). Furthermore, elite athletes will tend to require a greater degree of variation to optimize the effectiveness of their training (Plisk and Stone, 2003; Stone et al., 2000a).

In this section, sample mesocycles will be described to illustrate the periodization strategies proposed for each phase of the training year for a generic team sports athlete. The rationale for the approach used for each of the respective training cycles are outlined below. Specific programme variables, such as the length of each phase and exercise selection, will vary according to the length of the playing season and demands of the particular sport.

Off-season

For the purposes of clarity, the 'off-season' phase for team sports will be defined as the period prior to the start of structured technical and tactical practices. Whether the strength and conditioning coach actually has the luxury of a supervised off-season period when the players report back after the post-season break tends to depend on the willingness of the coaching staff to delay the start of practices to allow him to do so. As a consequence of the length of the playing season, particularly in European soccer and rugby football leagues, this is not always the case.

Due to the long season of competition, it is vitally important to allow a period of active rest following the end of the playing season (Wathen et al., 2000). That said, the length of the active rest period should be restricted to avoid players entering off-season training in a detrained state. Similarly, in view of the length of time players are engaged in supervised training, it may make sense to allow players to undertake the early initial part of off-season training in an unsupervised setting. This will undoubtedly have a psychological benefit in sports with an extended playing season by limiting the monotony of the training ground environment.

Programming during the off-season will resemble the classical 'general preparation phase'. As such, training parameters during this time of year will be characterized by relatively higher volume and frequency of training conducted at lower intensity, and exercise selection will emphasize general training modes for overall development. Accordingly, general strength exercises that might be considered non-specific do still have merit during this phase of the athlete's preparation (Siff, 2002). One aspect of this is that from the point of view of training variation, lifts which are considered sport-specific should not be used exhaustively throughout the duration of the training year (Wathen et al., 2000). The other determining factor is that the training goals for this point in the training year should be building a foundation of athleticism prior to concentrating on sport-specific development in later phases.

As such, the starting point when prescribing off-season strength training should be the results of the player's musculoskeletal and movement screening which should be undertaken when players report back to training at the beginning of the new training year. Exercise selection can then address any deficiencies identified and focus upon developing strength and motor abilities for fundamental athletic movements, such as variations of the squat, lunge, and step up. Likewise, upper body development during this phase will emphasize generic pushing and pulling lifts and raises in various planes of movement.

Metabolic conditioning modes will similarly be fairly generic – the objective of training during this phase will essentially be to establish a conditioning base to prepare players for the training cycles to follow. In a way similar to the non-specific strength training exercise selection during this phase, cross-training methods and recreational sports for metabolic conditioning will have application at this time (Wathen et al., 2000). Plyometrics, speed work, and agility training will not typically be performed at this early phase in the training year, but are reserved for later training phases.

Table 8.1 Example off-season mesocycle for rugby union football

	Day one	Day two	Day three
Weeks one and three	10-RM	10-RM	12-RM
	3 sets	*3 sets*	*3 sets*
	Barbell overhead squat	Prone DB external rotation	Leg press
	Seated cable row	Bench press	Incline DB bench press
	Dumbbell split squat	Swiss ball suspended row	Lat pulldown
	Narrow-grip dips	Seated DB shoulder press	Machine hamstring curl
	Dumbbell lateral raise	Prone DB lateral raise	Cable triceps pushdown
	DB single-leg calf raise	Dumbbell front raise	Dumbbell bicep curl
Weeks two and four	Day one	Day two	Day three
	10-RM	10-RM	12-RM
	3 sets	*3 sets*	*3 sets*
	Barbell overhead squat	Prone DB external rotation	Leg press
	Dumbbell split squat	Dumbbell front raises	Bench press
	Seated cable row	Narrow-grip dips	Machine hamstring curl
	Knee extensions	Prone DB lateral raise	Swiss ball suspended row
	Lat pulldown	Cable triceps pushdown	Seated DB shoulder press
	Single-leg calf raise	Dumbbell lateral raises	DB bicep curls

Preseason

As alluded to previously, ‘preseason’ for team sports is termed as the period of supervised training prior to the start of the playing season when technical and tactical practices are concurrently scheduled. Accordingly, during this phase, physiological training must be planned in the context of the other training and practices players are required to perform. From this point of view, it is therefore vital that scheduling of training is carried out in collaboration with the coaching staff.

As suggested earlier, the classic linear format for training periodization still has application during the preseason phase of training for team sports. Depending on the length of the preseason in the particular sport, the initial part of preseason may be a continuation of the general preparation phase begun during the off-season period. The remainder of the preseason period will resemble the ‘special preparation phase’ in the classic model. Broadly, there will be a progressive increase in training intensity prescribed and correspondingly decreasing volume over the period. Training goals will show a sequential shift from hypertrophy/strength-endurance to strength and culminating in power-oriented phase prior to the start of the playing season.

A suggested amendment to the classic linear model during the preseason preparation phase for team sports athletes is to shorten the duration of the respective cycles (Hedrick, 2002b). The relative emphasis in terms of length and nature of each mesocycle will be determined by the requirements of the sport (Hedrick, 2002b). For example, in a sport that is reliant on lean body mass, the higher volume hypertrophy-oriented cycles will be relatively longer and will feature more prominently. Conversely, sports in which excessive hypertrophy is counterproductive will similarly favour strength and particularly power cycles.

A further suggested manipulation is to incorporate day-to-day variation, by varying prescribed RM loads during each respective training week. This allows variation on multiple levels – both within and between microcycles. Such an approach has been suggested to favour optimal training responses (Stone et al., 2000a). As such, the periodization of training intensity and volume during preseason will comprise elements of both linear and undulating periodization, featuring weekly variation in intensity and volume within an overall trend for progressively increasing intensity and decreasing volume over the wider period.

Selection of strength-training modes will similarly follow the sequential progression in training goals during each respective phase from general strength during the initial stages to power development and sport-specific strength at the culmination of the preseason training period (Wathen et al., 2000). Strength-training exercise selection will thus feature progressive introduction of speed-strength training modes and increasingly sport-specific exercises as the player advances through preseason training cycles. During the period when players are not required to participate in competitive matches, scheduling of weekly training during preseason should aim to take account of fitness

Table 8.2a Example preseason mesocycle for rugby union football

	Microcycle training parameters	Example whole-body workout	Lower-body workout
Hypertrophy 1		10-RM; 3 sets	12-RM; 4 sets
	Frequency: 4 per week: 2(1)* upper-body 1(2)* whole-body 1 assistance **Week 2 frequency in brackets*	Parallel back squat Incline DB bench press Barbell step up Swiss ball suspended-row Dumbbell split squat Wide-grip dips	Front squat Single-leg knee extension Barbell step up Single-leg good morning Dumbbell split squat
	Intensity: 8–12-RM (all lifts) Volume: 3–5 sets		Upper-body workout 8-RM; 5 sets
	Workout format: Circuit		Bench press Narrow-grip chins Standing DB shoulder-press Cable fly One-arm dumbbell row
	Rest: Short rest (<60sec) between lifts Core work (~2 mins) between (circuit) sets		
Strength/hypertrophy	Frequency: 5 per week: 2 whole-body 2 upper-body 1 shoulder maintenance	Example whole-body workout 7-RM; 3 sets	Upper-body workout 10-RM; 5 sets
	Intensity: 7–10-RM (all lifts) Volume: 3–5 sets	Jump squat Hammer-grip chins Push press Front squat Bench press Barbell step up	Incline DB bench press Barbell bench row Standing DB shoulder-press One-arm dumbbell row DB upright row Dumbbell bicep curl
	Workout format: Circuit		
	Rest: Short rest (<60sec) between lifts Core work (~2 mins) between (circuit) sets		

and fatigue effects. As such, the sessions that require the greatest neuromuscular co-ordination will be placed early in the week while the athletes are fresh, whereas the more fatiguing workouts are performed at the end of the week to allow the athlete the weekend to recover (Chiu and Barnes, 2003).

Metabolic conditioning will follow a progression from extensive to intensive conditioning – aerobic interval conditioning will feature early in preseason, whereas the latter part of the preseason will be characterized by anaerobic interval and repeated sprint conditioning. The format of metabolic conditioning may consist of a mixture of high-intensity interval training, tactical metabolic conditioning (TMT) drills, and skill-based conditioning games early in preseason. There will then be a shift to a greater emphasis on conditioning games later in preseason as training time is more restricted and there is a greater demand for technical and tactical practices.

Table 8.2b Example preseason mesocycle for rugby union football

Strength	**Frequency:** 4 per week: 2 whole-body 1 upper-body 1 shoulder maintenance	**Example whole-body workout** 6-RM; 3 sets	**Upper-body workout** 7-RM; 4 sets
	Intensity: 5–7-RM multi-joint lifts 8-RM assistance lifts **Volume:** 3–4 sets **Workout format:** 2×3-lift complexes **Rest:** Short rest (<60sec) between lifts Core work (~2 mins) between (complex) sets	Clean pull Bench press Push press Parallel back squat One-arm DB row DB overhead split squat	Alt arm incline DB Bench press Barbell bench row Wide-grip dips Standing DB Shoulder-press Hammer-grip chins
Power	**Frequency:** 3 per week 2 whole-body 1 upper-body	**Example whole-body workout** 5-RM; 3 sets	**Upper-body workout** 6-RM; 3 sets
	Intensity: 4–6-RM (all lifts) **Volume:** 3–4 sets **Workout format:** 2×3-lift complexes **Rest:** Complete rest between consecutive lifts Core work (~2 mins) between (complex) sets	Power clean Bench press Box skips Split jerk Barbell lateral step up Ballistic push up	Alt arm incline DB bench press Wide-grip chins Alt arm standing DB-shoulder press Bent-over barbell row Wide-grip dips
Peaking	**Frequency:** 3 per week 2 whole body 1 shoulder maintenance	**Example whole-body workout** 4-RM; 3 sets	**Shoulder workout** 6-RM; 3 sets
	Intensity 4–5-RM (all lifts) **Volume:** 3–4 sets **Workout format:** 2×3-lift complexes (whole body); Circuit (shoulder workout) **Rest:** Complete rest between consecutive lifts Core work (~2 mins) between (complex) sets	Stop clean Box-to-box drop jump Wide-grip chins Split jerk Lateral box skips Ballistic push up	Prone DB external-rotation Supine dumbbell pull-over Alternate arm cable-reverse fly Prone DB lateral raise Dumbbell empty can raise Dumbbell bent-over raise

The prescription of speed and agility work will vary depending on the training cycle. Early in preseason the focus will be on movement skill development. Frequency and intensity of speed and agility sessions will tend to increase as the player moves into strength- and power-oriented cycles during latter stages of preseason period.

In-season

Undulating 'non-linear' periodization models are typically suggested for in-season training (Wathen et al., 2000). The rationale for this is that this approach may be better suited to maintaining the athlete close to their peak throughout an extended season of regular competitions. The variation in training prescription within each training microcycle under this format also allows the strength and conditioning specialist to concurrently account for the multiple training goals that are a common feature of team sports during the playing season (Zatsiorsky and Kraemer, 2006).

It has been identified that average training intensity should be maintained above 80 per cent 1-RM, in order to maintain strength levels during the course of a playing season (Hoffman and Kang, 2003). Similarly, 2 days per week training frequency is often recommended for training during the competitive phase (Wathen et al., 2000). High loads ($\geq$80 per cent 1-RM, or $\geq$8-RM) are thus implemented 2 days per week for multi-joint lifts. This loading scheme is shown to maintain, or even increase strength levels throughout the playing season in American Football (Hoffman and Kang, 2003).

In accordance with this, the majority of strength and conditioning coaches in professional leagues typically report strength training twice per week in-season (Ebben and Blackard, 2001; Ebben et al., 2004; Ebben et al., 2005; Simenz et al., 2005). However, these recommendations for in-season training need not be excessively restrictive. A range of training frequencies and training parameters are possible that will maintain average training frequency and intensity within the ranges recommended. Players may train between one and three times per week at various times in the season. Likewise, a variety of intensity prescriptions may be used at different phases, whilst still maintaining average training intensity above 80 per cent 1-RM throughout the season.

Low volume/high intensity in-season programmes may not be sufficient to maintain lean body mass in power sports athletes – specifically American football players (Allerheiligen, 2003). A novel approach suggested for such team sports players who are reliant on strength and power involves multiple mini microcycles. This method comprises short (two-week) hypertrophy, strength, power, and peaking cycles performed in series (Allerheiligen, 2003). This (8-week) series can be repeated throughout the length of the playing season. Hence, this approach is essentially a condensed version of the traditional linear periodization format.

An alternative framework for in-season periodized training is the 'summated microcycles' approach (Plisk and Stone, 2003). Variations of this method

Table 8.3a Example 4-week (3:1) in-season summated microcycle for rugby union football

	Day one	Day two	Day three
Week one	7-RM; 3 sets	6-RM; 3 sets	7-RM; 3 sets
	Jump squat One arm incline DB-bench press Box skips Push press Bent-over barbell row Barbell lateral step up	Power clean Box-to-box drop jump Ballistic push up Split jerk lateral box skips Wide-grip chins	Cable external rotation DB empty can raise Alternate arm cable-reverse fly Cable diagonal pulley DB bent-over raise Straight-arm cable pulldown
Week two	6-RM; 3 sets	5-RM; 3 sets	7-RM; 3 sets
	Power clean One arm incline DB-bench press Box skips Push press Bent-over barbell row Barbell lateral step up	Stop clean Box-to-box drop jump Ballistic push up Split jerk Lateral box skips Wide-grip chins	Prone DB external-rotation DB full can raise Alternate arm cable-reverse fly Cable diagonal pulley Prone DB lateral-raise Straight-arm cable Pulldown
Week three	5-RM; 3 sets	4-RM; 3 sets	6-RM; 3 sets
	Stop clean One arm incline DB-bench press Box skips Split jerk Bent-over barbell row Barbell lateral step up	Stop split clean Box-to-box drop jump Ballistic push up Power clean + press Lateral box skips Wide-grip chins	Cable external rotation DB empty can raise Alternate arm cable-reverse fly Cable diagonal pulley DB bent-over raise Straight-arm cable Pulldown
Week four	4-RM; 3 sets	6-RM; 3 sets	
	Stop split clean Box-to-box drop jump Ballistic push up Split jerk Lateral box skips Wide-grip chins	Prone DB external-rotation DB full can raise Alternate arm cable-reverse fly Cable diagonal pulley Prone DB lateral-raise Straight-arm cable Pulldown	

have been successfully applied in both rugby union and rugby league football (Baker, 1998). This format involves a step-like increase in volume load (the product of training volume multiplied by training intensity) followed by a pronounced taper. Classically, the summated microcycles format operates around a 4-week cycle, with the final week of the 4-week cycle acting as an unloading week with considerably decreased volume load. This is designed to accommodate the time course of physiological processes underlying training adaptations and fatigue effects (Plisk and Stone, 2003). These cycles are repeated in series at greater or lesser relative intensities. This basic pattern can be repeated to create a wave-like pattern in lifting intensity and training volume.

This approach may also be adapted in order to tailor respective microcycles to the fixture list, by modifying the length of each summated cycle. Important matches and games against particularly strong opponents represent natural times to taper training in-season. Periods with many games concentrated into a short space of time likewise require reduced training frequency. Both these instances will necessitate an unloading week, in order to allow players to enter these matches in peak condition. Hence, depending on the timing of these games the summated microcycle may range from 2 to 4 weeks in length, always concluding with an unloading week. Microcycles may therefore feature a 1:1, 2:1, or 3:1 ratio of loading:unloading weeks. How these variations of in-season microcycles are sequenced into the in-season plan will depend on the fixture list and density of games in different periods within the season.

Table 8.3b Example 3-week (2:1) in-season summated microcycle for rugby union football

	Day one	Day two	Day three
	6-RM; 3 sets	**5-RM; 3 sets**	**7-RM; 3 sets**
Week one	Barbell snatch	Stop split clean	Prone DB external-rotation
	Split bounds	Box-to-box drop jump	DB full can raise
	Wide-grip chins	Ballistic push up	Alternate arm cable-reverse fly
	Split jerk	Power clean + press	Cable diagonal pulley
	One arm incline DB-bench press	Single-arm single-leg dumbbell-row	Prone DB lateral-raise
	Lateral box skips	Cable resisted lateral-cross-over lunge	Straight-arm cable pulldown
	5-RM; 3 sets	**4-RM; 3 sets**	**6-RM; 3 sets**
Week two	Barbell snatch	Stop split clean	Cable external rotation
	Split bounds	Box-to-box drop jump	DB empty can raise
	Wide-grip chins	Ballistic push up	Alternate arm cable-reverse fly
	Split jerk	Power clean + press	Cable diagonal pulley
	One arm incline DB-bench press	Single-arm single-leg-dumbbell-row	DB bent-over raise
	Lateral box skips	Cable resisted lateral-cross-over lunge	Straight-arm cable pulldown
	4-RM; 3 sets	**6-RM; 3 sets**	
Week three	Stop split clean	Prone DB external-rotation	
	Box-to-box drop jump	DB full can raise	
	Single-arm single-leg-dumbbell row	Alternate arm cable-reverse fly	
	Barbell snatch	Cable diagonal pulley	
	Split bounds	Prone DB lateral-raise	
	Cable resisted lateral-cross-over lunge	Straight-arm cable pulldown	

Conversely there will generally be opportunities during the season for more intensive strength training – such as during fixtures in lesser competitions, or mid-season breaks for international matches. In sports with an extended competitive season, such as is seen in European soccer and rugby leagues, this may be necessary to maintain physiological adaptations. This will tend to be the case particularly in collision sports that are reliant upon high levels of lean body mass, strength, and power. At appropriate times mid-season, mini (one-week) overload microcycles may therefore be implemented. Such overload weeks can be used for shock elevations in volume-load mid-season that may be necessary for team sports that fulfil the relevant criteria.

Weekly scheduling of workouts in-season is dictated by the dual need to allow the player to recover from the previous match and avoid excessive residual fatigue at the end of the week in preparation for the next game. This is true of all the variations of the in-season training cycles. Similarly, the strength and conditioning specialist must be prepared on any given day to revise the schedule and modify the session plan as is appropriate to the current status of the player.

For reasons of time-efficiency, metabolic conditioning in-season may be carried out almost exclusively in the form of skill-based conditioning games given that this conditioning mode offers concurrent tactical and skill practice (Gamble, 2007b). Similarly, during the season, plyometric training, may be integrated into strength-training sessions by employing complex training methods. Frequency and volume of plyometric training may be limited in-season on the basis that team practices as well as matches will also provide

Table 8.3c Example 2-week (1:1) in-season summated microcycle for rugby union football

	Day one	Day two	Day three
Week one	6-RM; 3 sets	5-RM; 3 sets	6-RM; 3 sets
	Barbell snatch Split bounds Wide-grip chins	Stop split clean Box-to-box drop jump Ballistic push up	Prone DB external-rotation DB full can raise Alternate arm cable-reverse fly Cable diagonal pulley Prone DB lateral-raise Straight-arm cable pulldown
	Split jerk One arm incline DB-bench press Lateral box skips	Power clean + press Single-arm single-leg-dumbbell row Cable resisted lateral-cross-over lunge	
Week two	5-RM; 3 sets	6-RM; 3 sets	
	Stop split clean Box-to-box drop jump Single-arm single-leg-Dumbbell row	Prone DB external-rotation DB full can raise Alternate arm cable-reverse fly Cable diagonal pulley Prone DB lateral-raise Straight-arm cable pulldown	
	Barbell snatch Split bounds Cable resisted lateral-cross-over lunge		

a plyometric training element (Hedrick, 2002). Dedicated speed and agility training sessions may be performed on weekly or biweekly in-season, as is allowed by the competition schedule (Wathen et al., 2000). Speed and agility sessions will likewise be highly game-related and incorporate a sports skill element.

CHAPTER 9

TRAINING FOR INJURY PREVENTION

INTRODUCTION

Sport-specific physical conditioning can favourably influence injury risk when playing team sports. One general protective effect is that appropriately conditioned players are more resistant to the neuromuscular fatigue that renders athletes susceptible to injury (Hawkins et al., 2001; Murphy et al., 2003; Verral et al., 2005). The importance of this is illustrated in the common trend in many sports for higher injury rates in the latter stages of matches when players are fatigued (Best et al., 2005; Brooks et al., 2005a; Hawkins and Fuller, 1999; Hawkins et al., 2001). Participating in a preseason conditioning programme was shown to reduce by more than half the injuries sustained by female high school soccer players during the subsequent season (Heidt et al., 2000). More sport-specific metabolic conditioning appears more effective in guarding against these negative effects of neuromuscular fatigue (Verral et al., 2005). In this way, the general protective effect of metabolic conditioning regarding injury risk exhibits specificity effects.

Strength training similarly serves a general protective effect in making the musculoskeletal system stronger and thereby more resistant to the stresses incurred during games (Kraemer and Fleck, 2005). The addition of strength training to the physical preparation of male collegiate soccer players was followed by an almost 50 per cent reduction in injury rates during subsequent playing seasons (Lehnhard et al., 1996). One aspect of this is that trained muscle is more resistant to the microtrauma caused by strenuous physical exertion and also recovers faster (Takarada, 2003). The protective 'anatomical adaptation' (Bompa, 2000) function of strength training also exhibits specificity, as it is restricted to the bones and connective tissues associated with the limbs and muscles employed during the training movement.

