The isokinetic assessment of muscle strength in rugby union players

by

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Abstract

Strength is an important requirement in the game of rugby union. Activities such as tackling, scrummaging, rucking, mauling make upper body strength essential for success at the higher levels of competition. This aspect of strength has been assessed by a variety of weight lifting tests but no tests based on a sport specific movement have been developed for rugby.

The aim of this study therefore was to develop a test to measure the upper body strength of rugby union players. Isokinetic assessment of shoulder abduction and adduction strength was identified as providing a sport specific measurement based on the muscle actions involved in the rugby tackle.

A pilot study was conducted to assess the reliability of the isokinetic assessment of shoulder abduction and adduction. Test re-test measurements of concentric and eccentric strength at 1.08 rad•s^{-1} and 2.16 rad•s^{-1} in the dominant and non-dominant shoulder were made on 10 male subjects, 1 week apart. Intra-class correlation (ICC) ranged from r = 0.80 to 0.97 and the standard error of measurement (SEM) ranged from ± 3.2Nm to ± 14.9Nm. The most reliable measure was the average torque at 2.16 rad•s^{-1} in the dominant shoulder (concentric abduction r = 0.96, SEM ± 3.2Nm; eccentric adduction r = 0.97, SEM ± 4.2Nm).

Isokinetic shoulder strength was measured in 29 male rugby union players at three stages of the season, the pre-season training stage (PS), at the start of the competitive season (SS) and midway through the league season (MS). 19 subjects completed all 3 tests. Measurements were made of concentric abduction and eccentric adduction of the dominant shoulder at 2.16 rad•s^{-1}.

There were no significant differences between test measures taken at different stages of the season. Values for eccentric adduction were significantly greater than those for concentric abduction ($P<0.001$). Within the group changes in strength between tests were weakly correlated with initial strength (PS-SS, concentric abduction r = -0.48, $p<0.05$ and SS-MS, eccentric adduction r = -0.53, $p<0.05$) but not with the number of weight training sessions undertaken.

A comparison of strength between positional roles showed that forwards were significantly stronger than backs in absolute terms but that there was no significant difference when the strength was expressed relative to body weight.

The results of this study demonstrate that the isokinetic assessment of shoulder abduction and adduction provides a reliable measure of upper body strength in rugby union players.

The use of this test to measure strength during the season has shown that the playing and training activities of the players produced no consistent effects on shoulder strength. The greater absolute strength of forwards is related to their greater body mass, rather than to differences in positional roles.

The mean of the PS, SS and MS measures can be used to provide normative data for shoulder strength in rugby union players.

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Abbreviations

1C	1^{st} Class players.
2C	2^{nd} Class players.
1RM	1 repetition maximum.
$\dot{V}O_2$	Volume of oxygen consumed.
$\dot{V}O_2$ max	Maximum volume of oxygen consumed.
CT	Coupling time
RFD	Rate of force development
10 RM	Ten repetition maximum
RFU	Rugby football union
Kin Com	Kinetic communicator 500H isokinetic dynamometer.
GET	Gravity effect torque
Con	Concentric
Ecc	Eccentric
w/u	Warm up
m.v.c.	Maximal voluntary contraction
ANOVA	Analysis of variance
ICC	Intra class correlation
SEM	Standard error of measurement
C1.08	Concentric contraction at 1.08 $rad{\bullet}s^{-1}$.
C2.16	Concentric contraction at 2.16 $rad{\bullet}s^{-1}$.
E1.08	Eccentric contraction at 1.08 $rad{\bullet}s^{-1}$.
E2.16	Eccentric contraction at 2.16 $rad{\bullet}s^{-1}$.
DOM	Dominant

NON DOM	Non dominant
APT	Average peak torque
GLM	General linear model

Introduction

Rugby union is an intermittent sport involving high levels of physical contact. Players who take part in the game must be prepared for the rigorous demands that are placed upon them and have high levels of fitness covering aerobic, anaerobic and muscular power. A number of studies have measured fitness in rugby players but none have used a sport specific test.

The aim of the study is to develop a sport specific test to measure fitness in rugby union players.

Chapter 1 looks into the physiological testing of rugby players to date and discusses the physiological demands placed on players of the modern game. It identifies the role of fitness testing in modern day sports and finishes by highlighting the need for a sport specific test to examine the muscular strength of rugby players.

This theme is developed further in Chapter 2 where the various concepts of muscle strength and contraction types are explored. The biomechanical relationships associated with strength assessment are identified and the various modalities of strength assessment are discussed.

Chapter 3 looks in greater detail at the game of rugby and identifies a sport specific movement that is suitable for the development of a sport specific test. A method of testing is chosen and the methodological issues are considered. It concludes by outlining the experimental aims of the study.

Chapter 4 details the methodology used in the study.

Chapter 5 describes the test re-test study carried out to determine the reliability of isokinetic measurement of shoulder strength.

Chapter 6 describes the study carried out to measure shoulder strength in rugby union players during the pre-season and the competitive season.

Chapter 1

Physiological testing of rugby union players

1.1. The physiological requirements of rugby football union

Rugby football is a game which involves high levels of physical contact, low intensity aerobic exercise and periods of high intensity anaerobic activity (McLean 1992, Brewer and Davies 1995, Nicholas 1997). The game consists of two forty minute halves, separated by an interval and contested by two teams of fifteen players. To be successful at the higher levels of the sport in addition to the high skill levels required by the game, increased levels of fitness covering strength, power, speed and endurance are required. The demands placed on the players will vary depending on their playing position and the nature of the game plan for example a fast running game places different physiological demands on the player than a slower-paced rucking and mauling game. There are two distinct player groups involved in rugby union which are the forwards numbered one to eight and the backs numbered nine to fifteen. The role of the forwards during a game is to win possession of the ball either from set piece play such as the lineout or scrums, or, at secondary phase play in rucks and mauls. Once possession of the ball has been won, the backs are able to move the ball in an attempt to score by running with and either passing or kicking the ball. These positional differences result in varying physical demands being placed upon the players and as such, there are significant anthropometric and physical performance differences between the two player groups (Ueno et al. 1987, Rigg and Reilly 1987, Quarrie et al. 1995).