However, conventional training alone is not sufficient to address critical risk factors and neuromuscular control deficits identified for particular injuries. For example, a strength-training intervention in isolation had no significant impact upon the aberrant lower limb biomechanics that predispose female players to knee injury, despite significantly increasing strength levels (Herman et al., 2008). Targeted interventions have the potential to address such risk factors in order to specifically guard against certain injuries that team sports players may be exposed to. Specific neuromuscular and strength training can be employed to address the particular risk factors and injury mechanisms associated with a certain type of injury in the sport. A first step when prescribing sport-specific injury prevention training is therefore identifying the risk factors relevant to the particular sport and playing position, and the intrinsic risk factors that affect each individual player.

INJURY RISK FACTORS FOR TEAM SPORTS PLAYERS

Injury risk can be stratified into intrinsic risk factors associated with the individual player and extrinsic risk factors that concern the environment in which the player trains and competes (Arnason et al., 2004; Quarrie et al., 2001). A logical first step in designing injury prevention programmes is to identify both the intrinsic risk factors specific to the individual player and the extrinsic factors associated with competing in the sport (Murphy et al., 2003). Once predisposing factors and typical mechanisms for injury are identified, specific preventative measures can then be taken in order to address these intrinsic and extrinsic risk factors (Arnason et al., 2004; Bahr and Krosshaug, 2005).

Intrinsic injury risk factors

Profiling each individual player in the team offers a means to identify intrinsic risk factors. Relevant information will include age, ethnicity, gender, anthropometric characteristics, medical history (including previous and current injury status), training status, and a musculoskeletal assessment that includes dynamic tests of mobility and stability. For example, age can be a predictor of general injury risk (Murphy et al., 2003) – older players were reported to suffer higher frequency of injuries in a cohort of senior soccer players in Iceland (Arnason et al., 2004). Players of black ethnic origin are identified as being more prone to certain muscle injuries – particularly hamstring muscle strains (Woods et al., 2004). Team sports players with high body mass index are shown to be at greater risk for certain injuries, such as non-contact ankle sprains (McHugh et al., 2006).

Gender is a major intrinsic risk factor for team sports injuries: female players sustain a significantly greater number of lower limb injuries (Murphy et al., 2003). This female gender risk factor is particularly evident for knee injury – females are 2–10 times more likely to suffer anterior cruciate ligament (ACL) injury when participating in sport (Silvers and Mandelbaum, 2007). Examination of NCAA injury data shows that the rate of ACL injury among female collegiate soccer and basketball players has remained constant (and consistently higher than males) over recent years, whereas rates of ACL injury in male collegiate soccer have declined over the same period from 1990 to 2002 (Agel et al., 2005). This phenomenon of higher injury rates among female players endures despite considerable research attention and numerous injury prevention strategies designed to address the heightened risk of knee injury among female athletes.

Previous injury is identified as a key intrinsic risk factor that predisposes players to subsequent injury (Meeuwisse et al., 2003; Murphy et al., 2003; Quarrie et al., 2001). For example, senior soccer players who reported previous injuries were found to be 4–7 times more likely to suffer injury – particularly repeat incidence of a prior injury (Arnason et al., 2004). Inadequate rehabilitation and premature return to play following injury are similarly identified as intrinsic risk factors (Murphy et al., 2003). The consequences of reinjury also tend to be more severe in terms of days lost post-injury in comparison to new injuries (Brooks et al., 2005a; Brooks et al., 2005b).

Individual screening and functional assessment can identify intrinsic musculoskeletal risk factors (musculoskeletal and movement screening is covered in more detail in Chapter 2). Measures of joint laxity are associated with injury risk – higher levels of laxity indicative of mechanical instability are linked to increased injury incidence (Murphy et al., 2003). Muscle flexibility scores represent another intrinsic injury risk factor. The average preseason hamstring and quadriceps flexibility scores of soccer players who went on to sustain hamstring and quadriceps injury during the season were lower than those who remained injury-free (Witvrouw et al., 2003). A similar association between decreased scores on hip range of motion and subsequent incidence of adductor muscle strains in soccer players is also reported (Arnason et al., 2004). Imbalances in measures of strength and flexibility are also suggested to be associated with injury risk (Knapik et al., 1991).

Extrinsic injury risk factors

Environment-related extrinsic risk factors concern the characteristic demands of the sport and associated training, level of competition, equipment, environmental conditions, and the playing surface. The prevalence of certain types of injury tends to be characteristic of the particular sport. Players are also more likely to suffer injury during games than during practice (Murphy et al., 2003). Higher grades of competition within a particular sport are typically associated with greater incidence of injury in general, and also more frequent occurrence of specific injuries – such as ACL injury (Orchard et al., 2001).

Errors in training design and implementation also represent major extrinsic injury risk factors. For example, poor lifting technique and incorrect movement mechanics that expose musculoskeletal structures to excessive strain can be developed through inappropriate instruction and poor coaching. Similar training errors include poor strength-training design that creates muscle imbalances or exacerbates pre-existing ones. Likewise programming errors that impose excessive loading in terms of frequency or training volume can lead to non-functional overreaching which predisposes a player to overuse injury and injury due to residual neuromuscular fatigue.

Playing equipment may have a positive impact in terms of reducing contact injuries or negative impact. Negative examples include football shoes that increase shoe-surface traction in a way that resulted in a rise in ACL injuries (Lambson et al., 1996) and basketball shoes with air cells in the heel that were associated with four times greater incidence of ankle injuries, presumably by decreasing rearfoot stability (Mackay et al., 2001). Positive examples include the introduction of mandatory full-face masks in collegiate ice hockey that has served to reduce dramatically facial and dental injuries (Flik et al., 2005). Paradoxically, protective equipment may also lead to more aggressive play and risk-taking, which can in fact cause an increased number of injuries (Bahr and Krosshaug, 2005). The interaction between environmental conditions and the playing surface is an important factor from an injury risk viewpoint – particularly with respect to the effect of weather conditions on resistance between the playing surface and the sports shoe (Orchard et al., 2001).

Epidemiological studies reporting injury data for representative groups participating in a particular team sport offer a means to help identify the extrinsic risk factors associated with the sport. Participation in a team sport involves inherent risk that may also vary for different playing positions; in turn this will tend to be reflected in the particular injuries reported. Injury surveillance data therefore provides a useful source of information about the relative incidence of different types and sites of injury in the sport. Such data may also offer further insight into specific risks associated with different playing positions, relative risk of injury during training versus competition, and the frequency and types of injury common to different phases of play (Shankar et al., 2007).

REPRESENTATIVE INJURY DATA FOR SELECTED TEAM SPORTS

Baseball

The majority of injuries associated with baseball concern the shoulder complex; the typical injury mechanism is linked to repetitively performing the throwing motion during practices and games. Common injuries reported involve the rotator cuff musculature and onset is typically relatively insidious – hence, most are classed as overuse injuries (Mullaney et al., 2005). An apparent critical factor with respect to incidence of shoulder impingement injury is that there is appropriate balance between those muscles that act to hold the head of the humerus in the shoulder socket and the muscles that accelerate the throwing arm.

Potential for damage would appear to be increased by deterioration of sound throwing technique due to the effects of fatigue. That said, pitchers were found to be quite resistant to fatigue-related changes in pitching kinematics and kinetics during a simulated game under controlled conditions (Escamilla et al., 2007). A study assessing muscular fatigue reported that the collegiate and minor league pitchers examined were similarly resilient on a variety of upper and lower limb strength test measures with modest albeit statistically significant differences between pre-game and post-game force output scores (Mullaney et al., 2005). The lack of significant reduction in force output scores of the external rotator musculature found in this study may however have been a consequence of the fact that they contract in an eccentric fashion during the pitching action; and force output tends to be much better maintained with repeated eccentric muscle contractions.

Baseball pitchers often exhibit altered range of motion and strength ratios on their dominant (i.e. throwing arm) side compared to their non-dominant side. Specifically, a common finding is reduced range of motion in internal rotation accompanied with increased external rotation on the dominant versus non-dominant side (Mullaney et al., 2005). These changes in flexibility are mirrored by adaptations in muscular strength for these opposing movements. Pitchers commonly achieve higher force output in internal rotation but exhibit compromised external rotation force measured on their throwing arm in comparison to the contralateral side (Mullaney et al., 2005). Similarly, compromised strength scores are reported for specific tests of rotator cuff muscle strength – specifically supraspinatus – in these players.

A common complaint among young baseball players concerns damage to the epiphyseal cartilage at the head of the humerus (Sabick et al., 2005). A condition called ‘little league shoulder’, or sometimes termed humeral epiphysiolysis, is prevalent among young pitchers – essentially arising from repeated trauma to the growth plate at the neck of the humerus. Key factors in the incidence of this injury appear to be the combination of high rotational stresses and distraction forces during the throwing action and weakness of the developing musculoskeletal system (Sabick et al., 2005). It has been suggested that it is the torsional forces during throwing in particular which are likely to be the major cause of damage to the epiphysis, given that growth plates are less resilient to this type of loading.

Soccer

Available data indicate that an elite male soccer player can expect to sustain one performance-limiting injury each season (Junge and Dvorak, 2004). Senior players competing in the top two divisions in Iceland were reported to sustain 24.6 injuries per 1,000 player hours during matches and 2.1 injuries per 1,000 hours in training (Arnason et al., 2004). A study of four English professional soccer clubs reported injury incidence of 27.7 injuries per 1,000 player hours during matches and 3.4 injuries per 1,000 player hours for training (Hawkins and Fuller, 1999). The incidence of injury during both matches and training among youth players at the same English professional clubs was markedly higher – 37.2 and 4.1 injuries/1,000 player hours for matches and training respectively (Hawkins and Fuller, 1999).

Injuries commonly reported in soccer are lower limb – typically involving ankle and knee joints, and the thigh and calf musculature (Junge and Dvorak, 2004). Lower limb injuries comprised 82 per cent of all injuries during a season of competition in the senior elite leagues in Iceland (Arnason et al., 2004) and 87 per cent of all injuries in English professional soccer (Hawkins et al., 2001). In an earlier study of English professional soccer the most common sites of lower limb injuries were the thigh (23 per cent of total), ankle (17 per cent), knee (14 per cent), and lower leg (13 per cent) (Hawkins and Fuller, 1999). The majority of injuries observed were muscle strains (41 per cent of total injuries); sprains (20 per cent) and contusions (20 per cent) were the next most common types of injury.

A high incidence of muscle strains is reported in soccer: 8.4 injuries per 1,000 match hours and 0.8 injuries per 1,000 training hours were recorded during a season of competition at elite senior level in Iceland (Arnason et al., 2004). Due to the demands of the sport, soccer players are at particular risk for both hamstring (Verral et al., 2005) and adductor muscle injuries (Arnason et al., 2004; Nicholas and Tyler, 2002). Joint and ligament sprains are likewise relatively common – reported at 5.5 injuries per 1,000 match hours and 0.4 injuries per 1,000 training hours in Icelandic senior elite soccer, mostly involving knee or ankle (Arnason et al., 2004). Over three-quarters of knee ligament injuries recorded in English professional soccer were to the medial collateral ligament (MCL) (Hawkins and Fuller, 1999; Hawkins et al., 2001). However, severe knee ligament injuries in soccer most often involve the ACL (Arnason et al., 2004; Hawkins and Fuller, 1999).

On average, injuries reported in English professional soccer resulted in 24.2 days lost to training and competition (Hawkins et al., 2001). Around a third of injuries reportedly result from bodily contact with another player (Junge and Dvorak, 2004) – player contact was identified in 41 per cent of all injuries in English professional soccer (Hawkins and Fuller, 1999). Both senior professionals and youth players are also reported to sustain more injuries to their dominant leg – reflecting players' greater use of their dominant leg when tackling and being tackled (Hawkins and Fuller, 1999; Hawkins et al., 2001). Non-contact injuries are typically incurred when running or changing direction.

Studies of soccer players typically report a high incidence of reinjury; repeat injuries make up between a fifth and a quarter of all injuries sustained (Hawkins and Fuller, 1999; Junge and Dvorak, 2004). Such findings indicate that previous injury is a major risk factor for subsequent injury in soccer (Arnason et al., 2004). The severity of reinjuries with respect to time lost also tends to be greater than with the original injury (Hawkins et al., 2001). There is a suggestion that rehabilitation undertaken in elite-level soccer – particularly following ankle sprains and posterior thigh strains – is insufficient or incomplete (Hawkins and Fuller, 1999; Junge and Dvorak, 2004).

Training injuries in English professional soccer appear to peak in July, coinciding with the end of preseason training, whereas match injuries show a peak at the start of the playing season in August (Hawkins et al., 2001). This has led to suggestions that the content and effectiveness of preseason physical preparation and adherence to off-season maintenance training may be inadequate. Conversely, the number of injuries among youth players also tends to rise towards the end of the playing season (Hawkins and Fuller, 1999). In this case, cumulative fatigue associated with the burden of a large number of matches may play a role in the injury patterns observed with these young players.

Depending on the injury definition, overall injury rates for elite senior female soccer players appear to be similar to the corresponding data reported for males. Rates of 'traumatic' (as opposed to overuse) injury reported during matches in the German national league were 23.3/1,000 player hours during matches and 2.8/1,000 player hours during training (Faude et al., 2005). Reported match and training injury incidence among professional female soccer players in the United States were lower, possibly due to the different methods used in collecting injury data (Giza et al., 2005). The majority of injuries reported in elite senior women's soccer are lower limb – comprising between 60 per cent (Giza et al., 2005) and 80 per cent of total injuries (Faude et al., 2005). A study of female high school soccer players in the United States reported that all injuries sustained by 300 participating players (ages 14–18 years) during a season of play were to the lower limb (Heidt et al., 2000).

For the most part, injuries sustained by female soccer players appear evenly distributed between thigh, knee, and ankle (Faude et al., 2005) – however, a study of professional women's soccer in the United States has reported a relatively large number of head/facial injuries (Giza et al., 2005). Another study indicated that female soccer players may be prone to lower back injury (Nadler et al., 2002). This is supported by the surprisingly large number of back injuries reported by female players in the German national league (Faude et al., 2005). Women's soccer appears to involve a higher number of (lower limb) joint/ligament sprains but a lower proportion of muscle strains in comparison to men's soccer (Faude et al., 2005; Giza et al., 2005).

Another apparent difference is that injuries sustained by female soccer players are also more likely to be severe (Heidt et al., 2000). Of particular concern is the high incidence of ACL injury among female soccer players especially during matches – reported to be in the region of 0.90 (Giza et al., 2005) to 2.2 ACL injuries per 1,000 player match hours (Faude et al., 2005) in elite senior women's soccer. A review of NCAA injury data also revealed that female collegiate soccer players sustained significantly more ACL injuries than male collegiate soccer players (Agel et al., 2005). Furthermore a greater proportion of these ACL injuries sustained by female collegiate soccer players resulted from non-contact mechanisms compared to the corresponding data for male players.

Volleyball

The incidence of injury in volleyball is estimated at 4.1 injuries per 1,000 player hours during matches and 1.8 per 1,000 player hours during training (Verhagen et al., 2004). The majority of acute injuries reported in volleyball involve the lower limb and the most common type of injury is ligament strain.

Ankle was the reported site of injury in 41 out of the 100 injuries reported in male and female volleyball players during the course of a season in Holland (Verhagen et al., 2004) – ankle inversion sprains in particular are very common (Stasinopoulos, 2004). Nearly two-thirds of ankle sprains reportedly occur when players are at the net, sometimes due to contact with team mates or opponents upon landing (Verhagen et al., 2004).

In contrast to the data for men's volleyball, female volleyball players appear to suffer a similar number of injuries during practice and competition. Injury rates during NCAA competition in the United States although slightly greater (4.58 per 1,000 exposures) were not markedly higher than those during practice (4.1 injuries per 1,000 exposures) (Agel et al., 2007b). Ankle ligament sprains comprised 44.1 per cent of game injuries and 29.4 per cent of injuries during practice – the greater number of ankle injuries in games is partly due to the larger proportion of ankle injuries involving player contact during competition versus practice. Shoulder injuries are also quite commonly reported during games and practices in women's volleyball – particularly muscle/tendon strain injury (Agel et al., 2007b).

There appears to be a particular risk of reinjury following ankle sprains in volleyball (Verhagen et al., 2004) – a quarter of players reporting ankle injury had sustained an ankle injury during the preceding 12 months. Volleyball is also associated with particular overuse injuries – most often involving the shoulder or lower back, with knee injuries being the third most common overuse injury reported by volleyball players (Verhagen et al., 2004).

Elite volleyball players appear to exhibit various musculoskeletal issues associated with the shoulder on their dominant side, which are identified as risk factors for overuse shoulder injury (Wang and Cochrane, 2001). A study of elite volleyball players reported high incidence of a range of disorders, including: (dominant versus non-dominant side) muscular imbalance; restricted shoulder mobility; impaired eccentric strength; relative weakness in external rotation; and scapular asymmetry. Of these conditions, the imbalance between concentric internal rotator muscle strength and eccentric external rotator strength on the dominant side was shown to be significantly related with reported incidence of shoulder injury and pain in elite English volleyball players (Wang and Cochrane, 2001).

Another reportedly common condition among volleyball players is patellar tendinosis – a knee joint extensor overuse injury more commonly known as 'jumper's knee' (Gisslen et al., 2005). The incidence of this overuse injury is likely to be underestimated by injury surveillance studies, as players will tend to continue to play matches despite experiencing pain (Verhagen et al., 2004). 'jumper's knee' afflicts a large proportion of volleyball players over the course of their career and is even reported to be quite prevalent among elite junior players (Gisslen et al., 2005).

Basketball

A study of injury surveillance data from collegiate basketball in the United States reported the incidence of injuries during games to be 9.9 injuries per 1,000 athlete exposures during NCAA competition (Dick et al., 2007a). This is markedly higher than a study of men's intercollegiate basketball in Canada, which reported an overall injury rate of 4.94 injuries per 1,000 athlete exposures (Meeuwisse et al., 2003). This latter study also noted that injury rates for minor injuries (causing less than seven sessions to be missed) were similar between games and practices in Canadian collegiate competition, but the incidence of more severe injuries was 3.7 times higher during games than during practice. The rate of injury sustained reported during practices in NCAA competition is 4.3 per 1,000 athlete exposures (Dick et al., 2007a).

The majority of injuries in NCAA men's basketball involved the lower limb, with ankle ligament sprains comprising 26.2 per cent of game injuries and 26.8 per cent of practice injuries (Dick et al., 2007a). The ankle was also the most frequently reported site of injuries in Canadian collegiate basketball, but injuries to the knee resulted in the most time out of participation (Meeuwisse et al., 2003). Knee injuries similarly made up a substantial number of injuries (approximately 10 per cent of all game and practice injuries) reported in NCAA basketball – most commonly 'internal knee derangement' (ligament and/or cartilage injury) or patellar injuries (Dick et al., 2007a). Although not generally classed as a contact sport, a third of the injuries reported in Canadian intercollegiate basketball resulted from contact with another player (Meeuwisse et al., 2003). That said, ACL injuries in men's intercollegiate basketball are more commonly non-contact (Agel et al., 2005; Dick et al., 2007a). Most injuries were reported to occur in the 'key' area of the court and of all the playing positions, the most injuries were recorded by centres (Meeuwisse et al., 2003).

In women's basketball, knee injuries were reported to comprise up to 91 per cent of season-ending injuries (Ford et al., 2003). NCAA injury data spanning 1990–2002 reports that the rate of ACL injury was significantly higher for female collegiate basketball players than males (Agel et al., 2005). The majority (ranging from 64.3 per cent to 89.7 per cent of total depending on the year) of ACL injuries sustained by female collegiate players were the result of non-contact mechanisms. The lower back is the third most prevalent site of injury in women's basketball (Nadler et al., 2002).

American football

A recent and comprehensive injury surveillance study for American football reported an injury rate in high school and college football in the United States that is almost twice that of basketball (the second most popular sport among males in these age groups) (Shankar et al., 2007). This was supported by injury surveillance data from NCAA competition in the United States which reported 36 injuries per 1,000 athlete exposures for games – three and a half times the rate reported for NCAA men's basketball (Dick et al., 2007b). There was a greater relative injury incidence overall for collegiate versus high school football (Shankar et al., 2007). Unsurprisingly, a high incidence of contact injuries is reported – the majority being sustained when tackling or being tackled (Shankar et al., 2007).

The sites and types of injury appear to be broadly similar between high school and collegiate football. One study reported injuries to the knee (16.4 per cent of all injuries) were most common in collegiate football, followed by the shoulder (13.2 per cent of total) and then ankle (12.7 per cent) (Shankar et al., 2007). NCAA data indicated a similar pattern; however, ankle ranked as the second most common site of game injuries (Dick et al., 2007b). In high school football, knee (15.2 per cent of all injuries) and ankle (also 15.2 per cent of total) were the most frequent sites of injury, followed by the shoulder (12.4 per cent of total injuries). Concussions made up a significant number of game injuries in NCAA men's football (Dick et al., 2007b). There is similarly a high reported incidence of concussions in high school football (Shankar et al., 2007).