The most marked differences are that forwards tend to be taller and heavier than the backs (Table 1.1.). First class players tend to be taller and heavier than second class players but the differences between the forwards and the backs remain. The greater height and weight of the forwards is an indication of the strength and power that is required in this position for scrummaging, mauling and rucking. Height is an advantage in the lineout. A similar difference in the height and weight characteristics of forwards and backs has also been shown in rugby league players (Meir 1993, Brewer and Davies 1995) consistent with the forwards role as the ball winners and primary defence and the backs role as play finishers. In addition, positional roles within the broad groups are also reflected in the height and weight characteristics of the players. For example, the second row players have been found to be the tallest and heaviest of the forwards (Rigg and Reilly 1987) and the centres the tallest and heaviest of the backs (Quarrie et al. 1996).

Table 1.1. Height and mass characteristics (mean values ± SD) of rugby union players of differing standards.

Position	Class	n	Height (cm)	Mass (kg)	Reference
Forwards	Collegiate	99	176.5±5.9	80.6±8.5	Ueno et al. 1987
Half Backs	Collegiate		168.5±3.6	66.3±4.2	
Backs	Collegiate		171.9±3.9	69.5±5.1	
Front row forward	1	264	176.7±3.7	89.2±3.7	Rigg and Reilly 1987
Front row forward	2		176.2±2.7	80.0±8.1	
Second row forward	1		196.7±6.1	100.8±6.7	
Second row forward	2		185.3±2.1	86.7±8.0	
Back row forward	1		184.8±5.9	86.5±6.8	
Back row forward	2		176.1±4.1	80.9±5.8	
Half backs	1		172.8±5.4	77.0±5.8	
Half backs	2		172.0±2.2	72.0±8.9	
Backs	1		180.4±4.8	80.2±4.6	
Backs	2		179.6±4.6	77.3±5.2	
Forwards	Senior A	133	186.0	98.5	Quarrie et al. 1995
Backs	Senior A		177.8	81.8	
Forwards	Senior B		181.2	88.1	
Backs	Senior B		176.5	77.3	

Good muscular strength is a requirement of the game and generally the positional differences will determine the level of strength required. All players require good leg strength for power, the forwards so that they can successfully carry out scrummaging, driving play and jump in the line out and the backs for acceleration. Explosive leg power has been assessed in a number of studies using the vertical jump test (Table 1.2). Average team jump heights are in the range of 50 – 60 cm. Generally the backs scored higher than the forwards (Maud 1983, Rigg and Reilly 1987) but when assessed according to positional role the highest jump scores were recorded for the second row forwards and the backs (Rigg and Reilly 1987, Quarrie et al. 1996).

Table 1.2. Vertical jump assessment (cm) of rugby union players.

Player position	Level	N	Vertical Jump (cm)	Reference
Forwards	U.S. Club	8	49.9	Maud 1983
Backs		7	51.4	
Front row 1C	British Club	5	50	Rigg and Reilly 1988
Front row 2C		5	45	
Second row 1C		4	52	
Second row 2C		3	52	
Back row 1C		5	53	
Back row 2C		5	46	
Half-back 1C		4	55	
Half-back 2C		4	51	
Backs 1C		6	57	
Backs 2C		7	51	
Props	New Zealand Club	13	58.1	Quarrie et al. 1996
Hookers		6	55.9	
Locks		15	61.1	
Back row		15	62.3	
Half-backs		11	62.6	
Centres		15	61.2	
Wing/full back		18	65.3	

1C = 1st class level 2C = 2nd class level

A small number of studies have measured muscle strength in rugby players (Maud 1983, Tong and Wood 1996). A significant difference in upper body strength between forwards and backs, assessed by 1 repetition maximum (1RM) bench press, was identified in US club players. No significant difference in 1RM leg press maximum was identified although the backs tended to have higher values than the forwards (Maud 1983).

Rugby union has been classified as a high intensity intermittent sport (Nicholas 1997). Typical of this type of activity are short periods of high intensity exercise, such as sprinting, tackling and competing for the ball, set against a background of low intensity exercise such as walking, jogging and standing. The game of rugby has been shown to consist mainly of walking / jogging (47%) and standing (38%) with only 6% of the time spent sprinting and 9% tackling and competing for the ball (Docherty et al. 1988). High intensity activities typically last for 5 – 15 seconds with less than 40 seconds recovery between each high intensity period (Nicholas 1997). A high level of cardio-respiratory fitness is required, not only to support the aerobic phases of play but also, to maximise recovery following high intensity exercise and to reduce fatigue. This contributes to the maintenance of a high level of skill throughout the game that is essential for success.

In a study, which assessed the physiological characteristics of South African University rugby union players, the maximum oxygen consumption ($\dot{V}O_2$ max) of fifteen forwards and fourteen backs was evaluated. The forwards produced a mean result of 52.0 ± 4.8 ml•min^{-1}•kg^{-1} which was lower than the backs result of 55.8 ± 4.1 ml•min^{-1}•kg^{-1} (Jardine et al. 1988). Other studies summarised in Nicholas (1997) have identified $\dot{V}O_2$ max levels of between 45.1 and 59.5 $ml{\bullet}min^{-1}{\bullet}kg^{-1}$ for all players. $\dot{V}O_2$ max values in the region of 55 $ml{\bullet}min^{-1}{\bullet}kg^{-1}$ are typically found in intermittent sport players (Nowacki et al. 1988, Keane et al. 1995). Amongst the various football codes, Australian rules and soccer players had the highest $\dot{V}O_2$max values (64 $ml{\bullet}min^{-1}{\bullet}kg^{-1}$ and 59-63 $ml{\bullet}min^{-1}{\bullet}kg^{-1}$ respectively). They were followed by rugby players (54–60 $ml{\bullet}min^{-1}{\bullet}kg^{-1}$) and the lowest values were found in American football players (45–53 $ml{\bullet}min^{-1}{\bullet}kg^{-1}$) (Douge 1988). These differences may reflect the overall exercise intensity of the game, total playing time and/or work: rest ratio.

The high intensity aspects of rugby (sprinting, tackling and competing for the ball) utilise anaerobic sources of energy. A number of studies have assessed the anaerobic performance of rugby players by measuring peak mechanical power output. Values ranging from 8.96 ± 1.3 $W{\bullet}kg^{-1}$ to 13.68 ± 0.9 $W{\bullet}kg^{-1}$ have been recorded (Cheetham and Williams 1984, Ueno et al. 1987, Cheetham et al. 1987). Absolute power output is important in ball winning situations and has been shown to be greater in forwards than backs (Ueno et al. 1987) but, power relative to body weight which is important for sprinting, is similar between forwards and backs. Comparisons with other athletic groups are difficult due to the variety of protocols used. However, Ueno et al. (1987) cites comparative data for sprinters and middle and long distance runners with the peak power output for rugby players (13.38 $W{\bullet}kg^{-1}$) falling between that of middle distance runners (10.63 $W{\bullet}kg^{-1}$) and sprinters (14.16 $W{\bullet}kg^{-1}$).