Competitive play accounts for considerably higher rate of injury than practice sessions at both high school (*circa* four times greater injury rate) and collegiate level (nearly eight times higher) (Shankar et al., 2007). Injury rates during practices for NCAA players was reported to be approximately 4 injuries per 1,000 athlete exposures for practice in the fall (autumn), whereas in spring practice, the rate was appreciably higher – approximately 10 injuries per 1,000 athlete exposures (Dick et al., 2007b). During games there are a lower proportion of muscle/tendon strains (high school: 10 per cent during games vs 24 per cent during practices; college: 14 per cent games versus 25 per cent practices) (Shankar et al., 2007). Conversely, a higher proportion of ligament sprains is reported during competitive play (high school: 33 per cent during games versus 29 per cent practices; college: 39 per cent games versus 25 per cent practices) (Shankar et al., 2007).

Most injuries during practice are ligament sprains and muscle/tendon strains, which jointly comprised 53 per cent of reported practice injuries in high school football and 50 per cent of total collegiate football practice injuries (Shankar et al., 2007). Injuries during practices in high school football are less severe, with a faster return to play than those sustained during competition. It has been identified that practices during the spring season have a two- or three-fold higher injury rate in collegiate football (Dick et al., 2007b), with a particular increase in the number in severe injuries (Albright et al., 2004). This appears to be a consequence of players striving to compete for selection for the upcoming fall (autumn) season. The same study noted that of all strings of players (in terms of ranking order for selection) the 'non-players' (those rated as unlikely to be selected) sustained by far the greatest number of injuries during practices (Albright et al., 2004). This is likely a reflection of their typical role as 'cannon fodder' during practices.

For both high school and collegiate football, running plays are reported to account for the greatest number of injuries during games (Shankar et al., 2007). Running plays are also reported to result in more severe injuries, with the greatest number of season-ending injuries occurring during running plays. In keeping with this, the most frequently injured playing positions reported in high school football are offensive linemen and running backs, and linebackers are the most injured defensive positions (Shankar et al., 2007). At collegiate level, although these playing positions continue to be among the most injured positions, wide receivers also have a similarly high incidence of injury (12.3 per cent of total injuries) to running backs (12.1 per cent of total). Regardless of playing level, running backs reported the highest incidence of ankle injury of any playing position (Shankar et al., 2007). The data for match injuries indicate that passing plays most commonly result in injuries to wide receivers (offence) and cornerbacks (defence) – unsurprising given the high involvement of these playing positions in such plays (Shankar et al., 2007).

Rugby union football

Due to the contact nature of the sport, rugby union football has a high reported incidence of injury. Risk of injury also appears to increase as players progress towards higher levels of competition (Quarrie et al., 2001). The most extensive epidemiological study to date in professional rugby union was undertaken in the United Kingdom, with full participation of all English Premiership clubs over two seasons (Brooks et al., 2005a). Overall incidence of injury during domestic matches was reported to be 91 injuries per 1,000 player-hours – considerably higher than is reported for other professional team sports. Incidence of injury reported at international level is higher still – 97.9 per 1,000 player-hours during the 2003 World Cup competition (Best et al., 2005).

Perhaps unsurprisingly, contact injuries comprise the majority of injuries recorded during match-play (72 per cent) in professional rugby union (Brooks et al., 2005a). This is similar to findings reported in elite junior rugby union in Australia (McManus and Cross, 2004). Forward positions (responsible for contesting possession) have a higher incidence of contact injuries due to their involvement in set-piece phases (scrum, line-out, and kick-off). Similarly, forwards sustain a higher number of contact injuries when contesting possession at rucks or mauls, whereas contact injuries sustained by the back positions are more typically 'tackle injuries' – i.e. they occur when tackling or being tackled (Brooks et al., 2005a). As a group, backs are reported to sustain a greater number of non-contact injuries during domestic senior professional matches – this was also reported to be the case in elite junior rugby union in Australia (McManus and Cross, 2004).

The lower limb is the most frequent site of injury in rugby union football, and the most frequently reported lower limb injury in professional domestic rugby is thigh haematoma (Brooks et al., 2005a), albeit the severity of such injuries was typically minor in terms of time lost. Hamstring injuries were the second most common injury during matches, reflecting their high incidence among players in the back positions. Knee injuries represent the most costly injuries in professional rugby union: the moderately high incidence of knee injuries combined with their high average severity accounts for the fact that these injuries result in the greatest number of days of absence from training and competition of any injury type (Brooks et al., 2005a; Dallalana, 2007). A high proportion of knee injuries reported in matches (72 per cent) are sustained during contact (Dallalana et al., 2007). Tackle situations – particularly being tackled – account for a large number of the ACL (72 per cent) and MCL (46 per cent) injuries that occur during matches. Shoulder injuries have the second highest average severity in terms of days of absence per injury (Brooks et al., 2005a) – reflecting that this is the typical site of impact when tackling opposing players (Gamble, 2004b).

The different playing positions in rugby union have designated and quite specialized roles during play, and as such there is a greater distinction between positions – for example, in comparison to rugby league (Gamble, 2004b). This is reflected in marked differences between individual playing positions in terms of type, incidence, and severity of injury sustained during matches (Brooks et al., 2005a). For example, fly half (back) and hooker (forward) positions reported the highest frequency of injury during domestic professional matches, whereas the most severe injuries tended to involve right locks and open-side flankers (forwards). Overall, the playing positions at most risk (in terms of both frequency and severity of injury reported) appear to be hooker (forward) and outside centre (back) in these domestic professional games. Data from international (2003 World Cup) competition indicated injury rates were highest for Number 8, open-side flanker (forwards) and outside centre (back) positions (Best et al., 2005). Similarly, the Number 8 and flanker positions were found to be the playing positions most at risk of injury in an elite junior rugby union squad competing in the Australian National Championships (McManus and Cross, 2004).

Unsurprisingly, there is a much lower relative incidence of injury reported in professional rugby union during training – regardless of the type of training (Brooks et al., 2005b). Conversely, the severity of training injuries in terms of days lost is greater than that for injuries sustained during matches. The majority of training injuries reported are lower limb and mainly comprise either muscle/tendon strains or ligament sprains. Contact skills practices involve the highest injury rate; however, running conditioning also accounts for a large proportion of training injuries and non-contact injuries comprise a higher percentage (57 per cent) of the total training injuries reported (Brooks et al., 2005b). Strength training shows the lowest injury rates of all training modes, albeit the greater number of lumbar disk/nerve root injuries reported by forwards (as compared to backs) are attributed to strength training (Brooks et al., 2005b).

Rugby league football

As is the case with rugby union, the majority of injuries sustained during matches in rugby league football are tackle injuries (Gabbett, 2004). The act of being tackled in particular is a leading cause of injury in senior professional rugby league, as it is in rugby union. At amateur level, tackling (as opposed to being tackled) appears to account for a greater proportion of the total injuries during matches – possibly due to lower levels of defensive skills (Gabbett, 2004).

Another finding in common with rugby union is that injury rates in rugby league increase at higher levels of competition (Gabbett, 2004).

The head and neck are the most common sites of injury reported during matches among rugby league players (Gabbett, 2004). Muscular injuries are the most common types of injuries during rugby league matches at all levels of competition.

Rugby league football has a lesser emphasis on set-piece phases of play and possession is not contested after each tackle is made; consequently, playing positions in rugby league are more homogeneous in comparison to rugby union. Even so, as a group the forward positions tend to make and receive more tackles during a match and this is reflected in higher overall incidence of injury among forwards compared to backs at all levels of competition (Gabbett, 2004).

Rugby league football studies also report that injury rates during training are much lower than in matches (Gabbett, 2004). The majority of reported training injuries sustained by rugby league players are lower limb, with most being muscle strains. This mirrors the findings reported in professional rugby union football. A study of rugby league players showed that the use of skill-based conditioning games may reduce the incidence of training injuries during conditioning activities – in comparison to traditional running-based conditioning without any game skills element (Gabbett, 2002).

Australian rules football

A study of the Australian Football League over three seasons (1997–2000) reported that the incidence of new injuries during matches was 25.7 injuries per 1,000 player hours (Orchard and Seward, 2002). There was also a high reported frequency of recurrence of previous injuries. The thigh was the most frequently reported site of injury in the Australian Football League; the most common injury type being muscle strains (Orchard and Seward, 2002). Hamstring muscle injuries are a particular concern for the sport (Verral et al., 2005), especially given the very high 34 per cent recurrence rate reported for this injury as compared to the 17 per cent overall recurrence rate for all injuries in this study.

Following hamstring muscle strains, ACL ligament sprains are the next most prevalent injury reported in the Australian Football League – the majority of which attributed to a non-contact mechanism (Orchard and Seward, 2002). The relative incidence of complete ACL tears during matches in the Australian Football League was reported to be 0.82 ACL injuries per 1,000 player match exposures and 0.62 injuries per 1,000 player match exposures for non-contact ACL tears specifically (Orchard et al., 2001). A history of ACL reconstruction was identified as a significant intrinsic risk factor for these injuries in Australian Rules football players. Extrinsic risk factors identified as affecting ACL injury incidence in Australian Football League matches included weather conditions over the period preceding a game. Specifically, 28-day evaporation values and rainfall over the year prior to the game were identified as influencing frequency of ACL tears – likely due to the associated impact upon shoe-playing surface traction when there were particularly dry pitch conditions (Orchard et al., 2001).

Ice hockey

A study of Division One collegiate men's ice hockey in the United States reported injury rates during matches as 13.8 per 1,000 player exposures and 2.2 per 1,000 player exposures during practice (Flik et al., 2005). The majority of injuries reported were attributed to contact – occurring during collisions with opponents (32.8 per cent of all injuries) or the perimeter boards surrounding the playing area (18.6 per cent of total injuries). The most common sites of injuries reported with these players were knee/leg (22 per cent of total), head (19 per cent of total), and shoulder (15 per cent) (Flik et al., 2005).

Concussion was the single most frequently reported injury in American collegiate men's ice hockey – representing 18.6 per cent of all reported injuries – the majority of which occurred during competitive matches (Flik et al., 2005). Illegal activity – specifically elbowing – was identified as being the cause of many concussions during games. Forwards sustained the most concussions – suffering twice the number of concussion injuries reported by defencemen (Flik et al., 2005). MCL strains were the second most frequently reported injury in the study – all of them occurring during games. Another frequently reported injury that is particularly severe in terms of time lost is syndesmotic or 'high ankle sprain' – an injury that appears to be much more common in ice hockey than other sports. This reported incidence of ankle syndesmotic sprain injury appears fairly evenly distributed between games and practices (Flik et al., 2005).

It has been reported that overall injury incidence did not appear to differ significantly between collegiate men's and women's ice hockey in Canada (Schick and Meeuwisse, 2003). However, the women's collegiate ice hockey players featured in the study had played far fewer games. When match data were compared, injury rates were significantly higher: 22.4 injuries per 1,000 match exposures for men versus 10.43 injuries per 1,000 match exposures for female collegiate ice hockey players (Schick and Meeuwisse, 2003). Injury surveillance data over four seasons following the start of NCAA women's ice hockey competition in the United States in 2001 reported 12.6 injuries per 1,000 athlete exposures in games, compared to 2.5 injuries per 1,000 athlete exposures during practices (Agel et al., 2007a). These data are broadly similar to the injury data previously reported for women's collegiate competition in Canada (Schick and Meeuwisse, 2003).

Female ice hockey has key differences in the playing rules: games are shorter in length and the rules prohibit intentional body checking. Despite this, the vast majority of injuries that were reported in female ice hockey (96 per cent of the total) were categorized as contact injuries (Schick and Meeuwisse, 2003). NCAA data mirrored this finding with approximately half of all injuries sustained during women's collegiate ice hockey involving player contact (Agel et al., 2007a). Even so, data from Canadian collegiate competition indicated the severity of injuries suffered in collegiate women's ice hockey was less in terms of time lost subsequent to injury – the male collegiate players in the study reportedly sustained a much higher number of injuries which were categorized as severe (resulting in more than fourteen missed sessions following injury) (Schick and Meeuwisse, 2003).

As is the case with male players, the most common injury in women's collegiate ice hockey in Canada was reported to be concussion; the next most common injuries were ankle sprains and adductor muscle strains (Schick and Meeuwisse, 2003). NCAA data were broadly similar – concussions being the most common injury (21.6 per cent of total injuries), with knee internal derangement (12.9 per cent of total) and shoulder – specifically acromioclavicular joint injury – (6.8 per cent of total) being the next common (Agel et al., 2007a). Canadian male collegiate players also suffered a number of facial injuries, which were not reported at all during collegiate women's ice hockey participation in Canada (Schick and Meeuwisse, 2003).

SPECIFIC STRENGTH AND NEUROMUSCULAR TRAINING FOR INJURY PREVENTION

In addition to players' routine strength training, particular strength and neuromuscular training exercises may also be prescribed to specifically guard against common injuries reported in the sport. This specific injury prevention role for strength training has not received the research attention it would appear to merit. Too often specific strength exercises are only prescribed for team sports players once an injury has already occurred (Wagner, 2003). Although there are a growing number of studies detailing injury data for different sports, there are very few that assess injury prevention strategies for sports. For example, despite soccer's status as the most popular sport in the world, a review of the literature pertaining to injury prevention for soccer players found only four relevant studies that met inclusion criteria (Olsen et al., 2004).

The process of specific training prescription should begin with a needs analysis of the particular sport, including research into the injuries commonly sustained during competition. After examining injury data for the sport, the injury history of each player and any ongoing injury concerns will then help highlight the specific needs of each individual. Such analysis of the sport, combined with an assessment of the individual, will identify what areas of the body are prone to what type of injury.

Once identified, the design of the injury prevention intervention programme should aim systematically to address risk factors for each specific injury identified for the sport and the athlete (Nicholas and Tyler, 2002). Such preventative measures can only be taken by first gaining an understanding of the causative factors and injury mechanisms that are characteristic of the particular injury (Bahr and Krosshaug, 2005). Such data for injuries that are representative of different team sports are increasingly available (Junge and Dvorak, 2004) – and these are summarized in the next section.

Risk factors and injury mechanisms for common sites of injury in team sports

Ankle complex

The lower leg is the most frequent site of injury in the majority of sports (Thacker et al., 2003). Ankle sprains comprise up to a third of all injuries sustained during participation in sports (Osborne and Rizzo Jr, 2003). Once injured, the risk of subsequent reinjury to the ankle is greatly increased (Osborne and Rizzo Jr, 2003). Elite and recreational basketball players with a history of ankle injury were reported to have a five times greater likelihood of sustaining an ankle injury (McKay et al., 2001). Collegiate American football players who had suffered previous ankle injury are similarly reported to suffer six times higher ankle injury incidence (Tyler et al., 2006).

Ligament laxity is commonly observed following ankle sprain injuries, which results in decreased mechanical stability provided to the ankle joint (Wikstrom et al., 2007). In addition to this reduced mechanical stability post injury, neuromuscular and proprioceptive function is frequently also impaired; the function of afferent sensors originating in the joint are often disrupted following ankle ligament injury (Lephart et al., 1998). A consequence of this interference in somatosensory feedback is that the player is less able to sense joint position and motion at the ankle joint. This disruption of proprioception and neural control post injury is termed ‘functional ankle instability’, and is characterized by deficits in balance and ‘dynamic stabilization’ – i.e. ability to go from movement to a static stance in a stable manner (such as landing from a jump) (Wikstrom et al., 2007).

Mechanical and functional instability of the ankle following injury is demonstrated by the observation that corrective taping or external bracing to provide added stability are effective in reducing subsequent injury incidence. External support in the form of strapping or ankle braces is, however, only effective in reducing injury in athletes who have previously sustained ankle sprains (Osborne and Rizzo Jr, 2003; Stasinopoulos, 2004). Furthermore, the protective effect of external support offered by bracing appears to diminish with recurrent exposure to ankle sprain injury. Volleyball players with four or more previous ankle sprains appear to experience no benefit from external ankle bracing (Stasinopoulos, 2004).

The first-time incidence of ankle injuries (for players without any history of lower limb joint injury) appears to be influenced by gender, with a trend for more ankle inversion sprains suffered by female high school and collegiate players (Beynnon et al., 2005). The female basketball players studied were reported to suffer a significantly greater number of first-time ankle inversion injuries than male basketball players. Among female players, the type of field team sport they participate in also appears to influence first-time incidence of ankle sprain injury: female basketball players report more first-time ankle sprains than female lacrosse players (Beynnon et al., 2005). This does not appear to be the case for male high school and collegiate players.

A large proportion of ankle inversion sprains in team sports are reported to occur when landing – particularly when landing involves contact with another player. In volleyball, a common injury mechanism is landing on the foot of a team-mate or opponent in the area proximal to the net (Verhagen et al., 2004). In the same way, landing – often onto the foot of another player – was reported to account for almost half the ankle injuries sustained by elite and recreational basketball players (McKay et al., 2001).

A common injury mechanism for non-contact ankle injuries is twisting/turning the ankle when changing direction (McKay et al., 2001). As a consequence of the associated impairment of mechanical and functional stability, players with previous ankle injury are more vulnerable to these injuries. The combination of high body mass index and a history of previous ankle injury appears to render players at further heightened risk of non-contact ankle injury. Collegiate American football players with both high body mass index and history of ankle injury are reported to be at 19 times greater risk compared to players with normal body mass index and no previous ankle injury (Tyler et al., 2006). The greater inertia of heavier players challenges their ability to control their own momentum during change-of-direction movements to a greater extent and increases forces exerted on the supporting foot and ankle. The interaction of these greater forces with the lingering mechanical and functional instability of the previously injured ankle can then place the player's capacity to dynamically stabilize the ankle closer to its failure limits (Tyler et al., 2006).

Although less common than lateral ankle sprain, syndesmotic or high ankle sprains comprise a considerable number of ankle injuries sustained in contact sports (Williams et al., 2007) – notably high incidence is reported in ice hockey (Flik et al., 2005). This injury involves the ligaments associated with the distal tibia and fibula. The classic injury mechanism for syndesmotic ankle sprain involves application of an external rotation force while the ankle is dorsiflexed and the foot is pronated – the key factor being that the talus is forcefully rotated with respect to the lower leg (Williams et al., 2007). Syndesmotic ankle sprains typically result in more time lost subsequent to injury in comparison to lateral inversion sprains. Particularly severe disruption of the ligaments (categorized as Grade III syndesmotic injury) can require surgical intervention. Lack of awareness has been identified as a factor in syndesmotic ankle sprain injuries being under-diagnosed until recently. Similarly, there is currently a lack of data regarding these injuries – particularly with regard to rehabilitation and prevention of syndesmotic ankle sprain injuries (Williams et al., 2007). From the limited studies that have been published, guidelines with respect to stages of treatment and rehabilitation do exist. There are currently no such guidelines for prevention strategies for this specific injury. In the absence of this it seems prudent to follow guidelines suggested for the final stage of rehabilitation, which includes strength and neuromuscular training similar to that employed to guard against lateral inversion sprain injuries.

Much of the increased risk of reinjury with ankle sprains is attributed to a loss in proprioceptive function associated with the injured ankle. In accordance with this, training to develop proprioception in the previously injured ankle is demonstrated to be effective in reducing the risk of reinjury (Osborne and

Rizzo Jr, 2003; Stasinopoulos, 2004). A targeted single-leg balance training intervention for high school football players deemed to be at high risk for non-contact ankle injury was successful in reducing injury rates to the extent that the injury risk factors of previous ankle injury history and high body mass index were entirely offset in these players (McHugh et al., 2007). A study of male soccer players with a history of previous ankle inversion injury reported that of the three preventive interventions studied (strength training for evertor muscles, external bracing, and proprioception training) only proprioceptive ankle disk training successfully reduced the rate of reinjury (Mohammadi et al., 2007). Training with a mini trampoline was reported to be equally effective as balance disk training for reducing postural sway indicative of functional ankle instability in recreational athletes with previous ankle sprain injury (Kidgell et al., 2007). Importantly, the protective effect of proprioceptive training appears to be maintained even with athletes with a previous history of numerous (more than three) ankle sprains, which does not appear to be the case with external bracing (Stasinopoulos, 2004).

Proprioceptive function and active stability provided by muscles of the lower leg appear to be key to guarding against ankle injury in athletes with or without previous history of ankle sprains. A training intervention that included balance board exercises reduced the incidence of ankle sprain injuries in male and female high school soccer and basketball players with a history of ankle sprains and a strong positive trend ($p = 0.059$) was also seen in those without prior ankle injury (McGuine and Keene, 2006).