1.2. The role of fitness testing

There are many factors that contribute to the superior performances of athletes. The main influence is that of genetic endowment, which includes not only anthropometric characteristics, inherited cardiovascular traits and muscle fibre-type composition but also, the capacity to improve with training. Another important factor is the amount and the suitability of training that precedes competition. Finally the health and nutritional status of the athlete will influence performance on any given occasion.

Although sport scientists cannot alter the genetic makeup of an athlete, they are able to suggest training programmes to best suit the athlete's individual needs. They are also able to apply tests either in the laboratory or in the field, to evaluate any changes in fitness or performance. The role of the sport scientist in improving performance has been recognised for some time in the track and field events (Read and Bellamy 1990, Kuhn et al. 1991). This is being increasingly recognised in rugby union (Jardine et al. 1988, Tong and Mayes 1995 and Nicholas 1997).

An important aspect in the work of a sport scientist is in the assessment of physical fitness and the development of effective training programmes (Meir 1993). The sport scientist uses either field or laboratory testing to gather data, which then facilitates the decision making process which follows all testing. Fitness tests can be implemented for several reasons (MacDougall et al. 1991), although the final reasons for any testing is only established after consultation with the coaches and athletes. The information that is gathered from such tests could benefit those involved in several ways:

1. A testing programme provides information about an athlete's strengths and weaknesses in relation to their sport and in doing so, provides baseline data for individual training programme prescription.

Most sports require an athlete to possess high levels of physical fitness in different areas such as strength and power, aerobic and anaerobic fitness, flexibility, skill and judgement to gain success in their chosen event. All athletes will have strengths and weaknesses in their repertoire of attributes. By implementing a battery of tests that specifically assess the physical requirements of the sport or event in question, an athletic profile can be constructed. This will enable the coach and athlete to modify the overall training programme in an effort to improve the weaker aspects of fitness in relation to a given sport, whilst maintaining and if possible, improving the stronger qualities.

Having identified an athletic profile this information is relevant not just to the individual but to the athletic population in general, since such data helps to determine the relevance and relative importance of various aspects of fitness to the performance of a given sporting event (Reilly and Thomas 1977, Quarrie et al. 1995).

2. By comparing the results of tests carried out over a period of time it is possible to assess the effectiveness of a training programme, allowing changes to be made if necessary. It also enables the coach and athlete to identify any seasonal deterioration in fitness levels and address the problem quickly and effectively (Reilly and Thomas 1977, Koutedakis et al. 1992, Tong and Mayes 1995).

The success of any training programme can be evaluated by tests administered before and after periods of training (Mont et al. 1994). Alterations can be made to the programme on the basis of the test results. The most common way to train for strength and power is weight training and through its nature, progress is monitored readily by recording the increases in the maximum lift or the increase in the number of repetitions at a certain weight. Laboratory testing can give further information such as if strength has increased at a certain velocity or at a particular point in the range of motion. With other aspects of fitness such as speed and endurance, slight increases in performance may not be easily noticed without accurate testing. Laboratory and field tests such as those used by Posch et al (1989), Koutedakis et al. (1992) and Quarrie et al. (1995) can give an accurate measure of any changes in fitness status. It is, however, important to note that the most sensitive and unbiased monitoring of training occurs when the same equipment and movement is used for training and testing. To minimise any potential insensitivity to training progress it is essential that the training and testing methods be as specific as possible to the sport movement.

3. A testing programme provides information as to the health status of the athlete, which is relevant to injury prevention and rehabilitation. Training for high levels of competition is very physically demanding and stressful and may itself create health problems. An athlete may during the course of a season sustain an injury that could restrict participation in any form of activity. If pre-injury levels of fitness such as strength, power, aerobic and anaerobic fitness levels are available, then the extent of the decrease in fitness resulting from the injury can be quantified. This data can be extremely useful in determining the point at which the athlete can return to training

and competitive performance, reducing the likelihood of the injury re-occurring. An intercollegiate football team in the USA had the incidence and management of hamstring injuries examined over a nine-year period. In total one thousand and ninety eight subjects were examined. It was concluded firstly that the isokinetic assessment and rehabilitation of muscle imbalances could prevent hamstring strains and secondly, that isokinetic assessment of hamstring injuries could prevent re-occurrence by ensuring the athlete had regained near normal muscle strength before returning to competition (Heiser et al. 1984). In another study of sixty four intercollegiate track and field athletes it was concluded that leg imbalance, hamstring strength and the ratio of the flexor and extensor were parameters related to the occurrence of hamstring strains (Yamamoto 1993).

For a testing programme to be effective it is important that the following recommendations are adhered to: (MacDougall et al. 1991, Jakeman et al. 1994)

- The variables that are tested must be relevant to the sport.
- The tests that are utilised must be valid and reliable. For a test to be reliable the results must be consistent and reproducible.
- The test protocol must be as sport specific as possible. When designing a test protocol every effort should be made to mimic the sporting event being evaluated.
- Instructions and procedures should be standardised and rigidly adhered to.
- The athlete should be informed of what the testing involves and any risks involved with participation. Results should also be kept confidential.

1.2.1. Fitness testing of rugby union players

The game of Rugby Union has undergone considerable change in the last three years, it has entered a professional era and as a result the need for players to perform at their best is of paramount importance. Greater expectations are placed upon the players with regards to physical fitness and performance levels and therefore, the role of the sport scientist is becoming an essential requirement for many first class rugby teams. As mentioned previously there are many facets of fitness that are required by a player if they are to be successful. The training programmes that are implemented have to be very carefully planned and executed if the players are to receive the necessary benefits (Hickson 1980, McKenzie Gillam 1981, Meir 1993). The success of the training programme can then be evaluated by utilising a testing programme. The information gathered by implementing such a testing programme would make it possible to identify weak points and therefore adjust training programmes to accommodate weaknesses. The information could also be used to help prevent injuries by identifying muscular imbalances (Yamamoto 1993 and Heiser et al 1984) and in the event of an injury being sustained, the information provided by testing could be used to gauge the safe return of the injured player to competitive play.

The majority of published data on the testing of rugby players to date has been with the objective of producing a physiological profile of a 'rugby player'. The majority of the tests used have been field tests. Quarrie et al. (1995) used a battery of tests to provide a profile of the physical performance characteristics of players in New Zealand, while Rigg and Reilly (1987) used similar tests on 1st and 2nd class players in the UK. The anthropometric and physiological profiles produced by these studies are given in appendix 1. The types of test that were implemented in both studies were:

- A 20 metre multistage shuttle run test, to gauge aerobic performance.
- An agility run to assess a players agility and turning ability.
- A vertical jump test to assess the muscular power in the lower body.
- A press-up test to gauge the upper body muscular endurance.
- Sprint times for 30 metres from a standing start and from a 5 metre running start to assess speed. The momentum of a player was recorded using the following formula:

$$\frac{\text{Time taken for sprint from standing start (s)}}{30\ \text{m}} \times \text{body mass (kg)}$$

- Six repeated high intensity shuttles to measure the anaerobic endurance, or recoverability of the players.

Rigg and Reilly (1987) also examined suppleness by using the sit and reach test and a dynamic flexibility test pioneered by Fleishman (1964).

There is a place for field tests such as those outlined above, as several tasks involved in sporting activities are impossible to simulate under laboratory conditions. However, the results of field tests are often specific to the exercise task and extremely difficult to repeat due to a variety of factors. Individual interpretation of a test protocol can affect the results obtained, as can the equipment used by both the test administrator as well as the test subject. An example would be the footwear used by a participant in a multi-stage shuttle run test. Footwear with spikes of some description would allow better traction on a grass surface and therefore, allow better turning and acceleration in the test. Another consideration, which is beyond the control of the test administrator, is the climatic conditions. Temperature, wind and rain all affect the ability of a subject to perform a given task both physically and psychologically. It therefore makes the problem of field testing even more difficult to solve and great care needs to be exercised by the test administrator to ensure conditions are as similar as possible if any substantial comparisons are to be made.

Rigg and Reilly (1987) supported their field tests with a battery of laboratory tests, which were conducted on a separate testing day. They consisted of basic anthropometric measurements, the Wingate anaerobic test and a measurement of physical work capacity. Laboratory testing has also been used in rugby to assess $\dot{V}O_2$ max, anaerobic capacity and strength (Jardine et al. 1988, Cheetham et al. 1987, O'Connor 1996).

The aim of most laboratory tests is to provide valid measures of fundamental components of fitness e.g. aerobic capacity, anaerobic capacity and strength. These measures should not be influenced by the skill of the subject at the test. This type of testing is well suited to longitudinal studies e.g. to monitor training adaptations because of the level of control over the test conditions, protocols and equipment and the lack (or only minor influence) of learning effects.

Comparisons between studies, however, are complicated by differences between protocols and equipment used. For example, the peak power outputs quoted by Cheetham et al. (1987) and Rigg and Reilly (1987) cannot be directly compared because although both studies used a 30 second maximal exercise test Rigg and Reilly (1987) used a cycle ergometer protocol and Cheetham's group (1987) used a treadmill protocol. Similarly, the results of Ueno et al. (1987) and Rigg and Reilly (1987) cannot be directly compared because although both used a maximal exercise cycle ergometer protocol. Ueno et al. (1987) used a 7 second protocol with a resistance of 0.1 kg/kg body mass and Rigg and Reilly (1987) used a 30 second protocol with a resistance of 0.075 kg/kg body mass. Although peak power is attained within 5 – 10 seconds and therefore may be comparable, studies have shown that the peak power output is dependent on the resistance used making comparison difficult (Bar-Or 1987).

1.3. Development of a sport specific test for rugby union

Despite the importance of muscular strength to the game of rugby, not just to succeed in the sport but also to prevent and avoid injury, there has been limited interest in the assessment of muscular strength in rugby players as a population. Numerous studies have performed extensive anthropometric evaluations on players (Ueno et al. 1987, Cheetham et al. 1987, Rigg and Reilly 1987, Quarrie et al 1995, Tong and Mayes 1995) but have failed to provide full extensive data for the physiological aspects of the players fitness concentrating their efforts on aerobic and anaerobic fitness. The assessment of muscular strength has been left to field tests such as the press up test used by Quarrie et al (1995) and Rigg and Reilly (1987) or laboratory assessment, such as handgrip strength, which lacks specificity to the sport of rugby.

It is evident that there is a place for the accurate and specific assessment of muscular strength in rugby players as a population. This study will aim to develop a sport specific test for the assessment of muscular strength in rugby union players.

It has been decided to develop a single test to measure muscle strength in either the upper or the lower body as opposed to a series of specific tests. The reason for this is that the population to be used in this study are a volunteer group, subsequently their time is an important consideration. A multi-limb evaluation or a series of different tests would be very time consuming and as such would reduce the willingness of players to participate in the study and secondly increase the likelihood of subjects dropping out.

Chapter 2

Muscle strength and methods of assessment

Rugby as discussed in Chapter 1 is a very dynamic game that involves a large amount of physical contact and as such, high levels of muscular strength are essential. The game incorporates several types of muscular contraction. During scrummaging and mauling high levels of force are produced, the majority of which are the result of dynamic contractions. However, it is not unusual for sustained static contractions to be performed. For example, when two sides are evenly matched in the scrum they often push very hard against each other but fail to move. In a mauling situation, the player holding the ball will have to perform numerous sustained muscular contractions to keep possession of the ball, whilst the opposition attempt to take the ball from him. Both of the above are good examples of static contractions. However, the majority of muscular contractions performed during a game of rugby are dynamic.

2.1. Muscle strength

Muscular strength is defined as the maximal force, or tension, a muscle, or more correctly, a group of muscles can exert against a resistance. Strength can be measured as the peak force (in Newtons, N) or torque (in Newton-meters N•m) developed during a maximal voluntary contraction under a given set of conditions (Sale 1991). Peak force varies according to contraction type (isometric, concentric and eccentric), speed of movement and joint angle.