In view of the fact that the majority of ankle injuries occur when landing or changing direction, appropriate movement skills instruction and training is also identified as a possible means of reducing ankle injuries (McKay et al., 2001). This may be particularly beneficial for players who have a history of ankle sprains, in view of the fact that post-injury athletes have a tendency to exhibit altered motor control strategies (Wikstrom et al., 2007). Retraining 'correct' movement mechanics would appear especially important for players

Figure 9.1 BOSU ball knee raise and head turn.

showing these signs of functional ankle instability. In support of this, an intervention that consisted solely of instruction and practice of jumping and landing technique was equally as effective at reducing injuries among female volleyball players as proprioceptive training and bracing (Stasinopoulos, 2004).

Knee

Knee injuries are among the most debilitating injuries team sports players are exposed to (Thacker et al., 2003). Of all injuries, knee injury – particularly to the ACL and MCL – is associated with the longest enforced absences from practice and competition (Thacker et al., 2003). In two-thirds of cases, complete ACL rupture is accompanied by damage to knee cartilage, causing further impairment of function and mechanical instability (Silvers and Mandelbaum, 2007). At their most severe, injuries to the knee can even be career ending – particularly in the case of ACL injury. Following reconstructive surgery to repair complete ACL rupture, long-term pathology is also often seen, including premature onset of osteoarthritis in later life (Silvers and Mandelbaum, 2007). Unlike ankle injuries for which external bracing has been shown to help reduce risk of repeat injury, prophylactic bracing for the knee has not been demonstrated to have any positive impact upon injury rates (Hewett et al., 2006a; Silvers and Mandelbaum, 2007). This underlines the importance of training interventions to address knee ligament injury risk.

Aside from injuries to the knee ligaments and joint cartilage, chronic overuse injuries associated with the patellar tendon are also common in jumping sports particularly. Incidence of patellar tendinitis (‘jumper’s knee’) is notably high among volleyball players (Gisslen et al., 2005). Although debilitating, players will often continue to train and compete whilst suffering symptoms of this overuse injury (Verhagen et al., 2004). Particularly serious cases can, however, be career threatening, and surgical intervention may be required (Kettunen et al., 2002). Risk factors for patellar tendonitis include reduced flexibility of the hamstring and quadriceps muscles, which is postulated to increase strain on the tendons (Witrouw et al., 2001). Muscular imbalances or reduced eccentric strength are also identified as potential risk factors. Neuromuscular control and poor lower limb biomechanics are similarly implicated with this injury. In the presence of some or all of these risk factors, high volumes of games and practices involving repetitive execution of a particular movement (classically jumping activities) can lead to a gradual and progressive onset of symptoms of patellar tendinitis.

A history of previous knee injury is a noted risk factor for suffering subsequent injuries. Post ACL injury, the knee often exhibits greater joint laxity (mechanical instability) and compromised joint proprioception (functional instability) – both of which can increase risk of subsequent injury (Murphy et al., 2003). Disruption of proprioceptive function appears to endure longer at smaller angles (15-degrees) of knee flexion (Lephart et al., 1998). The 12-month period following surgical ACL reconstruction appears a critical phase during which players are susceptible to repeat injuries to the same knee (Orchard et al., 2001). Conversely, beyond this period although players continue to be more prone to suffering another ACL injury, this risk concerns both the uninjured and previously reconstructed knee equally.

Team sports players are particularly liable to suffer injuries to the knee; these can occur with or without direct contact. In particular, ACL rupture commonly results from a non-contact injury mechanism (Chappell et al., 2002) – more than two-thirds of ACL injuries occur in the absence of direct physical contact from other players (Hewett et al., 1999; Hewett et al., 2006a). Non-contact knee injuries commonly occur when deceleration is combined with change of direction with the foot planted (Silvers and Mandelbaum, 2007). This risk is greater when landing or changing direction with the lower limb in a relatively extended position (Ford et al., 2003, Hewett et al., 2006a; Quatman et al., 2006). The elements of jumping, landing, and changing direction that feature in team sports therefore expose players to knee injury risk.

Collision sports such as football and rugby football have the added risk of contact knee injury. Players in these sports must perform multidirectional movements under resistance from opponents and also sustain direct impact during tackles – reflected in greater incidence of contact ACL injuries and MCL injuries in particular (Thacker et al., 2003). This factor is also illustrated by NCAA injury data reporting greater incidence of ACL injury in male collegiate lacrosse in comparison to soccer and basketball, which was attributed to the differing levels of direct physical contact permitted in these sports (Mihata et al., 2006).

Sidestep cutting movements are identified as increasing knee valgus and internal tibia moments of force and anterior loading on the knee (Kaila, 2007) – all of which place the ACL under strain. During sidestep cutting movements specifically, it is this valgus loading rather than anterior shear forces in a sagittal plane that is the more likely cause of ACL rupture – in view of the relative magnitude of strain involved (Silvers and Mandelbaum, 2007). These torsional forces and potential risk of ACL rupture are greater if the sidestep cutting manoeuvre is executed with the tibia internally rotated and/or the planted foot is in a pronated position (Silvers and Mandelbaum, 2007). Joint kinematics and associated loads are shown to differ considerably between unanticipated versus pre-planned sidestep cutting movements. Specifically, although knee flexion/extension moments do not appear to be markedly different, valgus and internal rotation moments of force at the knee joint were significantly greater during sidestep cutting movements initiated in reaction to an external cue (versus pre-planned) (Besier et al., 2001). The fact that players are unable to pre-plan postural adjustments under unanticipated conditions therefore results in altered lower limb kinematics and joint loads, which in turn pose greater potential risk of injury to both ACL and MCL (Besier et al., 2001). Team sports players are thus exposed to particular knee injury risk – for example, when performing evasive sidestep cutting manoeuvres to avoid opposing players (McLean et al., 2004).

It is widely documented that female players suffer significantly higher ACL injury incidence – between two and ten times greater reported incidence – depending on the sport (Silvers and Mandelbaum, 2007). This disparity between genders may in part originate in growth and maturation effects – given that such differences in ACL injury rates are not apparent prior to puberty (Hewett et al., 2006a). Various anatomical and biomechanical factors have been suggested to contribute to the higher knee injury rates demonstrated by adolescent and adult female team sports players (Ford et al., 2003; Noyes et al., 2005). A cadaveric study of mechanical properties of the human knee report that at low knee flexion angles the female knee possesses significantly less passive joint stiffness (25 per cent) under torsional loads and also greater joint laxity in rotation (28 per cent) compared to those of males (Hsu et al., 2006). This apparently inherent reduced mechanical stability of the knee joint in female players is often also compounded by adverse lower limb biomechanics. Specifically, female players are reported to have a greater tendency than males to execute athletic movements in an upright posture with the lower limb relatively extended and the upper leg in an inwardly rotated position, which places the knee joint in a less mechanically stable position (Leetun et al., 2004). This is reported to occur frequently in female athletes, particularly when landing or changing direction (Thacker et al., 2003). When studied during pre-planned sidestep cutting movements, it was noted that female subjects showed markedly different hip, knee, and ankle/foot joint angles and more variable knee rotation motion (McLean et al., 2004).

Deficiencies in neuromuscular control are also often implicated as exposing female players to greater knee injury risk (Hewett et al., 2005). Female athletes are more liable to exhibit 'ligament dominance' – i.e. in the absence of active muscular stabilization they are over-reliant on ligaments to support the lower limb joints (Ford et al., 2003). Neuromuscular recruitment patterns also appear to differ in females (Hewett et al., 2006a). For example, female players have a greater tendency for preferential recruitment of quadriceps over hamstrings; this phenomenon is known as 'quadriceps dominance' (Ford et al., 2003). The action of the quadriceps can increase anterior shear at the knee joint – in turn increasing strain on the ACL (Silvers and Mandelbaum, 2007). In contrast, the hamstrings compress the knee joint and oppose anterior shear forces during weight-bearing closed-chain movements; as a result of these functions, the hamstring muscle group is described as an 'ACL-agonist' (Hewett et al., 1999). This quadriceps-dominant muscle recruitment strategy is therefore potentially injurious to the ACL in female players. Similarly, differences in gastrocnemius recruitment during unanticipated sidestep cutting have also been reported between female and male adolescent soccer players (Landry et al., 2007). Activation of the gastrocnemius, particularly in combination with quadriceps activation, has the potential to increase strain on the ACL. Female players displayed both higher overall activation of the gastrocemius and an apparent imbalance in recruitment between medial and lateral gastrocnemius, with relatively greater activation of lateral gastrocnemius (Landry et al., 2007). There is also some suggestion that female players do not fully utilize their hip musculature both during landing and sidestep cutting – consequently, more force must be absorbed through the knee and ankle joints (Hewett et al., 2006a; Landry et al., 2007).

Such anatomical, biomechanical, and neuromuscular factors in combination with the frequent occurrence of landing and changes of direction during team sports help explain the significantly greater incidence of knee ligament injury seen with female team sports players (Hewett et al., 2005; Thacker et al., 2003). The focus of interventions to reduce risk of ACL injury of female players in particular – and team sports players in general – is increasingly placed on addressing biomechanical and neuromuscular risk factors via corrective training (McLean et al., 2004). Adjustments in movement mechanics, alongside strength development, have the potential to reduce torques imposed upon the knee ligaments (particularly ACL) when landing and during cutting movements (Myer et al., 2005). Factors such as degree of knee and hip flexion upon landing affect the ability of soft tissues to absorb joint loading and capacity of relevant muscles (such as hamstrings) to generate protective forces upon lower limb joints (Lephart et al., 2005). Reflex activation of the hamstrings originating from mechanoreceptors at the knee joint is identified as crucial to dynamic stabilization of the knee joint (Lephart et al., 1998), again reflecting the role of the hamstrings as an 'ACL-agonist' during weight-bearing closed-chain movements (Hewett et al., 1999). Dynamic stabilization of the knee is therefore dependent upon both lower limb proprioceptive function and the functional capacity of the hamstring muscles. Hence, in addition to proprioceptive training, specific strengthening of the hamstrings would also appear to be important for knee injury prevention. This is particularly relevant to female players for whom hamstring strength typically plateaus early in their development: it is reported that hamstring strength measures of older age groups (13–17 years) do not differ significantly from those of 11-year-old females (Barber-Westin et al., 2006).

Studies with male athletes are currently somewhat lacking but various neuromuscular training interventions have been shown to reduce incidence of ACL injury with female team sports players (Hewett et al., 1999; Mandelbaum et al., 2005). Successful interventions have comprised a range of training modes, including resistance training, plyometrics, proprioception, and movement skills training (Hewett et al., 2006b). Typically, effective training interventions for prevention of knee injury feature some combination of proprioceptive and neuromuscular or movement skills training (Silvers and Mandelbaum, 2007). An apparently important feature of this training was the inclusion of specific coaching with feedback regarding 'safe' versus 'unsafe' biomechanics (e.g. posture and lower limb alignment) for athletic movements (Hewett et al., 2006b). The inclusion of high-intensity plyometric training also often differentiates successful interventions from other studies that did not report significant reductions in ACL injury incidence (Hewett et al., 2006b). Strength training, in combination with other forms of neuromuscular training, is also a common feature of most (but not all) successful knee injury prevention protocols.

Indirect evidence in support of other forms of neuromuscular training as a means potentially to reduce knee injuries has been offered by studies reporting improvements in recognized knee injury risk factors – such as measures of neuromuscular control and lower limb biomechanics (Lephart et al., 2005). In particular, balance and single-leg stabilization training was shown to have beneficial impact on knee injury risk factors (Myer et al., 2006). Similarly, an integrated programme of neuromuscular training, strength training, plyometrics, speed work and balance training, and movement skills practice was successful in improving lower extremity mechanics of high school female team sports players during a drop jump test (Myer et al., 2005). It is

Figure 9.2 Low box single-leg knee/ankle flexion.

proposed that preventive training programmes should also include specific practice of sidestep cutting movements in reaction to external cues to provide appropriate neuromuscular training under unanticipated conditions, as occurs during match-play (Besier et al., 2001).

Muscle flexibility – particularly concerning hip flexors and extensors – appears important in the prevention of patellar tendonitis given the association found with reduced quadriceps and hamstrings flexibility scores and incidence of this injury (Witrouw et al., 2001).

Hamstrings

Hamstring injuries are one of the most prevalent injuries reported in team sports such as soccer, rugby football, and Australian rules football. An injury surveillance study of the English professional soccer leagues identified hamstring injury to be the single most frequent injury diagnosis (12 per cent of total injuries), with particularly high incidence in the Premier League (28 per cent of total) (Woods et al., 2004). Hamstring injuries in soccer were reported to most commonly occur whilst engaged in running activities. Data from professional rugby union in England support this observation: the majority of hamstring injuries were sustained when running, although those sustained whilst kicking

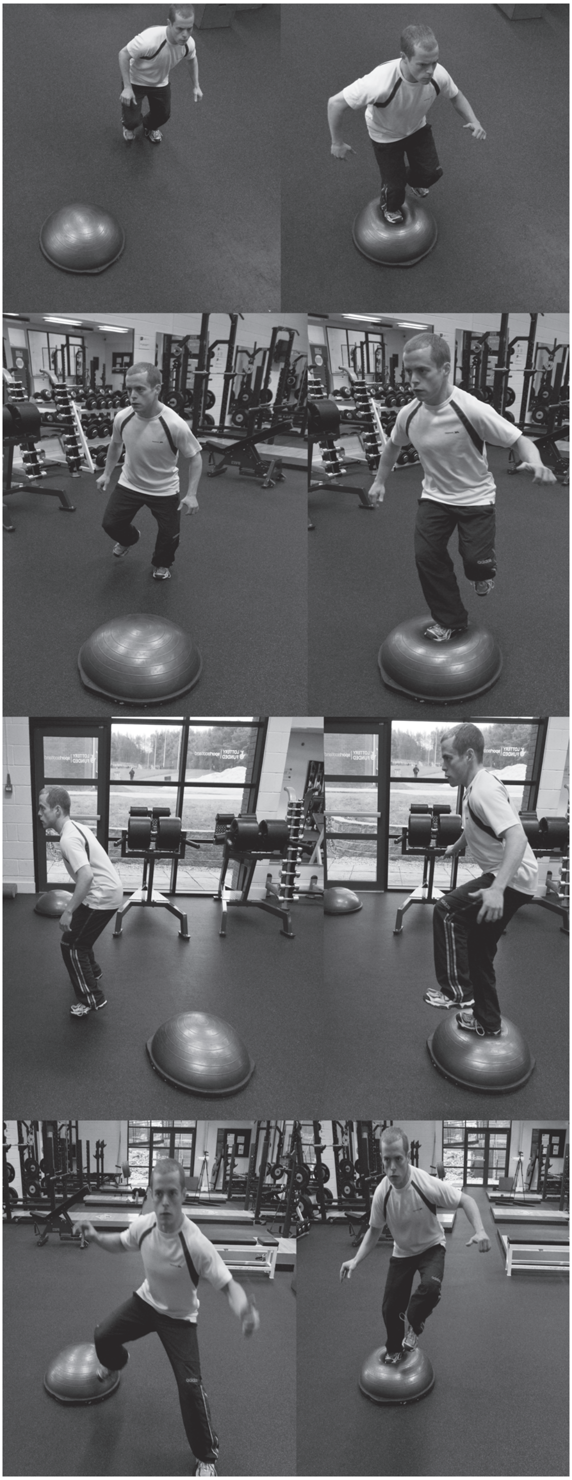

Figure 9.3 BOSU ball compass bounds.

are often the most severe (Brooks et al., 2006). Incidence of hamstring injury within a team sport is typically higher among playing positions that most frequently engage in high-speed running and change-of-direction activities. For example, in rugby union a higher incidence of hamstring injuries in matches (but not training) is reported for backs in comparison to the forward positions (Brooks et al., 2006).

The majority of hamstring injuries (53 per cent) reported in English professional soccer concerned the biceps femoris muscle (Woods et al., 2004). Commonly the site of hamstring strain injury is close to the muscle–tendon junction (Peterson and Holmich, 2005). The end of the swing phase is the point at which the player appears to be most prone to hamstring injury when running (Woods et al., 2004). This phase is marked by the transition between hamstring eccentric action to decelerate the leg to concentric action once the foot is planted and the hamstrings then work to drive the leg. It has been suggested that the hamstring muscle is most vulnerable to strain injury during this switch between eccentric and concentric action (Peterson and Holmich, 2005).

History of previous injury is a major risk factor for hamstring injury incidence (Verral et al., 2005). There is a high rate of reinjury reported with hamstring injuries in team sports – between 12 and 31 per cent depending on the sport and study (Peterson and Holmich, 2005). Furthermore, repeat injuries tend to be significantly more severe (Brooks et al., 2006). The first month following return to play appears a critical period – it was during this time interval that over half (59 per cent) of the total reinjuries were reported to occur in data from English professional rugby union (Brooks et al., 2006). It has been identified that there is a tendency for athletes with a history of recurrent hamstring injury to show marked strength deficits. These athletes often show reduced scores with their previously injured limb on a range of isokinetic measures (particularly eccentric scores and mixed concentric/eccentric ratio measures) compared to the healthy contralateral limb (Croisier et al., 2002). It has been demonstrated that these deficits can be offset via corrective training and doing so appeared to protect against sustaining further injury during a 12-month follow-up period (Croisier et al., 2002). Other authors have identified that the *optimal angle* – i.e. knee joint angle at which the highest isokinetic concentric knee flexor torque was recorded – is significantly different for the previously injured leg versus the healthy contralateral limb in athletes with a history of recurrent hamstring injury (Brockett et al., 2004). The clinical significance of this is still to be elucidated, but such a change in the previously injured muscle is likely to have consequences for function and injury risk.

Strength imbalances are implicated in the incidence of hamstring strain injury. Bilateral asymmetry (i.e. difference between dominant and non-dominant lower limb) between concentric and eccentric strength of both hamstrings and quadriceps, the ratio between quadriceps versus hamstring concentric strength scores, and a 'mixed ratio' of concentric quadriceps versus eccentric hamstring strength have all been used. A study of professional soccer players identified that imbalances in two or more of the isokinetic test measures listed above when measured during preseason was related to incidence of hamstring strain injury during the subsequent playing season if no corrective strength training was undertaken (Croisier et al., 2008). A sub group of the players identified as having a strength imbalance when tested at preseason did perform corrective strength training to normalize the relevant strength ratios. The rate of hamstring strain injury for these players was reduced to a level that was in line with players who exhibited no strength imbalance at baseline (Croisier et al., 2008). This finding supports the efficacy of corrective training to normalize strength imbalances in reducing hamstring injury risk.

Fatigue is a significant risk factor for hamstring injury (Verral et al., 2005). The rising incidence of hamstring injuries towards the end of the playing period is a scenario common to team sports including rugby football and soccer (Brooks et al., 2006; Woods et al., 2004), which strongly suggests a fatigue effect. The impact of residual fatigue is also evident in the observation that the incidence of hamstring injury during a match is reportedly greater when a higher volume of training was undertaken in the week preceding the match (Brooks et al., 2006). A fatigued muscle can sustain less loading whilst being stretched (Croisier 2004). This effect of fatigue on the ability of the muscle to absorb energy is complicated by the fact that the biceps femoris hamstring muscle receives dual innervation – from this arises the theoretical possibility of differential effects of fatigue within the same muscle (Croisier 2004). Parts of the muscle innervated from one source might be at a more advanced state of fatigue, hence operating with different contractile properties to other parts of the muscle. The high incidence of hamstring injury in team sports is believed to be in part due to the requirement to perform repeated bouts of high-intensity work during the course of extended playing periods (Verral et al., 2005).

Conversely, insufficient warm-up is implicated in the greater incidence of hamstring injuries among players entering the game as substitutes versus starting players, as has been reported in English professional rugby union (Brooks et al., 2006). A warm muscle also has distinctly different mechanical properties, particularly with regard to its viscoelasticity. Likewise, the type of warm-up undertaken – static stretching versus dynamic flexibility exercises – can also impact upon the function of the muscle (Bradley et al., 2007; Little and Williams, 2006a). The consensus in the literature is that dynamic flexibility exercises are the best option for use during warm-up, as they appear to prepare the player most effectively for athletic activity and have none of the detrimental effects on dynamic motor performance that some authors have identified with static stretching. Similarly, the occurrence of severe hamstring injuries immediately following the half-time break has led to suggestions that a further warm-up should be undertaken prior to the start of the second half (Brooks et al., 2006).

Lack of flexibility has been identified as a risk predisposing soccer players to hamstring muscle strains. Preseason hamstring flexibility scores of Belgian soccer players who went on to sustain hamstring muscle injury during the season were found to be significantly lower than those who did not suffer hamstring injury (Witvrouw et al., 2003). Furthermore, reduced hamstring flexibility has been identified in players following hamstring injury, which may contribute to the greater risk of reinjury (Croisier 2004). For this reason, flexibility training in the form of static and partner-assisted stretching does still have a role for team sports players – both for healthy players and as part of hamstring injury rehabilitation once the healing process is complete. However, stretching exercises may be best performed during a cool-down after games and training or as a stand-alone flexibility training session in order to avoid any potential adverse effects on performance.