2.1.1. Contraction types

There are two fundamental types of muscular contraction; these are static and dynamic contractions. The static or isometric contraction is a contraction whereby an external force is matched by the internal tension produced within the muscle, resulting in no overall change in the length of the muscle-tendon unit and consequently, no movement of the joint about which the force is applied.

In dynamic contractions the internal and external forces are not equal, resulting in a change in length of the muscle and consequently movement of the joint. The muscle performs a positive or concentric contraction when the muscle shortens in length as it overcomes an external resistance and a negative or eccentric contraction when the muscle body lengthens under tension, returning towards its original length.

There are several factors that influence the amount of tension that can be produced by a muscle during a contraction. These factors are explained in greater detail below.

2.1.2. The torque - velocity relationship

When force is produced about an axis of rotation, or throughout a range of motion it may be referred to as torque. The speed at which such contractions are performed affects the level of torque produced. Several studies have examined the torque - velocity relationship in different muscle groups (Taylor et al. 1991, Arnold and Perrin 1993, James et al. 1994, Mayer et al. 1994(ii)). During concentric contractions the greatest force is produced at slow speeds and as velocity increases there is a linear reduction in the force produced. This relationship is not applicable to eccentric contractions, whereas velocity increases, force remains the same or in some cases also increases. The physiological mechanism for the discrepancy in the concentric and eccentric force velocity relationship appears to be related to differences in the binding and interaction of actin and myosin within the muscle sarcomere. Upon activation of the excitation contraction coupling mechanism, myosin binds to actin as inhibitory factors on the actin binding site are removed by the release of calcium. Once attachment has occurred, the potential energy stored in the myosin filament is transformed into the mechanical events of the cross bridge action. This produces tension, or concentric shortening of the muscle. If the external resistance exceeds the cross-bridge ability to shorten (eccentric contraction), the actin myosin bond is broken before transduction of energy can occur. As the external force continues, the energised myosin is repeatedly reattached and pulled apart from the actin without transduction of energy. Not only does this process produce greater tension at a given sarcomere length than does shortening (concentric) contraction, it is also independent of velocity until the velocity of lengthening exceeds the binding rate of the actin and myosin. The practical application is that as velocity of the concentric contraction increases, fewer cross-bridges are formed and thus less force is produced. In contrast, the cross-bridge is not required to undergo the complete series of chemical events during an eccentric contraction and so, the ability to generate tension at higher test velocities is not adversely affected (Perrin 1993).

2.1.3. The length – tension relationship

It has been shown in isolated muscle that the contractile force is related to the extent to which the muscle fibres are stretched. A muscle is able to exert its maximal force while in an optimal stretched position. Consequently, when the muscle is too short or too long less tension can be produced. The physiological reason for this is, when there is excessive shortening, the actin filaments overlap and therefore interfere with the coupling potential of the cross-bridges on the other side. As a result there are fewer cross-bridges 'pulling' on the actin and therefore, less tension can be produced (Figure 2.1.). A similar situation occurs when the muscle is too long. The actin filaments move outside the range of myosin cross-bridges and with a reduced coupling potential, less tension is produced. In the body the resting muscle length will be determined by the joint angle and contributes to the relationship between torque and joint angle recorded in the whole body

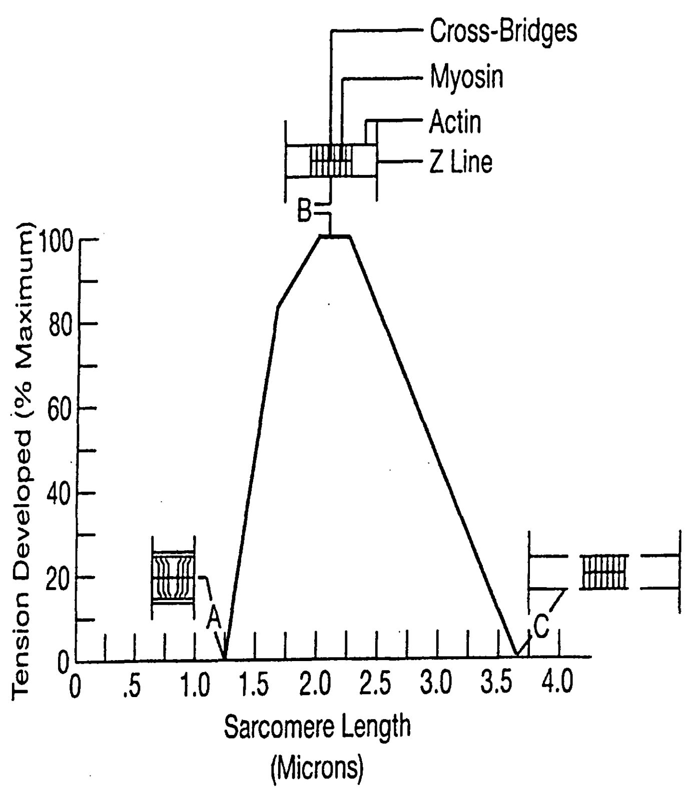


Figure 2.1. Relationship between the length of a sarcomere and the tension developed. A. With excessive shortening, there is an overlap of actin filaments such that the filament from one side interferes with the coupling potential of the cross-bridges on the other side, and no tension is developed. B. The length of the sarcomere is optimal, and all cross-bridges connect with the actin filaments, producing maximal tension. C. The sarcomere is stretched so that the actin filaments are beyond the range of the cross-bridges, and no tension is developed.

2.1.4. The torque – angle relationship

From the length tension relationship it may be concluded that an individual can lift the heaviest load when the muscle is at its optimum stretched length. This is however not necessarily true, as the human body relies on muscles to produce force and the skeletal system on which the muscles are attached to create levers. It is the arrangement of the muscles and the bones that determines the torque that can be produced and the resultant torque angle relationship. This relationship varies between joints as a consequence of fibre architecture, the number of joints a muscle spans and the influence of joint angle on the moment arm. For example, the elbow (forearm) flexor muscles produce the strongest torque between the angles of 30° and 110° where 0° is complete extension (Knapik et al. 1983). The torque - angle relationship is qualitatively similar in isometric, concentric and eccentric contractions, but the torque exerted in eccentric contractions is greater than that exerted in concentric contractions, with the values for isometric torque falling in between the two.