Lumbopelvic posture and stability are also factors that can increase the strain on the hamstring muscles. Video analysis of hamstring injuries in Australian Rules football identified that a common injury mechanism is running with the trunk in a forward flexed position – either in the act of accelerating or reaching to pick up the ball (Verral et al., 2005). Similarly, if the player exhibits a lumbopelvic posture with the pelvis in an anteriorly tilted position, this can place the hamstrings in an elongated position – potentially imposing greater strain on the hamstring muscles (Croisier 2004). In the absence of effective lumbopelvic stabilization from postural muscles, the hamstring muscles must also work to help stabilize the pelvis whilst simultaneously fulfilling their locomotor function. This is not only inefficient use of locomotor muscles but also acceleration of the onset of fatigue: both of these factors can make the hamstrings more susceptible to injury.

Appropriate metabolic conditioning appears to have a particularly important role in the prevention of fatigue-related hamstring injury by developing fatigue-resistance (Verral et al., 2005). This is supported by a study demonstrating significant reductions in hamstring injury following a programme of preseason training incorporating sport-specific anaerobic interval training drills (Verral et al., 2005). The success of the training intervention in reducing hamstring injuries and number of games missed due to hamstring injury was attributed to the adoption of high-intensity sport-specific interval training in place of the submaximal aerobic training emphasis of previous seasons (Verral et al., 2005).

Sport-specific strength training also has a role to play in helping guard against hamstring injury. Developing muscular strength offers a means to extend the functional limits of the hamstrings, in order that there is extra force-generating capacity in reserve when the muscles' function is impaired by fatigue. Specific development of eccentric strength at extended hamstring muscle lengths has been recommended (Croisier et al., 2002). Some authors suggest eccentric strengthening exercises may be important during hamstring injury rehabilitation as a means of shifting the optimal angle in the injured muscle back towards pre-injury values in order to restore full function and guard against reinjury (Brockett et al., 2004). Improving eccentric strength for the closed kinetic chain movements that are encountered during games also appears to be important.

There is some suggestion that a proportion of posterior thigh injuries presenting clinically as hamstring strains in fact are of lumbar spine origin – as indicated by a negative MRI scan for hamstring muscle injury strain (Orchard et al., 2004). It is believed this a consequence of the L5-S1 nerve supply of the hamstring muscles (for the same reason, athletes may also present with calf muscle pain). Impingement or entrapment of the nerve root in the lumbar spine region may cause symptoms characteristic of muscle

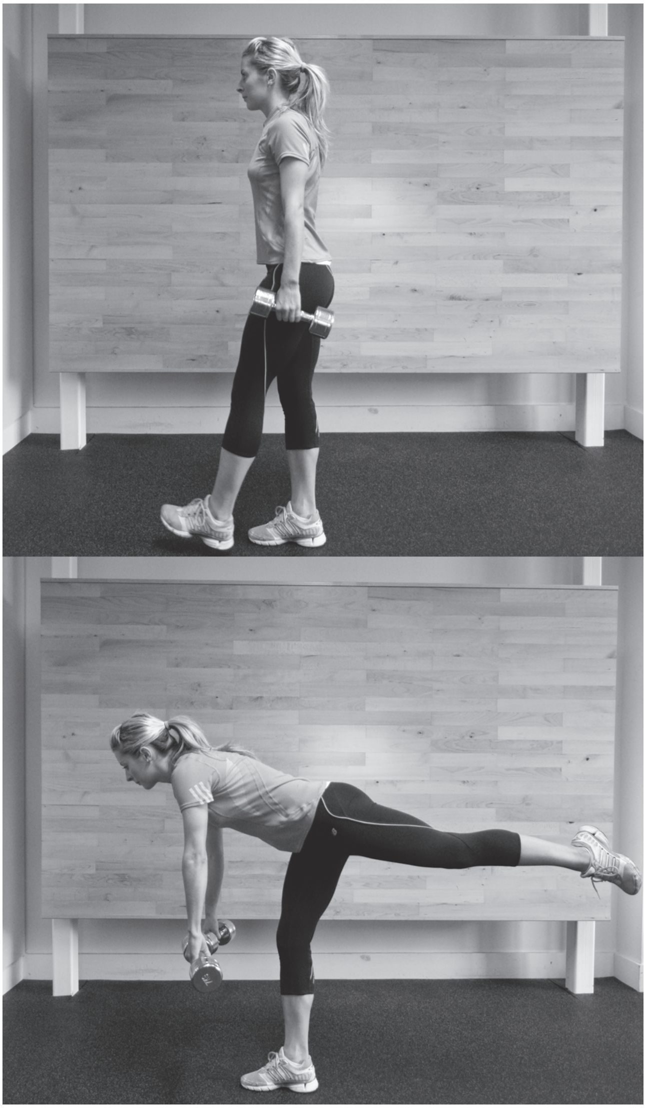

Figure 9.4 Single-leg dumbbell straight-legged deadlift.

injury (Orchard et al., 2004). Should this mechanism for 'lumbar spine-related hamstring injury' be proven, the lumbar region should be included in any training designed to protect the athlete against hamstring strain symptoms.

Adductors

Adductor or 'groin strain' injury is commonly reported in many team sports – in particular ice hockey, soccer, and Australian rules football (Maffey and

Emery, 2007; Nicholas and Tyler, 2002). A further complication with players presenting with groin pain is that medical staff, trainers, and coaches must also be vigilant for more serious conditions such as osteitis pubis and sports hernia (Lynch and Renstrom, 1999). Likewise, potentially serious medical conditions that can produce similar symptoms must also first be ruled out.

A common injury mechanism identified for adductor muscle injury with field sports players is sudden forceful external rotation of the hip whilst the upper leg is in an abducted position with the foot planted (O'Connor, 2004). The high incidence of adductor muscle injury is attributed to the elements of multidirectional acceleration and change of direction at high speed that are common to many team sports. The adductor muscles' role in stabilizing and decelerating the lower limb also involves a high degree of eccentric loading, and this has similarly been implicated in the high incidence of strain injury (Tyler et al., 2001).

Previous injury is a predisposing factor for subsequent adductor strain, with a high rate of reinjury reported (Maffey and Emery, 2007; Nicholas and Tyler, 2002). A study of professional ice hockey players reported that a history of previous injury within the preceding year was a significant risk factor for suffering further adductor muscle strain injury (Emery and Meeuwisse, 2001). Traditional passive methods of rehabilitation appear relatively ineffectual for treating groin pain – it has been identified that in order to be most effective, rehabilitation should feature active strengthening exercises to restore strength and function of the adductor muscles (Tyler et al., 2002).

Imbalance between adductor and abductor muscle strength measures is identified as a major risk factor for subsequent adductor muscle strain injury (Nicholas and Tyler, 2002). A study of a professional ice hockey team reported that if a player's preseason adductor strength test scores were less than 80 per cent of their strength scores for abduction, they had a significantly higher incidence of adductor muscle strain during the subsequent season (Tyler et al., 2001).

Similarly, players who start the season in a de-conditioned state appear more prone to suffering adductor strain injury (Maffey and Emery, 2007). Players who had failed to complete a certain number of off-season training sessions suffered a higher incidence of adductor muscle injuries when they reported to preseason training camp (Emery and Meeuwisse, 2001). The protective effect of sport-specific conditioning in reducing injury appeared to show a dose-response relationship – the more the training that players had performed, the lower the probability of injury (Emery and Meeuwisse, 2001). This suggests that fatigue is a risk factor for adductor strain injury, in much the same way as it is for hamstring strains.

Similar to the findings concerning hamstring injury risk, a relationship has been identified between impaired adductor muscle flexibility and risk of adductor muscle strain. Baseline scores of passive hip range of motion in abduction were found to be associated with subsequent incidence of adductor muscle injury in soccer players (Arnason et al., 2004). This association was not found in a study of professional ice hockey players, suggesting the influence of adductor muscle flexibility on injury risk may depend upon the sport (Tyler et al., 2001).

Deficits in lumbopelvic stability have also been identified as a risk factor for adductor strain injury (Maffey and Emery, 2007). In particular, impaired function of deep lumbar stabilizer muscles has been implicated in players with a long-term history of groin pain. Deficiencies in the way in which force is transmitted from the locomotor muscles to the torso as a result of suboptimal function of muscles that stabilize the pelvis and lower limb may expose the adductor muscles to injury risk (Maffey and Emery, 2007). In the presence of instability at the pelvis or lower limb mal-alignment the adductor muscles may try to compensate, thus placing them under additional strain (Lynch and Renstrom, 1999). For this reason, it is suggested that treatment for groin pain should include active strengthening for the hip and abdominal muscles that help provide lumbopelvic stability.

Targeted adductor muscle strengthening has shown to be effective in decreasing adductor strain injury incidence (Nicholas and Tyler, 2002). A pre-season strength-training programme for the adductor muscles significantly reduced the incidence of adductor muscle strains in the subsequent season, compared to injury rates from the previous season (Tyler et al., 2002). This is particularly important for players with an identified imbalance in their strength scores for adduction versus abduction (Tyler et al., 2001). Given that the adductor muscles are primarily employed in closed kinetic chain movements during competitive play, it follows that strength training for the adductors should similarly feature closed chain exercises.

Lumbar spine

After the ankle and knee, the lower back is commonly reported to be the third most common site of injury in sports (Nadler et al., 2000). This is particularly the case in female athletes – a study of injury incidence among NCAA collegiate athletes for the 1997–1998 season indicated almost twice the number of lower back injuries in females (Nadler et al., 2002). The mechanism for low back pain and injury is often cumulative; there may or may not be

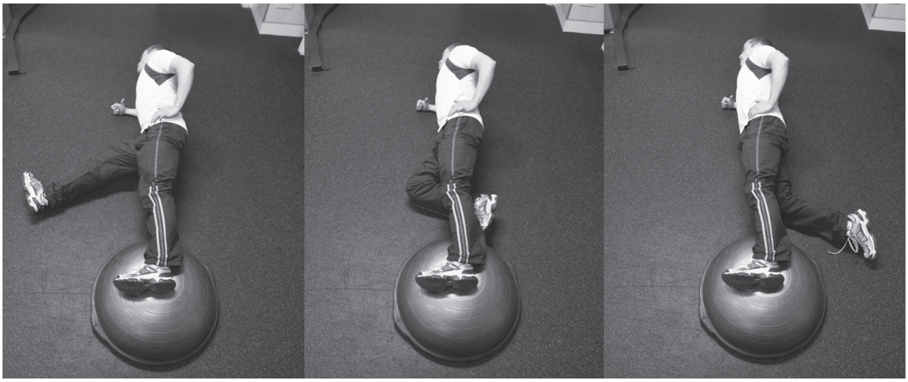

Figure 9.5 BOSU ball side bridge 'wipers'.

a single triggering event (McGill, 2007). Similarly a distinction must be made between acute back pain or injury and chronic conditions. Acute episodes of low back pain respond well to rest and treatment or even resolve spontaneously (Rogers, 2006). Conversely, chronic lower back problems (lasting longer than three months) do not respond to rest or passive therapies; in these cases, the consensus is that active approaches involving appropriate training interventions are most effective (Daneels et al., 2001).

The observation that when stripped of supporting musculature, a cadaver human spine will buckle under 20lb (≈9kg) of load illustrates the contribution made by the various supporting muscles in providing active spine stability (Barr et al., 2005). Low back pain is often accompanied by disrupted motor patterns of various stabilizing muscles (Rogers, 2006). A common finding is that deep lumbar spine stabilizer muscles are atrophied in individuals with chronic lower back pain (Barr et al., 2005). Importantly, this atrophy does appear to be reversible with appropriate training intervention, with associated improvements in low back pain symptoms (Hides et al., 2001). Individuals with chronic lower back pain also exhibit impaired neuromuscular feedback and delayed muscle reaction, which is accompanied by reduced capacity to sense the orientation of their spine and pelvis (Barr et al., 2005). There is some debate whether these functional deficits are primarily a cause or consequence of chronic low back pain (McGill, 2007).

Team sports players in particular have a need for both strength and endurance for the muscles that stabilize the spine in all three planes of motion (Barr et al., 2005; Leetun et al., 2004). Weakness or impairment at any point in this integrated system of support can lead to damage to structural tissues (ligament and articular structures), causing injury and pain (Barr et al., 2005). Imbalances in strength and endurance of flexors and extensors of the trunk have also been implicated as a risk factor for low back pain (Rogers, 2006). Endurance rather than absolute strength of trunk muscles has been identified as being the most decisive factor with regard to low back pain incidence (McGill, 2007). Fundamentally, the postural muscles are designed to operate isometrically to provide stability to the lumbar spine. Accordingly, training modes that incorporate a static hold are found to be most effective in eliciting gains in cross-sectional area of deep lumbar stabilizers (multifidus) in patients with chronic low back pain (Daneels et al., 2001).

The hip musculature serves a major role in all dynamic activities performed in an upright stance – these muscles are involved particularly in stabilizing the pelvis during single-leg stance and force transfer from lower limb(s) to the spine (Nadler et al., 2000). Impaired function of the hip extensors and hip abductors are observed with athletes who are suffering lower back pain (Nadler et al., 2002). Strength imbalances in these muscles are also implicated in lower back pain incidence, particularly in female athletes (Nadler et al., 2000). Correcting hip abductor strength imbalances via a core strengthening programme shows the potential to reduce subsequent lower back pain incidence (Nadler et al., 2002). Isometric hip external rotation strength was identified as the single best predictor of lower back and lower extremity injury incidence in collegiate athletes (Leetun et al., 2004). Despite this, the hip rotators are often overlooked in physical preparation. Inflexible or weak hip rotators can predispose the athlete to poor pelvic alignment; excessive lumbar spine motion can also occur in an attempt to compensate for impaired hip rotator function (Regan, 2000). Both of these factors can lead to pain and the incidence of lumbar spine injury.

A frequently overlooked aspect of injury prevention is neuromuscular and movement skills training to reinforce safe and spine-sparing postures and movement patterns. One key aspect of this is that motion of the torso should occur predominantly from the hips, rather than moving at the lumbar spine. When in a flexed position, the lumbar spine is less able to resist both compressive and shear forces (McGill, 2007). A neutral spine alignment is the most advantageous from the point of view of stability – maintaining this spine posture when performing athletic tasks therefore helps keep the lumbar spine within the tissues' failure limits. Adopting these 'safe' postures and movement strategies will not only spare the spine but also often facilitate superior athletic performance (McGill, 2007).

Specific training aimed at addressing the various functional deficits associated with low back pain and injury is likely to serve a protective function for athletes. This should include developing strength and particularly endurance of muscles that provide lumbopelvic stability, addressing hip muscle weakness and imbalances, and developing proprioceptive awareness of lumbar posture and positioning of the pelvis (Rogers, 2006). Lumbopelvic training should address all components that contribute to 'core stability' – including training for the deep lumbar stabilizers, hip muscles, and the various trunk and middle back muscles (Gamble, 2007a). Emphasis should be placed on coordinated function of these muscles in various positions – stabilizer muscles work in different combinations, depending on the posture and movement; a variety of exercises is therefore required (Axler and McGill, 1997). Progressions should also include exercises performed in standing postures and involving weight-bearing closed chain movements, in order to integrate the hip musculature and help develop balance and proprioception. Neuromuscular and movement skills training should be included that reinforces safe lumbar spine posture and emphasizes moving the torso from the hips (Barr et al., 2005; McGill, 2007). Maintaining function range of motion of muscles that cross the hip is key to allowing these movement strategies and postures to be adopted; it follows that flexibility training for the hip and lower limb is another important aspect of training to help prevent low back pain and injury.

Shoulder complex

As a consequence of the high degree of mobility of the shoulder joint, it is heavily reliant on dynamic (i.e. muscular) stability (Wagner, 2003). It follows that functional deficits in strength and proprioception and imbalances between stabilizing muscles will inevitably have major consequences for the stability and corresponding risk of injury to the shoulder complex. In collision sports – such as rugby football, American football, and ice hockey – injuries to the shoulder represent a leading cause of lost participation in training and matches. In professional rugby union in England the number of days lost to shoulder injuries was reportedly second only to knee injuries (Headey et al., 2007). Similarly, high incidence of shoulder injury is reported in American football: half of all elite collegiate players participating in the 2004 NFL Combine reported history of shoulder injury; and of these players, a third had previously undergone shoulder surgery (Kaplan et al., 2005). A study of ice hockey injuries in Finland likewise identified a high number of shoulder injuries among players of various ages, particularly those in the 20–24 and 25–29 age groups. The majority of the reported injuries (79 per cent) were the result of body checking or other collisions with players or the boards surrounding the ice rink (Molsa et al., 2003).

Contact shoulder injuries in collision sports most often occur during tackles. Accordingly playing positions with the greatest exposure to tackle situations generally and high-speed collisions in particular, typically report the highest incidence of shoulder injuries (Headey et al., 2007). Acromioclavicular (A-C) joint separations are the most commonly reported type of injury among elite collegiate American football players (Kaplan et al., 2005). Anterior instability is another common condition that was reported – predominantly affecting defensive positions among this sample of elite collegiate players (Kaplan et al., 2005). A study of English professional rugby also reported that the most common contact injuries sustained by players were A-C joint injuries (Headey et al., 2007). The most severe tackle injury involving the shoulder in English professional rugby union in terms of time lost subsequent to injury was shoulder dislocation (Headey et al., 2007). Rotator cuff tears and impingement injuries are also frequently reported among both English professional rugby players (Headey et al., 2007) and elite collegiate American football players (Kaplan et al., 2005). Rotator cuff tears appear to be most commonly sustained from direct impact on the shoulder as a result of a fall or collision with another player.

The incidence of shoulder injury in English professional rugby union football is reported to be highest in the final quarter of matches and during the latter stages of training sessions (Headey et al., 2007). This finding implies a fatigue element in the incidence of contact shoulder injuries in collision sports. It has also been proposed that repeated exposure to impact forces during collisions may lead to cumulative microtrauma, which in turn could potentially lead to impaired active and passive stability of the shoulder complex. Biochemical markers of muscle damage following a competitive rugby match showed that the degree of muscle damage was directly linked to the number of tackles each player had performed and sustained during the course of the match (Takarada, 2003). Such muscle damage results in short-term reductions in function, which are fully restored after a period (several days) of recovery. It therefore appears that coaches in collision sports must allow for this by scheduling adequate recovery time following competitive matches and contact skills practices to guard against cumulative damage that may decrease function and predispose the player to more serious shoulder injury. Training status also has a major effect on the degree of muscle damage following strenuous physical exertion – hence, appropriate physical preparation (including strength training and contact skills conditioning) also serves an important protective effect in limiting muscle damage and allowing players to recover more quickly (Takarada, 2003).

There is a high rate of reinjury reported with shoulder injuries – 27 per cent of all shoulder injuries reported in a study of professional rugby union in England were recurrences of previous injuries (Headey et al., 2007). Recurrent injuries were also more severe than new injuries in terms of time lost subsequent to the injury (Headey et al., 2007). This high rate of reinjury appears particularly evident with dislocation/instability injuries; these injuries were reported to have a 62 per cent recurrence rate among English professional rugby union players (Headey et al., 2007). It is likely this is a consequence of lasting instability following injury and associated difficulties in achieving effective injury rehabilitation in order to restore full function.

Shoulder injuries can also be prevalent in non-contact team sports – in particular, those that involve throwing and striking, such as volleyball. In the absence of corrective strength training, repeatedly performing ballistic throwing or striking movements during practice and competition can cause relative weakness in the opposing antagonist muscles (Behnke, 2001). The cumulative stresses placed upon those muscles that must work eccentrically to decelerate the humerus and stabilize the glenohumeral joint can result in injury. Reduced eccentric strength of external rotator muscles relative to the concentric strength of internal rotators shows a significant association with shoulder pain and injury in overhead sports players (Wang and Cochrane, 2001). Similarly, development of imbalances or relative weaknesses as a result of repetitious sports activity and eccentric overload can also lead to impaired sense of scapula position and control of scapula stabilizers (Wang and Cochrane, 2001). Such disruption in scapulohumeral rhythm (scapula movement and positioning in response to movement of the upper arm) can lead to glenohumeral joint instability (Brummitt and Meira, 2006). This is suggested to be a common mechanism leading to pain and injury particularly in overhead athletes (e.g. volleyball players) (Wang and Cochrane, 2001). Scapular stabilizers mainly comprise the middle back muscles – rhomboids, and middle and lower trapezius – and serratus anterior (Behnke, 2001; Brummitt and Meira, 2006).

Functional problems with the shoulder complex are not always a result of activity: poor posture can also place the scapulae (shoulder blades) in a protracted position. Errors in physical preparation can have a similar effect on scapula position: unbalanced development of anterior (particularly chest) muscles can result in the rounded shoulder posture. Strength training for the middle and lower back muscles (rhomboids, middle and lower trapezius) that retract the scapulae can serve an important role in correcting this. Appropriate exercises can strengthen these middle back muscles whilst actively stretching the shortened anterior muscles, helping to bring the resting position of the shoulder blades back towards the desired anatomical position.

The 'rotator cuff' is a functional unit made up of four individual muscles: supraspinatus, infraspinatus, subscapularis, and teres minor; each originates from different parts of the scapula and attach to the upper arm (Behnke, 2001). Each of the four rotator cuff muscles is activated to varying degrees depending on the position of the upper limb and the movement being performed (Decker et al., 2003; Takeda et al., 2002). As a unit, the rotator cuff muscles act to maintain the integrity of the shoulder joint; collectively, they function to hold the head of the humerus in its socket when the arm is held in different positions (Behnke, 2001). During ballistic actions, such as throwing or spiking a ball, the rotator cuff muscles act to accelerate the head of the humerus during the throwing action and brake the motion of the throwing arm after releasing or striking the ball to maintain its position in the shoulder socket (Behnke, 2001).

To prevent these non-contact overuse shoulder injuries, it is therefore key to maintain balance between the eccentric strength of muscles that act to decelerate the humerus and those muscles that work concentrically to produce internal rotation during throwing and spiking movements. In addition, the muscles that stabilize and control positioning of the scapula serve a critical role in controlling the position and orientation of the socket in which the head of the humerus sits, in order to maintain joint integrity and avoid impingement at the glenohumeral joint (Behnke, 2001). Targeted strength training would appear to be critical for players in a variety of team sports in order to develop strength specifically to prevent or correct imbalances between the muscles that act on the glenohumeral joint and stabilize the scapula (Wagner, 2003). Both strength and strength endurance should be addressed, in view of the observed influence of fatigue on shoulder injury incidence (Headey et al., 2007).

Assessing the strength ratio between internal and external rotators is a recommended starting point when addressing balance between muscles of the glenohumeral joint (Beneka et al., 2006). This assessment can be undertaken using an isokinetic device if available (Giannakopoulos et al., 2004) or dumbbells if not (Beneka et al., 2006); in either case, both internal and external rotators are assessed in a position with the upper-arm abducted at 90-degrees. Given that the external rotators act predominantly in an eccentric fashion when stabilizing the glenohumeral joint during throwing and striking movements, it follows that eccentric strength or torque measurements are most relevant for these muscles (Niederbracht et al., 2008). Strength ratio expressed between internal rotators' *concentric* strength versus *eccentric* strength of external rotators is therefore suggested to be more valid. Once identified, various modes of training may be used to address rotator cuff

Figure 9.6 Prone dumbbell external rotation.

muscle imbalances. Isolated exercises with dumbbells, isokinetic training and multi-joint upper-body strength training exercises all have application in improving external versus internal peak torque ratios (Malliou et al., 2004). As alluded to previously, improving eccentric strength scores of the external rotators in relation to concentric strength of the internal rotators would appear to be the more critical issue (Niederbracht et al., 2008). Concentric strength improvements of external rotators are not always shown in following injury prevention training interventions. However, regardless of any lack of changes in concentric torque, eccentric strength measures are shown to improve in response to specific strength training for the external rotator muscles (Niederbracht et al., 2008).

Figure 9.7 Prone dumbbell lateral raise.

Injury prevention strength-training exercise prescription must also address the stabilizer muscles associated with the scapula (Behnke, 2001; Wagner, 2003). To this end, appropriate strength-training exercises to offset scapula stabilizer imbalances and improve motor control of scapula position during movement should be included. A range of exercises have been recommended for scapula stabilization, including dumbbell and cable exercises (Brummitt and Meira, 2006).

The optimal approach taken to preventive strength training for the shoulder complex may be in part dependent on the profile of the player: if a particular imbalance has been identified, then isolated exercises to strengthen particular muscles appear warranted (Beneka et al., 2006). If no imbalance has been identified or pre-existing imbalances have been resolved, the use of more complex exercises has been advocated (Malliou et al., 2004). Such exercises allow muscles of the shoulder and upper limb to be recruited in a more integrated fashion (enabling sport-specific movements to be incorporated) and also facilitate greater gains in functional strength (Giannakopoulos et al., 2004). However, ongoing targeted strengthening for rotator cuff and scapula stabilizers should not be neglected for players in sports that are known to be particularly prone to shoulder injury (Gamble, 2004b).

For overhead striking (e.g. volleyball) and throwing sports (baseball, softball, team handball) in particular, flexibility training to offset characteristic changes in internal versus external rotation range of motion appears warranted (Lintner et al., 2007). The common profile of baseball pitchers is for them to exhibit reduced internal rotation at the shoulder alongside increased range in external rotation (Mullaney et al., 2005). This is believed to be a consequence of repeatedly performing the throwing action during practices and games, often spanning a period of many years. Whereas the increased external rotation

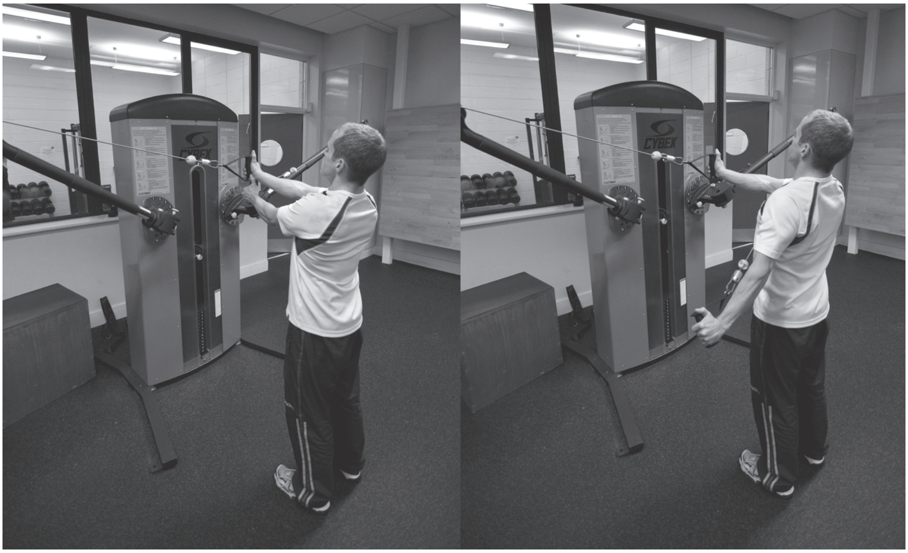

Figure 9.8 Alternate arm cable reverse fly.

Figure 9.9 Cable diagonal pulley.

appears to be a structural (i.e. bony) adaptation in the orientation of the humeral head and as such a relatively permanent adaptation, the reduction in internal rotation does appear to be modifiable. Professional baseball pitchers who had undertaken a programme of flexibility training targeted at addressing posterior capsule tightness over a prolonged period, scored significantly higher on internal rotation range of motion measured on their dominant (throwing) arm (Lintner et al., 2007).

Summary

Intrinsic risk factors have been described that can predispose a player to sustaining injury. As discussed, playing a given sport exposes players to conditions – 'extrinsic risk factors' – that may expose them to certain injuries. Epidemiological data have been summarized that detail the incidence and severity of injuries that are characteristic of participation in different team sports. When a player who exhibits intrinsic risk factors is then exposed to extrinsic risk factors by competing in a particular sport, all that remains is for a triggering event to take place for an injury to result (Bahr and Krosshaug, 2005). This triggering event pertains to the injury mechanism – typical injury mechanisms have been summarized for the injuries commonly identified in team sports.

Based upon this analysis, the next step is to design training interventions to address those of the above risk factors that are reversible and attempt to specifically guard against identified injury mechanisms. Such interventions have the dual aim of reducing overall injury incidence and reducing the severity of injuries sustained by players. Depending on the inciting event, some injuries – such as those resulting from contact with an opponent – are not avoidable; however, the severity of the damage that is sustained may be limited by prior preventative training (Bahr and Krosshaug, 2005).

CONCLUSIONS

The paucity of well-controlled injury studies make definitive recommendations with regard to evidence-based injury prevention training difficult – particularly in the case of muscle injuries such as hamstring strains (Peterson and Holmich, 2005). In the absence of such studies, it is necessary to rely upon what is known about specific injury mechanisms and relevant modifiable risk factors for the particular injury. Common themes include:

- addressing functional stability by improving proprioception and neuromuscular control;
- incorporating all parts of the lower limb kinetic chain – recognizing the role of the hip musculature in controlling lower limb alignment and absorbing landing forces (Hewett et al., 2006b);
- increasing muscle strength and correcting strength imbalances in order to increase mechanical stability provided to a joint;
- addressing muscle tightness and imbalances in mobility and flexibility via targeted flexibility training where deficits are identified.

In order to be most effective, the design of an injury prevention training intervention should not only be specific to the injury but also to the sport (Bahr and Krosshaug, 2005). Practically, this means that exercise prescription should favour exercises that reflect the specific conditions of the sport.

CHAPTER 10

PHYSICAL PREPARATION FOR YOUTH SPORTS

INTRODUCTION

Youth training requires a specific and quite different approach to design and implementation of physical preparation. As famously stated by Tudor Bompa, young people cannot merely be considered 'mini adults' (Bompa, 2000). The physiological makeup of children and adolescents is markedly different from that of mature adults (Naughton et al., 2000) – it follows that the parameters applied to training design should reflect these differences.

The young athlete's neural, hormonal, and cardiovascular systems develop with advances in biological age, leading to corresponding changes in neuromuscular and athletic performance (Quatman et al., 2006). Rates of development of a number of physiological and physical performance parameters measured in young team sports athletes are shown to peak at approximately the same time as they attain peak height velocity (Philippaerts et al., 2006). The age at which this occurs is highly individual; 'typical' ages are around 11.5 years for females (Barber-Westin et al., 2006) and for males in the range of 13.8–14.2 years (Philippaerts et al., 2006). However, this does vary considerably – levels of biological and physiological maturation can be markedly different between young athletes of the same chronological age (Bompa, 2000; Kraemer and Fleck, 2005).

What constitutes appropriate strength training and metabolic conditioning for young team sports players is therefore determined by, and is specific to, the individual player's stage of physical development. The phase of growth and maturation also influences the mechanism of training effects – such as whether improvements are predominantly mediated by neural factors, or if morphological and physiological adaptation play the greater role (Stratton et al., 2004). The emotional and psychological maturity of the individual is another important factor to be considered when designing and implementing training for youth sports players (Kraemer and Fleck, 2005; Stratton et al., 2004).

Another area of training for young athletes that has received less attention is neuromuscular training, including specific instruction and practice of fundamental movement mechanics. Neuromuscular and postural control as well as movement biomechanics for jumping, landing, running and changing direction can all be developed in the young team sports player as a means to improve athleticism. Such development of fundamental movement skills may also help reduce injury risk by equipping the young player to be better able to react to challenges in the game environment.

NEED FOR PHYSICAL PREPARATION WITH YOUNG TEAM SPORTS PLAYERS

A major public health concern is the sedentary behaviours and declining levels of physical activity of youth worldwide (Hills et al., 2007). Regular physical activity in combination with proper nutrition exerts a major influence upon growth and development in children and adolescents. From this perspective, appropriate physical preparation assumes increased importance in a young player's athletic development given the apparent lack of habitual physical activity elsewhere in their lifestyle. The absence of such a programme of physical preparation to help achieve a threshold level of physical activity may otherwise hinder young players' development during critical periods in their growth and maturation to the extent that they may not fulfil their genetic potential (Hills et al., 2007).

As a result of modern sedentary lifestyles, young people are also often not physically prepared for the rigours of youth sports (Faigenbaum and Schram, 2004; Kraemer and Fleck, 2005). Accordingly, the increase in participation in organized youth sports in North America has been accompanied by a dramatic rise in sport-related injuries (Goldberg et al., 2007; Kraemer and Fleck, 2005). It has not been documented whether the increase in number of injuries has been proportional to the increased numbers participating or whether there has been a relative increase in the rate of injury among these young players.

Whatever the case, approximately one-third of young athletes participating in organized sports in the United States sustain injuries requiring medical attention (Barber-Westin et al., 2005). Incidence of medical treatment for sports injuries peaks at ages 5–14 years and then progressively declines thereafter (Adirim and Cheng, 2003). The ankle and knee are the most frequent sites of injury reported in these young athletes (Adirim and Cheng, 2003; Barber-Westin et al., 2005). Youth sports players also appear to be at greater risk of low back pain and acute lumbar spine injury, particularly during adolescence (Kujala et al., 1996).

Inadequate physical preparation is believed to play a role in the majority of sport-related injuries in young athletes (Kraemer and Fleck, 2005). Conditions of muscle fatigue do place athletes at greater risk of injury: tired players in the latter stages of a game are more likely to sustain injury than when they are fresh. Likewise, players are more likely to be injured early in the season when their fitness levels are not up to standard (Thacker et al., 2003).

Physical preparation, which includes strength training in addition to training to develop cardiorespiratory fitness, is therefore an established part of strategy for prevention of sports injuries, including those in children and youth sports (Mackay et al., 2004). Inadequate motor skills are another factor identified as increasing youth sports injury risk (Adirim and Cheng, 2003). Again, these abilities may be developed via appropriate athletic preparation.

Injuries incurred during youth sports are a commonly cited reason for ceasing to participate in sport as an adult (Mackay et al., 2004). This has negative health implications given the established links between physical inactivity, obesity, and chronic disease in adulthood. From this perspective, prevention of injury in youth sports assumes increased importance, beyond merely enhancing young players' sports performance (Mackay et al., 2004).

'Overuse' injury incidence in youth sports

When organizing participation of adolescents in physical training and organized sports, it is important to recognize that young people are still growing (Bompa, 2000; Kraemer and Fleck, 2005). Coaches must consider the fact that the bones, muscles, and connective tissues of the young athlete are not yet fully developed. As such, high volumes of repetitive practice may render the young player susceptible to overuse injury. This dictates that there is a need not only for age-appropriate practice and competition schedules but also for young players' physical preparation to be designed to reflect their specific stage of growth and maturation.

Biomechanical factors seem to play a role in the incidence of overuse injuries with youth sports participation. The rapid changes in the size and length of limbs during growth spurts alter the mechanics of athletic movements (Hawkins and Metheny, 2001). As young players grow, this actually increases the forces and mechanical stresses involved in sports movements. When the young player is undergoing a growth spurt, particular care should be taken in view of the combined strain associated with rapid growth and physical stresses during competition and practices (Naughton et al., 2000). During this time, the immature skeleton may be more susceptible to injury than at later stages in the player's development – lumbar spine injuries particularly appear to increase in young adolescent athletes (Kujala et al., 1996). Growing cartilage is similarly more prone to injury in comparison to when the player reaches physical maturity, which can also be a factor in some overuse injuries (Adirim and Cheng, 2003).

Given time, muscles and connective tissues respond to accommodate these growth-related changes; however, there is a time lag before this adaptation takes place (Hawkins and Metheny, 2001). Under normal circumstances, connective tissues remain within their failure limits during this lag phase. However, during puberty in males particularly, there is a rapid increase in body mass and strength; tendon and ligament strength respond relatively slower than muscle. Consequently, these structures are closer to their failure limits in young players during this phase of maturation (Hawkins and Metheny, 2001). Repeatedly performing a given sports movement during this sensitive period in the young player's development can then lead to overuse injury.

The point of attachment of tendon to bone ('apophysis') is an area particularly prone to overuse injury in the growing player (Adirim and Cheng, 2003). Microtrauma injury – apophysitis – commonly occurs at the heel (Sever's disease) and the elbow ('little league Elbow') in younger children (ages 7–10). A similar condition – 'Osgood-Schlatter disease' – occurs at the insertion of the patella tendon and is often seen between ages 11 and 15 years (Adirim and Cheng, 2003).

In certain youth sports, there is a risk of overuse injuries simply due to the strains involved in repetitive performance of a particular sports skill movement during practices and games – such as in throwing sports. In the United States, it has been estimated that these overuse injuries make up approximately one-half of all sport-related injuries requiring medical treatment (Hawkins and Metheny, 2001). In an effort to combat this, some governing bodies suggest limits for the number of repetitions of particular sports movements (e.g. number of throws) that should be performed by the young player during a practice session (Hawkins and Metheny, 2001).

'Trainability' of young athletes

The scope for improvements in different aspects of fitness and motor performance varies as the young athlete passes through different stages of physical maturation. Rates of development of a number of physiological parameters appear to peak at around the same time as peak height velocity (stage of maximal growth in height) in young team sports players (Philippaerts et al., 2006). The age at which peak height velocity is attained varies considerably, but is reported to occur at around 11.5 years for females (Barber-Westin et al., 2006) and for males is in the range of 13.8–14.2 years (Philippaerts et al., 2006).

Preadolescents exhibit considerable potential for motor learning. Many authors state that complex motor skills are not mastered until ages 10–12 (Adirim and Cheng, 2003; Barber-Westin et al., 2006). It is suggested that there is a prime window of opportunity for motor development prior to puberty. Teaching basic movement mechanics for running, decelerating, and changing direction should form a fundamental part of training for all young players. Performing complex whole-body training exercises is advocated to enhance co-ordination and athleticism. Such training also develops kinaesthetic awareness and proprioception, making the young player better able to retain their balance under pressure from opponents and adjust to uneven terrain. Improving these functional abilities might therefore have a protective effect, helping to guard against injury (Faigenbaum and Schram, 2004).

Previously, the presumption had been that strength training prior to puberty was not viable or effective. However, it now appears that prepubescents exhibit significant scope for strength gains, far beyond those attributable to normal growth and maturation (Faigenbaum et al., 1996). Relative gains in strength documented with resistance training in prepubescent subjects are in fact of similar magnitude to those shown by adolescents (Faigenbaum et al., 1996).

That said, there are trends for greater absolute strength gains in adolescent subjects. Puberty triggers major physiological and hormonal changes (Naughton et al., 2000). Increases in circulating anabolic hormones during puberty impact considerably on how the young player responds to strength training – particularly the scope for tissue hypertrophy. This is the case especially among adolescent male players. However, the power per kilogram (body mass) that adolescents are capable of generating is still less than adults (Naughton et al., 2000).

During puberty, spontaneous growth-related improvements in motor performance and physiological parameters occur. A longitudinal study of youth soccer players showed that these natural gains may plateau during the interval prior to the young athlete reaching peak height velocity – performance may even decline during this period, as occurs with 30-m speed scores (Philippaerts et al., 2006). Once the player reaches the age when peak height velocity is attained, several of these natural gains in physiological and motor performance scores appear to reach their peak rate of development. In the following 12–18 months after peak height velocity, declining rates of growth-related improvements are then observed in several parameters (Philippaerts et al., 2006). Hence, scores in motor performance (in the absence of training interventions) appear to plateau at the end of this phase of development in youth sports players.

Changes in both musculoskeletal and cardiorespiratory systems during and following puberty have major implications for metabolic conditioning (Naughton et al., 2000). There are marked differences between prepubescent and adolescent players in terms of responsiveness to anaerobic and aerobic training. Both children and adolescents exhibit gains in cardiorespiratory fitness with aerobic training (Naughton et al., 2000). However, significant gains can be made particularly during puberty in young players as they reach peak height velocity (around 14 years of age in boys, 12 years in girls), partly due to aforementioned maturation effects (Philippaerts et al., 2006). During puberty, the responsiveness of young players for anaerobic exercise progressively increases (Naughton et al., 2000). Prior to puberty, young athletes have very limited capacity for this type of training. The rate of maturation-related improvements in anaerobic capacity during puberty peaks around peak height velocity, but natural gains do continue thereafter (Philippaerts et al., 2006).

TRAINING TO BUILD A FOUNDATION OF ATHLETICISM FOR YOUNG TEAM SPORTS PLAYERS

Given the growing awareness of ‘sport-specific training methods’ among coaches, parents and the young players themselves there is often a pressure to solely prescribe training that mimics the chosen sport in which the young player participates. One of the most important recommendations from authorities on youth training is that during all stages of development, the young player should perform a range of sports and training activities to facilitate overall athletic development (Bompa, 2000). It is advocated that the young player should only specialize in terms of sport and playing position as they advance into late adolescence – much the same applies in terms of physical preparation.

Gray Cook describes a pyramid model for the abilities that comprise athleticism (Cook, 2003a). The base layer of the athleticism 'pyramid' consists of 'mobility and stability': mobility being active range of motion for functional movements; stability being the ability to maintain posture and balance during athletic movement. The next layer up in the athleticism pyramid could be described as 'functional movement' – all sports and athletic events feature fundamental movements in some combination, which include squatting/lifting, pushing/pulling, lunging, locomotion (e.g. running), and twisting (McGill, 2004). The top layer of the athleticism pyramid is 'functional skill'. This can be viewed in terms of sport-specific strength and movement skill training.

This pyramid model for athletic development can be applied to youth training. Logically, training to build young athletes should begin at the foundation of the athleticism pyramid and build upwards. It follows that development of mobility and stability is therefore the first priority when training young players. In turn, these qualities underpin the player's ability to perform fundamental movements that are common to all sports. As Cook states: 'Fundamental movement supports specific movement' (Cook, 2003a). That is, players' fundamental movement abilities will determine their ability to perform sport-specific movements. As such, there is little point in trying to impose sport-specific training upon deficient fundamental movement capabilities. It follows that training activities at this stage of the athlete's physical preparation should predominantly feature fundamental athletic movements. Exercise selection can then progressively shift to sport-specific movements with advances in the athlete's physical development.