2.1.5. The stretch – shorten cycle

This phenomenon which is also referred to as eccentric–concentric coupling is based primarily on the mechanical behaviour of the contractile elements in the muscle and the tendons. When an eccentric contraction is immediately followed by a concentric contraction of the same muscle, a greater concentric torque is recorded than would be possible without the initial 'stretching of the muscle'. In a study by Bosco et al. (1981), vertical jump scores were compared in subjects who performed with and without preliminary eccentric contractions. With pre-stretching the subjects produced significantly higher results for both force and power (66% and 81% respectively), than jumps performed without a pre-stretching manoeuvre. The two factors that affect the efficiency of the stretch - shorten cycle are the coupling time (CT) and the extent of stretch. The CT is the transition period between the eccentric and concentric contractions and is commonly measured in milliseconds. The extent of the stretch is pertinent, as a relatively large range of stretch will result in a longer CT and therefore reduce the efficiency. Conversely a short range of stretch will contribute to a large eccentric force and a short CT (Dvir 1995). The reasons that a pre-stretch as part of the stretch – shorten cycle assists the individual to produce an improvement in performance, whatever that action may be, is due to three factors. These are the elastic energy that is produced within the fibre itself, the pre-load placed upon the muscle and reflex potentiation of the subsequent contraction.

2.2. The measurement of muscle strength

Three forms of dynamometry are utilised in the measurement of muscle strength, these are isometric, isotonic and isokinetic.

2.2.1. Isometric dynamometry

Isometric dynamometry is a widely employed method of strength testing (Knapik et al. 1983, Moss and Wright 1993, Lannersten et al 1993, Wilson and Murphy 1996). Subjects produce maximal force at a specified joint angle against an immovable resistance. The force applied is measured with a device such as a strain gauge, cable tensiometer or force platform. Typically, maximal isometric force and / or maximal rate of force development (RFD) are recorded (Wilson and Murphy 1996).

Measurement of maximal isometric force has high test - retest reliability, with correlation coefficients of $r > 0.9$ typically quoted (Clarke 1948, Wilson et al. 1993, Abernethy et al. 1995), provided that the test protocol isolates the muscle group of interest and limits the involvement of compensatory muscle groups (Wilson and Murphy 1996). Reliability coefficients for maximal RFD are typically lower than for maximal isometric force, this may be related to the discomfort associated with the test and the high levels of motivation required from the subject (Wilson and Murphy 1996).

Although isometric testing provides a reliable measure of strength there is a question of whether it provides a valid measure of muscle performance during sporting activities. This area has been reviewed by Wilson and Murphy (1996) who found that maximum isometric force was only moderately related to performance with correlations ranging from r = 0.3 - 0.6. However, in some studies stronger correlations were reported, for example, Häkkinen (1987) reported a correlation of r = 0.81 between isometric strength and the counter movement jump. The ability of tests to differentiate between performers at different levels was mixed with only half the studies reviewed by Wilson and Murphy (1996) reporting that isometric strength could discriminate between different levels of ability. Isometric RFD measures an individual's ability to rapidly develop force and it may be supposed that this would relate to dynamic muscle action since dynamic actions, particularly in sport, tend to be powerful and occur over a short period of time. However, although Viitasalo and Aura (1984) demonstrated a high correlation between leg extension RFD and high jump performance, most other studies have reported only moderate correlations (Wilson and Murphy 1996).

The poor validity of isometric testing to assess muscle function in sporting situations reflects neural and mechanical differences between isometric and dynamic contractions. In terms of neural function it has been demonstrated that muscle activation patterns differ between isometric and dynamic contractions (Nakazawa et al. 1993). In terms of mechanical differences isometric tests measure force at a single joint angle, whereas dynamic performance is over a range of joint angles. Although time consuming, it is possible to create a profile of muscular performance throughout a range of motion by performing multiple angle isometric tests. This is comparable to the torque - joint angle curve generated by dynamic testing (Knapik et al 1983). However, in addition, dynamic performance usually involves the stretch shorten cycle whereas isometric contractions do not.

In view of these differences it may be concluded that muscle function in sporting situations is generally better assessed by the use of dynamic tests of muscle function rather than by isometric tests (Wilson and Murphy 1996).

2.2.2. Isotonic dynamometry

The term Isotonic means 'same or constant' (iso) tension (tonic). A true isotonic contraction requires a fluctuating level of resistance to a moving body part, in order that the muscle performing the contraction exerts a true constant force. Although a contraction using free weights could be described as an isotonic contraction, it is not an action of true isotonic nature. When performing an exercise such as a bench press, the weight of the bar remains constant, but this consistency only applies to the moving body segments (the skeletal levers). The amount of tension that the muscle groups have to exert to move the bar from the start position with the arms out straight down to the chest and back to the start position varies. This is due to the length of the muscle, the angle at which force is applied to the skeletal levers and the speed of contraction. Some authors (Abernethy et al. 1995, Wilson and Murphy 1996) advocate the use of the term isoinertial rather than isotonic. The term isoinertial is used to reflect the constant resistance to movement during a weightlifting task and is felt to be a more accurate term than isotonic, since the force applied to the load and the tension developed by the muscle is not constant during these actions.

A common method of measuring isotonic strength is the use of the 1 repetition maximum (1RM) (Knapik et al. 1983). This has been shown to be highly repeatable with test – retest correlation coefficients of r = 0.92 – 0.98 in experienced lifters (Abernethy et al. 1995). The 1RM is the greatest weight that can be moved under control through a defined range of motion. Another method of assessment is to use the 10 repetition maximum (10RM) test, which involves the individual being tested performing 10 repetitions with the heaviest weight possible. Some researchers have developed formulae to enable the 1RM value to be predicted from the number of repetitions completed at a lesser load (Abernethy et al. 1995). This could be advantageous if there is any serious concern of increased likelihood of injuries being sustained by the subjects involved. 1 RM assessment can be made using free weights or multigym equipment. It is therefore a method of assessment that is simple in its application and can be performed in any normal weights gym.

1RM testing is widely used to profile athletes and to monitor improvements in strength during weight training programmes. An advantage of 1RM testing over isometric testing is that it is a dynamic form of assessment and if the test is performed as an eccentric followed by a concentric muscle action, it can utilise the stretch - shorten cycle which is used in most sporting activities. However, the usefulness of 1RM testing in assessment of performance may be limited because the procedure, although dynamic, bears little resemblance to many athletic movements in terms of posture, pattern or speed of movement. Furthermore, a 1RM lift is limited to some extent to the weight lifting skill and experience of the individual (Abernethy et al. 1995).