Neuromuscular and movement skills training

As discussed above, mobility and stability are major training goals in order to build the foundation of athleticism in the young player. Neuromuscular training interventions often comprise dynamic stability and balance training exercises (Myer et al., 2006). These forms of neuromuscular training offer a means for development of whole body balance and postural control (Yaggie and Campbell, 2006), which underpin stability. Functional movement abilities – the next tier up in the athleticism pyramid – can likewise be developed via appropriate movement skills instruction and training (Myer et al., 2006).

Prepubescent athletes exhibit lower levels of mechanical efficiency compared to adolescents. Although this improves as the young athlete progresses through puberty, adolescent athletes still exhibit lower mechanical efficiency than adults (Naughton et al., 2000). It follows that there is considerable scope for this aspect of performance to be improved via specific instruction and practice. Exercise economy has been identified as an area for development in young athletes (Naughton et al., 2000) – allowing the young player to sustain a higher relative work rate throughout the course of a match.

There is some evidence to support the potential of neuromuscular training to improve athletic performance in young players. Jump training incorporating specific instruction and training of proper movement mechanics was shown to improve vertical jump as well as movement biomechanics in high school female athletes (Myer et al., 2005). A neuromuscular training intervention significantly improved lower limb alignment – reduced knee valgus angles – in young female athletes (Noyes et al., 2005). Similarly, balance training improved shuttle run agility performance in a mixed gender recreationally active training group (Yaggie and Campbell, 2006). Dynamic balance training is also shown to significantly reduce impact forces upon landing in adolescent female team sports players (Myer et al., 2006). The neuromuscular control capacities that allow an athlete to dissipate impact forces and maintain proper lower limb alignment have been identified as key factors in reducing players' relative risk of injury (Quatman et al., 2006). Both forms of neuromuscular training described above may thereby help guard against injuries via different mechanisms.

It has been identified that prepubescent athletes have a tendency to exhibit neuromuscular control deficits – in particular, valgus hip/knee/ankle alignment during jump-landing tasks (Barber-Westin et al., 2005). This is indicative of impaired ability to control lower limb joint motion, particularly at the knee – and as such is associated with increased injury risk (Ford et al., 2003). Training to specifically improve lower limb neuromuscular control would therefore appear important in order to correct the potentially injurious lower limb alignment when it is observed in these prepubescent team sports players.

Young females in particular showed these traits (Barber-Westin et al., 2005). Neuromuscular control issues may contribute to making female athletes 'ligament dominant'. Specifically, as a result of inadequate active muscular stabilization, females can have a greater reliance on ligamentous support to assist in stabilizing lower limb joints – subjecting these ligaments to greater strain (Ford et al., 2003). In combination with anatomical factors, including hypermobility and joint laxity of lower limb joints, this can make females more prone to lower limb ligament injury in comparison to males. Females appear to exhibit valgus knee motion to a greater extent on their dominant leg (Ford et al., 2003). Such side-to-side imbalances in neuromuscular control and co-ordination represent another risk factor for injury.

As males pass through puberty, they undergo a 'neuromuscular spurt'. Accompanied by limb growth and favourable changes in body composition (increased muscle mass relative to fat mass), these natural gains in strength and neuromuscular performance bring about a natural improvement in male players' biomechanics during movement (Quatman et al., 2006). One observed aspect of this improvement is an enhanced ability to dissipate ground reaction forces upon landing. These landing impact forces in turn directly influence the loading absorbed through lower limb joints (Hewett et al., 1999). This 'neuromuscular spurt' phenomenon does not occur in females. The lack of any marked improvement in neuromuscular power and control – in combination with limb growth and body mass gains – can in fact reduce lower limb stability in adolescent females (Quatman et al., 2006).

Certainly female players continue to have a tendency to exhibit potentially injurious lower limb alignment and movement mechanics as adolescents (Barber-Westin et al., 2006; Quatman et al., 2006). In the absence of neuromuscular training, female players also have a tendency to preferentially recruit the quadriceps over the hamstring muscles during activity; known as 'quadriceps dominance' (Ford et al., 2003). Such biomechanical factors and aberrant recruitment patterns are implicated in the gender differences in rates of ACL injury post-puberty, which is not seen before this stage of development. Various studies report adolescent female players to have between 2–10 times greater incidence of ACL injury compared to male players, depending on the sport (Goldberg et al., 2007).

Neuromuscular training to address these issues therefore remains a priority for adolescent female players (Barber-Westin et al., 2005; Quatman et al., 2006). There are numerous studies supporting the capacity of neuromuscular training to offset this increased knee injury risk. Following a neuromuscular training intervention, the knee injury incidence rates of high school female team sports players were reduced to a level in line with that of the untrained male athletes studied (Hewett et al., 1999). The rates of knee injury among these adolescent female players post-intervention were nearly four times lower than the untrained female players participating in the study.

Recent studies show that post-pubescent male athletes may also continue to exhibit valgus lower limb alignment during drop landing tasks, despite markedly increased lower limb strength levels (Barber-Westin et al., 2006; Noyes et al., 2005). It follows that appropriate screening and neuromuscular training should therefore also not be neglected with adolescent male team sports players. The continuing need for neuromuscular training in males during adolescence is also apparent in view of the rapid gains in body mass and strength in males particularly characteristic of this stage of their physical development. In prepubescent players, such neuromuscular control issues and injurious lower limb alignment is offset by their lower body mass and movement velocity (Barber-Westin et al., 2006). In contrast, adolescent players are much heavier and generate greater forces and movement speeds – markedly increasing imposed stresses as a result of adolescent players' greater inertia and momentum (Barber-Westin et al., 2006). The consequences of any deficits in neuromuscular control in adolescent players are therefore greatly magnified.

Metabolic conditioning

Both prepubescent and adolescent players can benefit from conditioning to increase aerobic endurance (Naughton et al., 2000). Intensity, duration, and volumes prescribed for metabolic conditioning will vary according to the respective stages of growth and maturation. The selection of training modes employed should also alter as the player grows and matures. A wider variety of activities and cross-training modes is suggested for prepubescent players (Bompa, 2000; Kraemer and Fleck, 2005). As the young player matures, training guidelines change to reflect corresponding changes in physical capabilities: training modes will become more specific to the sport and the intensity of conditioning activities will likewise increase.

It is recommended that endurance training activities employed with prepubescent players should be selected to avoid monotony and aim to incorporate a fun element (Bompa, 2000; Kraemer and Fleck, 2005). Prior to puberty, it is likewise suggested that intensity be limited to moderate levels and that training volumes (duration or distances covered) be gradually increased for training progression (Bompa, 2000). Both these perspectives point to a less-regimented approach in relation to that used with older groups of players. In this way, conditioning not only remains enjoyable but the young player can also self-regulate work intensity. Skill and sport-related movement drills can be adapted for conditioning purposes (Bompa, 2000; Hoff, 2005). Ball games with simplified rules are another good choice for conditioning activities with these young players (Bompa, 2000).

Throughout puberty, growth-related gains in endurance occur naturally as a result of development of cardiovascular and respiratory systems, and these can be harnessed to augment training responses. During this stage, young athletes' capacity for anaerobic exercise also increases (Philippaerts et al., 2006). However, individual players' tolerance for training will differ according to their stage of development. This can vary widely in a group of players of the same chronological age (Bompa, 2000; Kraemer and Fleck, 2005). Consideration must be given to this fact when training players of an age where they may be undergoing puberty. A continuing emphasis on appropriate metabolic conditioning would appear to be vital for female players particularly in order to counter the decline in aerobic endurance that is otherwise observed in females after the onset of puberty (Naughton et al., 2000).

Adolescence is identified as the time for specialization in young players' physical preparation (Bompa, 2000; Naughton et al., 2000). Physiological changes during puberty increase young players' capacity for, and responsiveness to, anaerobic training (Naughton et al., 2000). This form of conditioning is a requirement of the majority of team sports; it therefore follows that anaerobic training should feature increasingly in adolescent players' physical preparation. Various modes of interval training are shown to be effective in improving measures of endurance fitness and performance indices with team sports players (Helgerud et al., 2001; Hoff et al., 2002). High-intensity interval hill running was shown to elicit significant endurance improvement (including lactate threshold) in young soccer players, which importantly also carried over to measures of soccer performance during matches (Helgerud et al., 2001). A soccer-specific protocol running through a set course involving dribbling a ball alternated with backwards and forwards shuttle sprints through cones is also reported to elicit sufficiently high intensities (93 per cent HRmax or 91 per cent VO_2max) for anaerobic conditioning in older players (Hoff et al., 2002).

Skill-based conditioning games also show potential for use in developing anaerobic capacity in different team sports – notably rugby union and soccer

(Gamble, 2004b; Hoff et al., 2002; Little and Williams, 2006b). By manipulating the number of players on each side, playing area and rules exercise intensities in the range of 87–91 per cent HRmax (Little and Williams, 2006b) and 91 per cent HRmax (Hoff et al., 2002) have been reported in different groups of first division male soccer players in England and Norway respectively.

Aerobic endurance remains a key requirement for young players in the majority of sports. There is a need for the training modes used to develop aerobic endurance with adolescent players to become increasingly specific to the sport. Given this, cross-training modes should only be emphasized during the off-season. Selecting appropriate work bouts and rest/recovery intervals, it is possible for repeated high-intensity training to elicit both aerobic and anaerobic endurance gains (Tabata et al., 1997). Over time, it follows that the maturing player's aerobic endurance development may be predominantly achieved via this form of training (Little and Williams, 2006b), particularly during the playing season. Again, this may be achieved via appropriate skill-based conditioning drills or conditioning games (Helgerud et al., 2001; Hoff et al., 2002).

Strength training

Safety and effectiveness of youth resistance training

The benefits of youth resistance training are well documented and are becoming universally accepted among health professionals, particularly in the United States (Faigenbaum et al., 1996; Faigenbaum and Schram, 2004) and also increasingly in the United Kingdom (Stratton et al., 2004). Fitness professional associations and health organizations are now in agreement that age-appropriate youth resistance training is safe and beneficial when performed under qualified supervision (Faigenbaum and Schram, 2004; Kraemer and Fleck, 2005; Stratton et al., 2004). However, public recognition of these benefits continues to lag behind, and misunderstanding and misconceptions remain.

Historically, the concerns about youth resistance training stem from a perceived risk of damaging growth plates, which could potentially interfere with normal growth. In fact, such damage to growth plates has never been documented with strength-training programmes for children that were administered and supervised by qualified personnel. Studies employing appropriate youth resistance training in fact report very low incidence of injuries of any type (Faigenbaum et al., 1996). Far from stunting growth, the contemporary evidence is that resistance training, in combination with proper nutrition, has the potential to enhance growth within genetic bounds at all stages of development (Faigenbaum et al., 1996).

The most frequent causes of injury when children and adolescents undertake resistance training are incorrect lifting technique, attempts to lift excessive loads, inappropriate use of equipment, and absence of qualified supervision (Faigenbaum et al., 1996). All of these factors can be reduced or eliminated with properly administered and supervised training (Stratton et al., 2004). Naturally, young players, as with any inexperienced lifters, should only engage in strength training programmes prepared by qualified coaches, with safe equipment, and supervised by qualified instructors. However, if these conditions are met, there are no safety grounds to preclude young players undertaking supervised strength training (Kraemer and Fleck, 2005).

The reality is that children are exposed to far greater forces – and of longer duration – during sports and recreational physical activity than those encountered during strength training, even if they were to perform a maximal lift (Faigenbaum et al., 1996). Of all resistance training exercises, the Olympic lifts possibly impose the greatest forces upon the young musculoskeletal system. Even so, injury data suggest that Olympic weightlifting training and competition conducted under the supervision of qualified coaching is one of the safer athletic activities engaged in by young athletes (Hamill, 1994).

Mechanisms for strength gains in prepubescent and adolescent athletes

In the case of prepubescent athletes, lower levels of circulating anabolic hormones limit the contribution of hypertrophy (lean tissue growth) to strength gains (Faigenbaum et al., 1996). The changes to muscles that do occur appear to be more qualitative than quantitative. Neural effects thus appear to underpin much of the gains from resistance training in these younger subjects.

Such neural adaptations are suggested to include improved recruitment and activation of the muscles mobilized during the training movement. Enhanced motor co-ordination, both within and between muscle groups, is also thought to contribute to strength gains following training. By the nature of these training adaptations, such strength gains would seem to be less permanent; prepubescent players will exhibit marked detraining effects once regular resistance training is discontinued (Faigenbaum et al., 1996). However, modest (one or two days per week) maintenance programmes do appear to be sufficient to sustain strength gains.

The greater hormonal response to resistance training in adolescents than at earlier stages of development leads to structural changes to the muscles and associated connective tissues (Faigenbaum et al., 1996). As a result, marked changes in terms of muscle hypertrophy and gains in fat-free mass are seen in this older age group. Such increases in muscle cross-sectional area and changes in muscle proteins therefore augment the gains in strength of neural origin that occur.

Strength training for performance enhancement in youth sports

It is becoming recognized that young players can experience similar benefits from strength training as those observed with adults (Faigenbaum et al., 1996). All youth sports demand to varying degrees strength and power, in order to overcome the player's own body weight when moving and the resistance of opponents – particularly in contact sports. It follows that developing strength via resistance training should positively impact upon performance in the young player's sport (Stratton et al., 2004).

The effects of strength training in young players, which include increased strength and improved motor skills and co-ordination, have the potential to improve athleticism. Improvements in scores on motor performance measures are often observed following resistance training in children (Stratton et al., 2004). Positive changes have been noted in vertical jump, standing long jump, sprint times, and agility run times (Faigenbaum et al., 1996).

The available data from the limited number of studies that have been published indicate that increases in flexibility can be made, particularly if the resistance training incorporates specific stretching and warm-up/cool-down (Stratton et al., 2004). This appears to refute concerns in some youth sports that resistance training will lead to the young athlete becoming muscle-bound and consequently decrease their flexibility and range of motion. Warm-up prior to training and team practices should comprise dynamic flexibility exercises; this form of stretching appears to offer most effective preparation for dynamic activity (Little and Williams, 2006a). There is also some evidence of adverse effects on athletic performance associated with performing static stretching immediately prior to dynamic activity (Bradley et al., 2007). Static and partner-assisted stretching does still have a role to play as a means to develop flexibility; however, based on the available evidence it seems sensible to restrict their use to the cool down following sessions, or stand-alone flexibility sessions, to avoid any detrimental effects on performance.

Strength training for injury prevention

Participation in team sports does involve some inherent risk of injury. Although these injuries can never be entirely eliminated, appropriate training can help reduce the number of injuries and severity of injuries that do occur. Young players are subject to additional risk due to physiological and developmental factors. The strains on connective tissues during growth and the changing properties of the growing tissues render these structures more prone to injury in the young player than adults (Adirim and Cheng, 2003). Strengthening muscles and connective tissues via strength training offers a means to increase the forces they are capable of sustaining, helping to make the young player more resistant to soft tissue injury. In adolescents particularly, it is important to strengthen these connective tissues to accommodate the rapid gains in strength and body mass that occur during puberty (Adirim and Cheng, 2003).

Strengthening muscles around upper-limb and lower-limb joints via appropriate training similarly offers a means to increase the active stability provided to these joints, which can serve a protective function (Stratton et al., 2004). Strength training was shown to improve neuromuscular control indices during jumping and landing in female adolescent athletes (Lephart et al., 2005). Such development of motor control and co-ordination helps improve postural balance, dynamic stabilization, and active joint stability – all of which are beneficial in reducing incidence of lower limb injury.

In the case of young female players, lower limb strength development in general and hamstring strengthening in particular should be a major area of emphasis (Barber-Westin et al., 2006). Measures of hamstring strength are reported to plateau very early in female athletes' physical development – with older age groups (13–17 years) showing no significant gains on this measure compared to 11-year-old females (Barber-Westin et al., 2006). The hamstrings compress the knee joint and oppose anterior shear forces during weight-bearing closed-chain movements – as a result of these functions, the hamstring is described as an 'ACL-agonist' (Hewett et al., 1999). The relative weakness of the hamstring of female players is of clinical relevance given the 2–10 times greater rates of non-contact knee ligament injury in adolescent female athletes, compared with males (Goldberg et al., 2007).

Prepubescent athletes are shown to have a greater tendency than older populations to exhibit asymmetrical lower limb performance, based on scores with single-leg hopping functional tests (Barber-Westin et al., 2005). In the absence of intervention, such imbalances may persist post-puberty in both males and females (Barber-Westin et al., 2006). Appropriate strength training offers a means to help correct such right–left imbalances in lower limb function, particularly in combination with plyometric or dynamic balance training (Myer et al., 2006). This role of strength training in correcting side-to-side strength imbalances is crucial for young players at all stages of development. Strength and flexibility imbalances are identified as major risk factors for injury (Knapik et al., 1991). Strength imbalances can have negative consequences for both limbs: over-reliance may place excessive strain on the stronger limb, whereas the weaker limb is less able to actively counter injurious forces (Ford et al., 2003).

Studies show that young players who have strength-training experience tend to sustain fewer injuries (Faigenbaum and Schram, 2004). Incidence of injury in strength-trained youngsters is approximately one-third that of young athletes without any strength-training experience (Bompa, 2000). As well as serving to reduce overall incidence of injury, strength training can also help reduce the severity of injuries. Following injury, strength-trained young players also respond better to rehabilitation (Faigenbaum and Schram, 2004). Hence, strength training can assist the young player in making a more rapid return to training and competition (Kraemer and Fleck, 2005).

For these reasons, strength training is recommended in a 'preconditioning' role for young people before they start to compete in organized youth sports (Bompa, 2000). Young players who are better conditioned and less prone to injury due to appropriate physical preparation – including strength training – are more likely to continue to participate in youth sports. In this way, strength training can help reduce drop-out rates, which in turn can help keep youngsters healthy in later life (Faigenbaum and Schram, 2004).

Aside from the benefits of general strength training, targeted strength training involving particular exercises may also be used to guard against certain injuries that commonly occur in sports. This targeted injury prevention role for strength training is often overlooked, particularly in young athletes. Too often, exercises to strengthen areas that are prone to injury are only prescribed once an injury has already occurred. Unfortunately, there are currently an insufficient number of prospective studies in the literature involving youth sports players to provide evidence-based training guidelines regarding effective training for injury prevention (Mackay et al., 2004).

Training to develop bone health and connective tissue

In much the same way as for adults, it is established that physical activity has positive links to bone mineral density and connective tissue integrity in young people (Greene and Naughton, 2006; Stratton et al., 2004). Although genetics is a determining factor, the major stimulus for accumulation of bone mass and mineral content is mechanical loading (Greene and Naughton, 2006). The cross-sectional area and architecture of connective tissues are also trainable; appropriate strength training can therefore also be applied to develop strength and size of tendons and ligaments (Conroy and Earle, 2000).

Mechanical loads must exceed a threshold in order to trigger adaptive responses (Conroy and Earle, 2000). In accordance with this, both high-force weight-bearing and strength-type activities appear most suitable to elicit bone and connective tissue adaptations. Dynamic skeletal loading – i.e. loading during movement – appears to be relatively more osteogenic than the same loads applied under static conditions (Greene and Naughton, 2006). It follows that relatively high mechanical loading occurring during dynamic training activities should result in the greatest bone adaptation.

Recommended exercises generally involve weight bearing – so that the young player's own body weight provides additional loading (Conroy and Earle, 2000). Athletic activities that involve high ground reaction forces are associated with increased bone mineral content and density (Greene and Naughton, 2006). Sprinting, jumping, and other lower-body plyometric exercises are identified as good training activities for developing bone strength as they offer high ground reaction forces and impact loading. Young athletes in all running-based sports and athletic events can benefit from these training modes. However, the volume of such training (e.g. total foot contacts for plyometric training) must be monitored in order to avoid excessive strains and potential overuse injury.

Applying resistance via strength training is another means to generate the mechanical stresses required for an osteogenic response (Greene and Naughton, 2006). This particular role of strength training for young athletes has been termed 'anatomical adaptation' (Bompa, 2000). Associated positive effects include increased strength of supporting connective tissues and passive joint stability, as well as increased bone density and tensile strength (Faigenbaum and Schram, 2004). In the same way as weight-bearing activities are recommended, 'structural' multi-joint strength training lifts (e.g. variations of the squat, lunge and step-up) offer a means to elicit whole-body skeletal adaptations. The strength and conditioning specialist can also harness site-specific gains in strength and cross-sectional area of bone and connective tissues associated with the muscles recruited during particular strength-training exercises (Conroy and Earle, 2000). Specifically, strength-training exercises can be used to strengthen bones and connective tissues at particular sites that tend to be exposed to strain in the particular sport – such as the shoulder girdle in contact sports.

Immediately prior to and during puberty appears to be a key phase that offers a window of opportunity for skeletal adaptations (Greene and Naughton, 2006). It is suggested that osteogenic training activities can therefore be used to amplify the skeletal growth and growth-related gains in lean body mass that occur naturally during these stages. Studies have shown that post-puberty females may be less responsive to skeletal adaptation – this suggests that there is an earlier and narrower window of opportunity for developing bone and associated connective tissues with female players (Greene and Naughton, 2006).