'Isotonic' testing can be carried out on some of the commercially available 'isokinetic' dynamometers. In the isotonic mode the speed of the lever arm is continually varied, as the subject applies force, so that a constant pre-set load is maintained. This form of testing enables acceleration, peak velocity, work and power to be assessed, which cannot be assessed by simple weight lifting tests. However it has not been widely used in sport science research, perhaps, because it is limited by the velocities attainable by isokinetic dynamometers.

A number of isoinertial tests have been developed (Viitasalo 1985, Häkkinen 87, Murphy and Wilson 1996) in which the force developed during a constant load task is measured. Viitasalo (1985) used weighted squat jumps on a force platform, together with electronic goniometry, to construct a force - velocity curve. An alternative method that can be used in the field is to measure the jumping height with increasing loads and construct the height-mass relationship. Viitasalo (1985) compared the two methods and showed that both methods had similar test - retest correlation coefficients (r = 0.86 – 0.96) but the coefficients of variation showed that as load increased, there was greater variability in the jumping height than in the force developed.

Murphy and Wilson (1996) have developed an isoinertial test for measuring upper body strength that involves measuring the peak force produced when accelerating (concentric action) or decelerating (eccentric action) a load. The intraclass correlation coefficients for these tests are high (r = 0.94 – 0.95). The isoinertial test measures were shown to be significantly related to a number of tests of dynamic muscle performance, although the strength of the relationships showed some contraction type and load specific effects. For example, the eccentric test was not related to the seated shot put throw (which is a concentric action), but was related to the drop bench press throws (10 kg load and 30% max load) which required an eccentric followed by a concentric action (10 kg load r = 0.52, 30 % max load r = 0.79, seated shot put r = 0.36). The seated shot put throw was most closely related to the isoinertial test measure involving concentric action with a low load (r = 0.59).

2.2.3. Isokinetic dynamometry

The second type of dynamic contraction is called 'Isokinetic', meaning constant (iso), speed (kinetic). The isokinetic concept of exercise was developed and introduced by Thitstle et al. (1967) and Hislop & Perrin (1967) and since its inception has gradually increased in popularity, particularly over the last twenty years. Isokinetic testing allows for maximal force production throughout a range of motion while holding the speed of movement constant (Moss and Wright 1993). This maximal force is obviously dependent upon the motivation and commitment of the participant. Modern dynamometers are able to measure both concentric and eccentric contractions and have a host of other features to allow the strict control of the protocol being performed. During isokinetic contractions the force produced is normally referred to as torque, as the force is produced about an axis of rotation. In addition to maximal torque, other studies have observed the angle at which maximal force is produced, torque ratios between agonist and antagonist muscles and RFD (Kuhn et al. 1991, Arnold and Perrin 1993, Kannus and Beynnon 1993, Moss and Wright 1993, Mayer et al. 1994 (i), Chen et al. 1994 O'Conner 1996). It is also possible to identify work rates and levels of power during each contraction performed.

There have been numerous studies that have examined the repeatability and reliability of isokinetic protocols as well as the isokinetic equipment itself (Farrell and Richards 1986, Kramer 1990, Gross et al. 1991, Malerba et al. 1993, Frisiello et al. 1994, Mayer et al. 1994 (ii), Mayhew et al. 1994). High repeatability r = > 0.85 is often presented, however studies have shown that the level of repeatability is strongly related to the body part being examined. Generally speaking, lower body parts such as the knee have higher repeatability (r = 0.92-0.95 (dominant) and r = 0.95-0.98 (non dominant) Molczyk et al. 1991, r = 0.86-0.91 Kramer 1990, r = 0.87-0.97 Gross et al. 1991) than upper body parts such as the shoulder (r = 0.72–0.83 Griffin 1987 and r = 0.80–0.94 Hellwig and Perrin 1991, r = 0.62-0.95 Malerba et al. 1993, r = 0.75-0.86 Frisiello et al. 1994). This is primarily due to the structure and stability of the lower limbs compared to the three dimensional and free movement of the shoulder.

An indication of the precision of the measurement, as represented by the standard error was given for the flexion and extension of the knee in male sprinters and distance runners during the action of knee extension and flexion. Percentage values ranging between ±3.2% and ±11.2% were produced (Gleeson and Mercer 1992).

Isokinetic dynamometry has been shown to be a valid means of assessing muscular performance (Hagerman and Staron 1983, Heiser et al. 1984, Posch et al. 1989, Telford et al. 1991, O'Conner 1996). A study which examined strength and sprint kinematics in elite sprinters identified that there was a significant relationship between sprinting times for the 100 meters and peak torque scores ($N \cdot m \cdot kg^{-1}$) (Alexander 1989). In the male sprinters there was a significant correlation between fast concentric knee extension and slow eccentric dorsiflexion and sprint performance. In female sprinters only slow concentric dorsiflexion was significantly correlated with sprint performance (Alexander 1989). Another study showed that an increase in isokinetic shoulder strength of 11% resulted in an increase in tennis serve velocity of over 11%. This was compared with a control group who had actually decreased their shoulder strength and only managed a 1% increase in serve velocity (Mont et al. 1994). Significant increases in isokinetic strength ($P<0.01$) were recorded after seven months of strenuous winter training in well-conditioned swimmers (Telford et al. 1991), however, the study did not evaluate if there had been any changes in swimming performance during this period. Although some studies have shown a link between improvements in isokinetic strength and sporting performance, other studies (Ellenbecker 1991) have failed to show a correlation between the two. This may be due to the fact that isokinetic assessment is primarily performed on the cardinal planes of motion and is therefore only comparable to some sporting actions.

Chapter 3

The design of a rugby specific strength test

With the lack of sport specific research into muscle strength in rugby players and the obvious demands made upon the players involved in the game, there is a strong case for a study that specifically examines the muscular strength of a population of rugby players. Strength in rugby players has been assessed by a variety of weight lifting tests (Maud 1983, Tong and Wood 1996), but no tests based on a sport specific movement have been developed.

3.1. Principles of sport specific strength testing

The ways in which strength testing can be made specific to a particular sport have been outlined by Sale (1991). Three levels of specificity are described.