Increases in bone density brought about by strength training are of relevance to female players from a longer-term health perspective. Females have a higher incidence of osteoporosis in comparison to males during late adulthood. During adolescence, the growing skeleton seems to be particularly responsive to training (Greene and Naughton, 2006). For this reason, young players (females in particular) are recommended to perform dynamic weight-bearing exercise and appropriate strength training during childhood and adolescence (Conroy and Earle, 2000; Kraemer and Fleck, 2005). Increasing the female player's bone mineral content at this stage of development is likely to have a favourable impact on their risk profile for osteoporosis in later life.

Youth training and body composition

As mentioned in a previous section, it is suggested that there is a threshold level of physical activity which, in combination with proper nutrition, is required in order that young players achieve their genetic potential in terms of growth and maturation (Hills et al., 2007). A structured programme of physical preparation offers a means to ensure that this is achieved, particularly at critical periods in the young player's growth and maturation. Furthermore, dedicated training for youth sports also appears vital to help these players maintain lean body composition in view of the declining physical inactivity and rising obesity among youth in general.

During and following puberty, there are some characteristic changes in body composition that can be unfavourable to performance and potentially to health – in particular the gains in body fat mass noted in females (Naughton et al., 2000). Appropriate resistance training, in conjunction with aerobic exercise, has been proposed for losing body fat and for weight maintenance with young people – in much the same way as is recommended for adults (Faigenbaum and Schram, 2004). In view of the increasing incidence of childhood obesity, the potential of physical preparation which includes resistance training to favourably alter body composition is also advantageous from a health perspective (Hills et al., 2007).

Conversely, the potential for strength training to increase lean body mass is of relevance to players in collision sports from a selection and performance perspective. In sports such as rugby and American Football, physical size is a determining factor for participation at higher levels (Olds, 2001). Young players are naturally predisposed to – and selected for – particular playing positions on the basis of their anthropometric (height and body mass) characteristics as well as their strength capabilities (Duthie et al., 2003). Without a background of systematic strength training, young players are unlikely to have undergone the requisite physical development for selection at the highest levels.

Summary

The need for different aspects of physical preparation – including strength training, metabolic conditioning, and also neuromuscular training – has been described for a range of sports and for young athletes at different stages of maturation. The efficacy of each of these different components of physical preparation for athletes in general and young team sports players in particular is becoming increasingly well established. The nature of responses to each of these forms of training at different stages of growth and maturation has also been elucidated, though further research is necessary to provide a clearer picture.

Any training programme should be geared to the physical and emotional maturity of the individuals in the group. Due to the paucity of well-controlled studies in the literature, there is a shortage of conclusive recommendations regarding training design for young populations at different stages of maturation (Naughton et al., 2000). That said, guidelines have been published that differentiate between chronological age and, more importantly, biological age (Bompa, 2000; Faigenbaum et al., 1996; Kraemer and Fleck, 2005). Fundamentally, the primary emphasis of training for young team sports players is on balanced physical development and building a foundation of athleticism. Only once this is undertaken and physical maturation has taken place should the focus then progressively shift to specialized preparation for the particular sport and playing position.

TRAINING RECOMMENDATIONS FOR YOUNG PLAYERS

As discussed, rates of growth and maturation within a group of young athletes can vary widely. When training young team sports players, it is therefore difficult to define phases of development within a squad of players. For the purposes of this section, guidelines will be divided into: 'prepubescent' – stage of development prior to exhibiting physical signs indicating the onset of puberty; 'early puberty' – defined as the phase between the onset of puberty and attaining peak height velocity; and 'adolescence' – the period following peak height velocity being attained and advancing into adulthood.

The divisions between stages are necessarily vague: the average age at which peak height velocity is attained (marking the transition between 'early puberty' and 'adolescence' as defined above) is around 12 years of age for girls and 14 years for boys (Malina et al., 2004), but there is considerable variability in this. Observing changes in physical characteristics, assessing neuromuscular performance, and monitoring seated and standing heights at regular intervals will help in determining the progression between stages. The latter – standing and seated heights – are the most helpful objective measure to track with young players when used to plot velocity curves (gain in height per unit of time) for each player (Baxter-Jones and Sherar, 2006). Seated height is helpful, as trunk length tends to lag behind leg growth. Ultimately, it is dependent on the coach to use their experience and observations of each player's performance during training over time as the deciding factor that determines how and when to progress training for each individual player.

Within these guidelines, consideration must also be given to the training age of the young player entering a programme of physical preparation. Prior training experience – of strength training particularly – will influence individual decisions regarding training prescription. For example, one player who falls into the 'early puberty category' based on age and physical characteristics who enters the programme with a background of two years strength training may be ready for more complex training exercises than another player who is significantly older but has no prior strength-training experience. Regardless of the age or stage of growth and maturation of the player, initial training prescription will reflect the primary objective of developing competency performing fundamental movements and addressing any functional deficits. Only once this has been undertaken should the focus then shift to performance-related training goals and more advanced training.

Prepubescent players

Neuromuscular and movement skills training

Neuromuscular training should be initiated early in young players' physical preparation. This is important to help correct the valgus lower limb alignment during athletic movements that is common in prepubescent athletes of both genders (Barber-Westin et al., 2005). This form of training also has a role to play improving the movement efficiency that has been identified as lacking among these young players (Naughton et al., 2000).

The starting point for proven short-term neuromuscular training programmes appropriate for young team sports players is instruction of athletic position and safe movement mechanics (Hewett et al., 1999). This fundamental phase of established neuromuscular training protocols can be implemented with young players during this stage of development. This includes instruction and practice of jumping, landing, and change-of-direction movements as discrete skills. Neuromuscular movement skill training with young athletes may be effectively augmented by postural balance and dynamic stabilization exercises (Myer et al., 2006). The emphasis with all neuromuscular training exercises should be sound posture and correct lower limb alignment for prepubescent players of both genders.

Metabolic conditioning

It follows that the lower capacity of prepubescents for anaerobic exercise should be reflected in the training employed with these players. The majority of training at this stage of development should be aerobic in nature. However, the training modes used to achieve this may be skill-based to reduce training monotony and include fun and competition elements.

Skill or game-related movement drills can be adapted for use as conditioning activities. For example, an obstacle course can be constructed involving different movements and ball skills, perhaps running relays between teams of athletes (Bompa, 2000). Alternatively, ball games with simplified rules may be used – the numbers on each team and playing area can be manipulated to alter exercise intensity. This less-structured approach allows the young player to self-regulate work intensity according to their individual tolerance.

Strength training

In general, if a child is ready for participation in organized sports, he/she likely ready to undergo instruction and resistance training. However, for young players with known or suspected medical conditions, medical clearance should be sought prior to participation in resistance training, as with other sports (Faigenbaum et al., 1996). The specific design of training for young team sports players should be reflective of their stage of psychological and emotional development, in order to engender motivation and facilitate compliance (Stratton et al., 2004).

When coaching prepubescent players, it is important that training should be enjoyable and give the young player an immediate sense of fun and discovery-based learning (Stratton et al., 2004). In practical terms, the choice of training exercises and loads used should be conducive to allow this approach to be safely implemented. For example, body-weight resistance exercises are more appropriate when training more complex whole-body movements.

Figure 10.1 Swiss ball suspended row.

Meta analyses have identified repetition schemes from 6–15 reps and 50–100 per cent RM to be effective for resistance training with young athletes (Falk and Tenenbaum, 1996). In general, resistance training volumes of 2–3 sets and frequency of training of 2–3 days per week appear to be most effective. When young players are introduced to strength training, light loads and high repetition schemes (12–15 reps) are most appropriate (Faigenbaum et al., 1996). During this early stage of training, progression should be achieved by increasing number of sets performed and number of exercises in the workout. The relative loading and number of training days employed can then be increased at a later stage.

Adequate rest and recovery are key component of successful youth resistance training. Younger players and those in the early stages of their physical preparation will require more recovery time between training days. Training on non-consecutive days is therefore recommended for prepubescent players, in order to maximize the effectiveness of training and reduce the risk of injury (Faigenbaum and Schram, 2004).

Given that many of the benefits of strength training prior to puberty stem from improved co-ordination, balance, and proprioception, it follows that exercise modes that favour development of these aspects should be emphasized when training prepubescent players. Body weight resistance exercises and free weights offer advantages from this point of view, in comparison to fixed resistance machines, although these exercises may require closer supervision. Another consideration if choosing to use resistance machines with young players is that the apparatus must be fitted to the dimensions of the young person. Some apparatus cannot be adjusted sufficiently to be suitable for use (Faigenbaum et al., 1996).

Exercise selection should feature a combination of unilateral and bilateral exercises appropriate to the young player's capabilities. The inclusion of unilateral exercises in prepubescent players' training is important in order to promote balanced development between limbs (Kraemer and Fleck, 2005).

Figure 10.2 In-line single-leg squat.

Table 10.1 Training guidelines: prepubescent players

	Training modes	*Intensity*	*Volume, frequency*
Strength training	Combination of unilateral and bilateral general strength training exercises	8–15-RM	1–3 sets; 2–3 sessions per week (non-consecutive days)
Metabolic conditioning	Combination of cross-training, conditioning games, and skill-based conditioning activities	Self-regulated	Duration should be progressed before intensity
Neuromuscular training	Instruction and practice of fundamental movement skills; single-leg balance exercises (stable surface)	Self-paced, low intensity (full recovery between drills)	Short high-quality sessions (minimizing fatigue effects); up to 2 sessions per week

These exercises do not allow the young player to compensate with their stronger limb as can happen with bilateral exercises. Bilateral exercises should also feature in the young player's programme at this stage of maturation as a means to develop strength from a more stable base of support.

Early puberty

Neuromuscular and movement skills training

Puberty is characterized in males particularly by a progressive improvement in neuromuscular abilities – this is known as the *neuromuscular spurt* (Quatman et al., 2006). However, prior to attainment of peak height velocity there may be short-term decrements in some aspects of neuromuscular performance. It follows that neuromuscular training should be progressed during this phase of the young player's development in a way that is responsive to their individual rate of neuromuscular development and sensitive to any short-term changes.

Training to reduce the potentially injurious loading that occurs with poor neuromuscular control of lower limb alignment assumes increased importance given the gains in body mass that occur during puberty (which in turn increases the loading and stresses imposed on joints and connective tissues). In female players, this form of training is advocated as a means to artificially create a 'neuromuscular spurt' similar to that which occurs naturally in males during this phase of maturation (Quatman et al., 2006). Neuromuscular training is a priority for female players to tackle the higher rates of lower limb injury (in comparison to males) that become apparent from this stage of maturation onwards (Lephart et al., 2005).

Neuromuscular training during this stage will continue to feature dynamic balance and stabilization work. These exercises have numerous progressions, which can be implemented as appropriate with advances in maturation and neuromuscular performance.

Metabolic conditioning

During and following puberty, metabolic training responses become increasingly specific to the type of metabolic training employed. It follows that the training modes used must account for this and increasingly reflect the demands of the sport and playing position from this stage of maturation onwards. Cross-training activities will tend to feature less during the playing season (however, these remain an important training tool particularly for off-season training).

Depending on individual tolerance, intensity of metabolic conditioning will likewise be progressively increased during this stage – in order to reflect the higher intensities of exertion experienced during competitive games. Conditioning games can be manipulated (reducing number of players each side, modifying size of playing area, etc.) to become more demanding. The rest intervals used between conditioning drills may also be decreased – again within individual tolerance.

Strength training

Adequate rest and recovery continues to be an integral aspect when scheduling strength training during puberty. Given the concomitant strains of growth and maturation during this stage, recovery time is crucial between training days. Training on non-consecutive days therefore continues to be advocated during puberty (Faigenbaum and Schram, 2004).

Exercise selection will also reflect the need for balanced development and improving strength for fundamental movements. General strength exercises and unilateral exercises should feature prominently during puberty. With advances

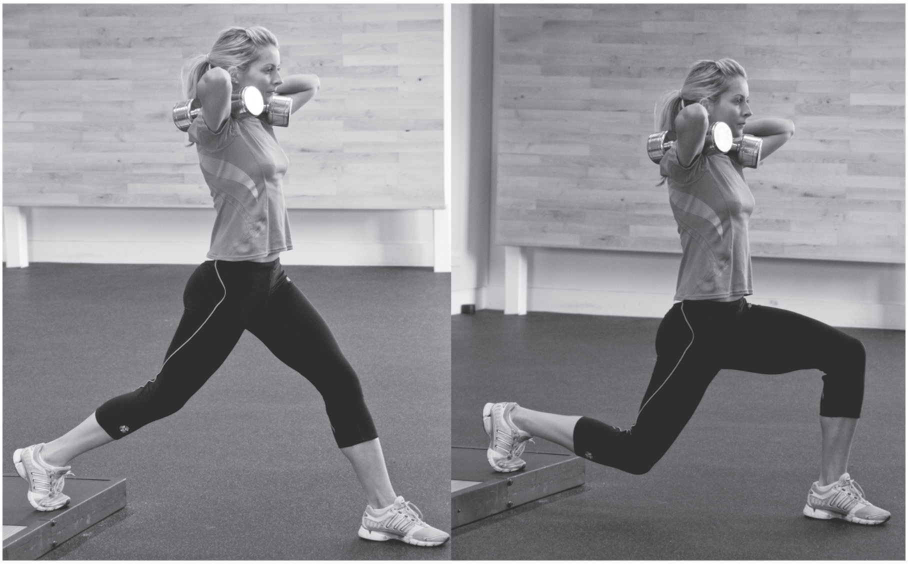

Figure 10.3 Dumbbell split squat.

in training experience, structural multi-joint lifts (variations of the squat and deadlift) can be introduced. In the case of experienced young lifters, Olympic-style lifts can also be integrated into the strength-training programme as appropriate; under qualified supervision this form of training carries no greater risk for young players than other athletic activities (Hamill, 1994). Olympic lifts and their variations should be taught initially using a light implement such as a broom handle or empty barbell, with the emphasis on the quality of the lifting movement.

Whatever the exercise, the focus throughout should be on proper lifting form, with loading limited until the young player has mastered lifting technique. The coach should also be vigilant for temporary reductions in co-ordination and performance that may occur as the young player approaches peak height velocity, and be prepared to modify exercise selection and loading accordingly. Likewise, loading should be restricted from the point of view of attenuating the stresses on skeletal and connective tissue structures during phases of rapid growth (Naughton et al., 2000). Loading of the lumbar spine particularly should be carefully monitored in recognition of the higher risk of lumbar spine injury at this phase of development (Kujala et al., 1996).

In the absence of corrective training, significant asymmetries are observed both before and following puberty (Barber-Westin et al., 2006). From both function and injury-prevention perspectives it is vital that any differences in performance between dominant and non-dominant limbs are addressed during this stage via strength training. Practical recommendations include manipulating the number of repetitions and sets performed with each limb for single-limb strength exercises (Cook, 2003b). For example, the young player may perform three repetitions on their weaker side for every two on their dominant side (keeping the load constant).

Table 10.2 Training guidelines: early puberty

	Training modes	*Intensity*	*Volume, frequency*
Strength training	More complex strength training exercises – greater emphasis on unilateral exercises and introduction Olympic lifting movements	6–12-RM	Max of 3 sets (not including warm-up set); 2–4* sessions per week (non-consecutive days)
Metabolic conditioning	Predominantly interval-based conditioning – including (more demanding) conditioning games and skill-based conditioning activities	Higher intensity – still largely self-regulated to allow for individual differences in tolerance	2–3 sessions per week (non-consecutive days)
Neuromuscular training	Progression of movement skill development; single-leg balance (unstable surface) and dynamic stabilization exercises	Self-paced, progression in intensity (full recovery)	2–3 sessions per week (non-consecutive days)

Notes:
*Number of sessions will depend on how the strength training programme is structured – specifically whether it is a split routine; whatever scheme is used, each body part should only be trained a maximum of twice per week.

For female players targeted hamstring strength training should begin during this stage – ideally in conjunction with neuromuscular training to help increase hamstring recruitment during dynamic activity (Hewett et al., 1999). This is important to offset the quadriceps dominance that can increase strain on the ACL in female athletes (Ford et al., 2003).

Adolescent players

Neuromuscular and movement skills training

The fundamentals phase characteristic of earlier neuromuscular training will be progressed during this stage of development to more demanding jumping exercises and more sport-specific change of direction drills. For all exercises, the emphasis should remain on posture, sound movement mechanics, and correct lower limb alignment, particularly during landing and change-of-direction movements (Myer et al., 2006).

As the player matures and their neuromuscular performance develops, further advances in training may include single-leg plyometric-type jumping and landing exercises in various directions, and unanticipated change-of-direction movement drills. Postural balance and dynamic stabilization exercises can similarly be progressed during this stage by incorporating various training devices to increase demand for balance and proprioception (Myer et al., 2006; Yaggie and Campbell, 2006).

Metabolic conditioning

In many team sports, adolescent players will require repeated sprint conditioning to elicit appropriate anaerobic training effects (Naughton et al., 2000). Accordingly, anaerobic interval training appropriate to the sport should be progressively introduced during this stage (Bompa, 2000). Various modes of high-intensity interval conditioning can be effective – including hill running (Helgerud et al., 2001) and high-intensity sport skill conditioning drills (Hoff, 2005; Hoff et al., 2002). By manipulating numbers on each team, playing rules and playing area, skill-based conditioning games can also elicit sufficiently high exercise intensities for repeated sprint conditioning (Gamble, 2004b; Hoff et al., 2002; Little and Williams, 2006b).

Where it is appropriate to the sport, speed-endurance work may be introduced into speed and agility work undertaken by players – provided that the adolescent player is technically proficient. Prior to this stage in development, any speed and agility training undertaken by players would exclusively be categorized as neuromuscular training, with emphasis on movement mechanics and complete recovery between repetitions.

Aerobic endurance remains a training priority for adolescent players. As this is a stage of increasing specialization in training, the training modes used for individual training should be increasingly mode-specific. It follows that cross-training should be largely restricted to off-season training. Furthermore, aerobic endurance development may be predominantly achieved via interval training, using appropriate work bouts and rest/recovery intervals (Tabata et al., 1997). Optimal combinations of work:rest ratios can elicit almost maximal stimulus for both anaerobic and aerobic effects (Tabata et al., 1997). However, these repetition schemes will, by definition, be highly demanding and as such should be progressively introduced during late adolescence. Skill-based conditioning games aimed at aerobic endurance development employed in squad training should likewise become more specific to the sport.

Strength training

Adolescent athletes are more conducive to a more adult longer-term approach with regard to physical preparation undertaken in a more structured training setting (Stratton et al., 2004). The starting point for any strength training will depend on the adolescent player's training history. If appropriate strength development has occurred prior to and/or during puberty, then strength training may be progressed to include a more advanced and sport-specific exercise selection. However, if significant deficits are noted then the starting point will be to develop strength for fundamental movements and address imbalances. In this case, initial exercise selection will be more reflective of generic strength training for improve athleticism.

Assuming physical preparation has been undertaken prior to this stage of maturation, training design should be increasingly based upon a comprehensive

Table 10.3 Training guidelines: adolescent players

	Training modes	*Intensity*	*Volume, frequency*
Strength training	Increasing sport-specific emphasis: unilateral exercises, Olympic and multi-joint strength training exercises	4–12-RM	3–5 sets; 3–5* sessions per week
Metabolic conditioning	Anaerobic interval-based conditioning – including (more demanding) conditioning games and skill-based conditioning activities	Higher intensity; shorter recovery durations to develop anaerobic capacity	2–4 sessions per week (non-consecutive days)
Neuromuscular training	Progression of speed and decision-making components of movement skills; progression of single-leg balance and dynamic stabilization (featuring unstable support training devices)	Increased intensity, progressive introduction of speed-endurance development	2–3 sessions per week (non-consecutive days)

Notes:
*Number of sessions will depend on how the strength-training programme is structured – specifically whether it is a split routine; whatever scheme is used, each body part should only be trained a maximum of three times per week.

needs analysis of the sport and playing position. As with adults, exercise specificity influences young players' responses to strength training. Exercise selection should therefore be progressively sport-specific, within the constraints of the skill level and training experience of the young player.

Sport-specific exercise selection will vary according to the team sports and playing position. Typically, multi-joint lifts for speed-strength development (Olympic-style lifts, barbell jump squats, etc.) that incorporate triple extension of hips, knees, and ankles will feature in the adolescent player's programme – given that this is the principle biomechanical action common to many dynamic movements in team sports (Gamble, 2004a). Likewise, unilateral support exercises should necessarily comprise a significant portion of the young team sport athlete's training – on the basis that the majority of game-related movements are executed supported partly or fully on one or other leg (McCurdy and Conner, 2003). The reader is referred to Chapters 3 and 5 for guidelines on strength training and speed-strength training exercise prescription.

Exercise selection from an injury prevention viewpoint should be based upon injury data for the sport, and for the playing position where available. Specifically, targeted strength-training exercises should be included in adolescent players' training to address areas identified as being prone to injury in the sport (and playing position) – see Chapter 9 for this topic. In the case of contact sports, hypertrophy may be an important programme goal for adolescent players, to varying degrees depending on their playing position. The shoulders should be an area for specific strengthening and hypertrophy, as this is the site for impact forces during collisions with other players (Gamble, 2004a).

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