1. Testing the muscles involved in a sports movement.

   This is the most basic level of specificity. The muscles tested should be those that are used in movements that are specific to the sport in question. For example, tests of leg extensors and flexors are typically used in sports such as running, football and basketball (Alexander 1989, Perrin et al. 1991, Hoffman et al. 1991) whereas testing of upper body muscle groups have been used in sports such as tennis and swimming. (Telford et al. 1991, McMaster et al. 1992, Mont et al. 1994).

2. Simulating the sport movement pattern as closely as possible during testing, this should include the anatomical movement pattern, contraction type (isometric, concentric, eccentric) and stretch shorten cycle.

Although it is relatively straightforward to measure muscle strength using the appropriate contraction type, with or without the stretch shorten cycle, replicating the anatomical movement pattern can be more problematic. This is because most commercially available dynamometers test single joint movements and cannot replicate the multi-joint movements common to many sports. Dynamometers have been developed to test strength and power in specific sport movement patterns e.g. swim bench (Telford et al. 1991). Alternatively, equipment can be adapted or custom built to allow replication of specific movement patterns.

3. Matching the velocity of testing to the velocity of joint movement.

Maximum force varies with speed of joint movement in both concentric and eccentric actions (described in section 2.1.2.). Since strength gains have been shown to be specific to the velocity of training (Behn and Sale 1993, Gülch 1994) and since speed and power athletes do better on high than on low velocity strength tests (Thorland 1987), the velocity of joint movement during testing should be similar to that of the sporting movement. Isokinetic dynamometry allows the velocity of movement to be controlled, but may not be suitable for the replication of very high velocity movements, since the maximal velocity that can be tested is often below the velocity of the specific movement pattern.

Factors such as ease, speed and convenience of test set-up and data acquisition and analysis should be considered. In addition, the feasibility of testing arrangements such as availability or purchasing of equipment and the possible adaptation of this equipment are all important points to be considered.

3.2. A sport specific test for rugby

Upper body strength is important in rugby union players for rucking, mauling and tackling (see section 1.1). This aspect of strength has been assessed by a variety of weight lifting tests such as the 1 repetition maximum bench press test and the press up test (Maud 1983, Tong and Wood 1995, Quarrie et al. 1996), but no tests based on a sport specific movement have been developed. One action, which is almost entirely specific to rugby, is the rugby tackle. This movement could provide the basis of a sport specific test of upper body strength.

3.2.1. The rugby tackle

The rugby tackle, whether it is from the front side or rear, involves the tackler's shoulder making contact with the opposing player. The tackler's arms are then wrapped around the opposing player to restrict their movement. The correct procedure for the execution of a safe and effective tackle from front, side or rear is given by the Rugby Football Union (RFU) and is shown in Figures 3.1, 3.2 and 3.3. These diagrams are taken from an R.F.U coaching handbook, the game has however progressed in to the professional arena and now tackles are generally made in an aggressive attacking movement. A first division match was observed and the tackles scrutinised, the majority of the successful tackles completed in the game were made going toward the player to be tackled with shoulder abduction as the primary movement. Heavy impacts were made therefore suggesting an eccentric action before the tackle was completed.

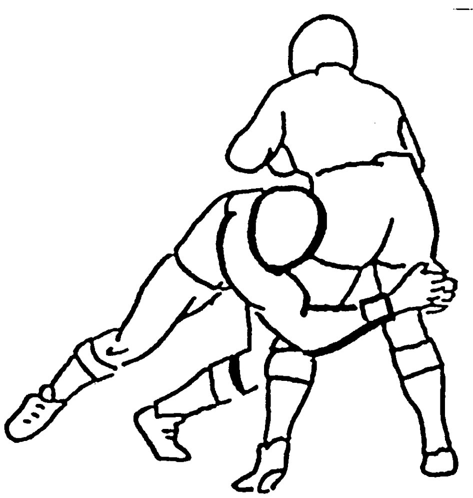


Figure 3.1. A rugby tackle from the front as outlined the English RFU.

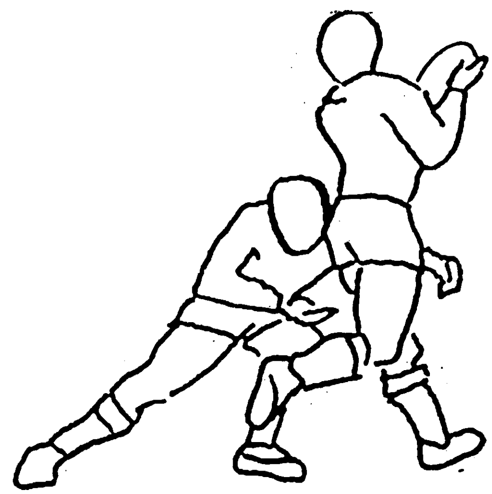
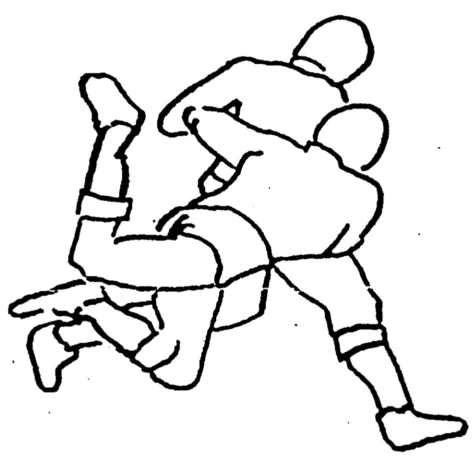


Figure 3.2. A rugby tackle from the side as outlined by the English RFU.

Figure 3.3. A rugby tackle from the rear as outlined by the English R.F.U.



The primary movement of the shoulder during a tackle is abduction. Pure abduction on the coronal plane is accomplished primarily by the actions of the deltoid muscle (Figure 3.4.). The rotator cuff plays a significant role in the stabilisation of the shoulder during this action and therefore is also important (subscapularis (Figure 3.4.), supraspinatus, infraspinatus and teres minor (Figure 3.5.)). There is however an aspect of horizontal adduction in the shoulder when tackling. This action employs the sternal and clavicular portions of the pectoralis major (Figure 3.4.) and the coracobrachialis muscles (Figure 3.4.).

The player starts the tackle by making a concentric contraction to bring the arms forward and to take hold of the opposing player. Once contact is made the arms and shoulder will be forced back with the pressure of the collision and therefore, the eccentric action is of great importance to the tackling mechanism. The ability to sustain the eccentric action at this point may be significant in the completion of a successful tackle.

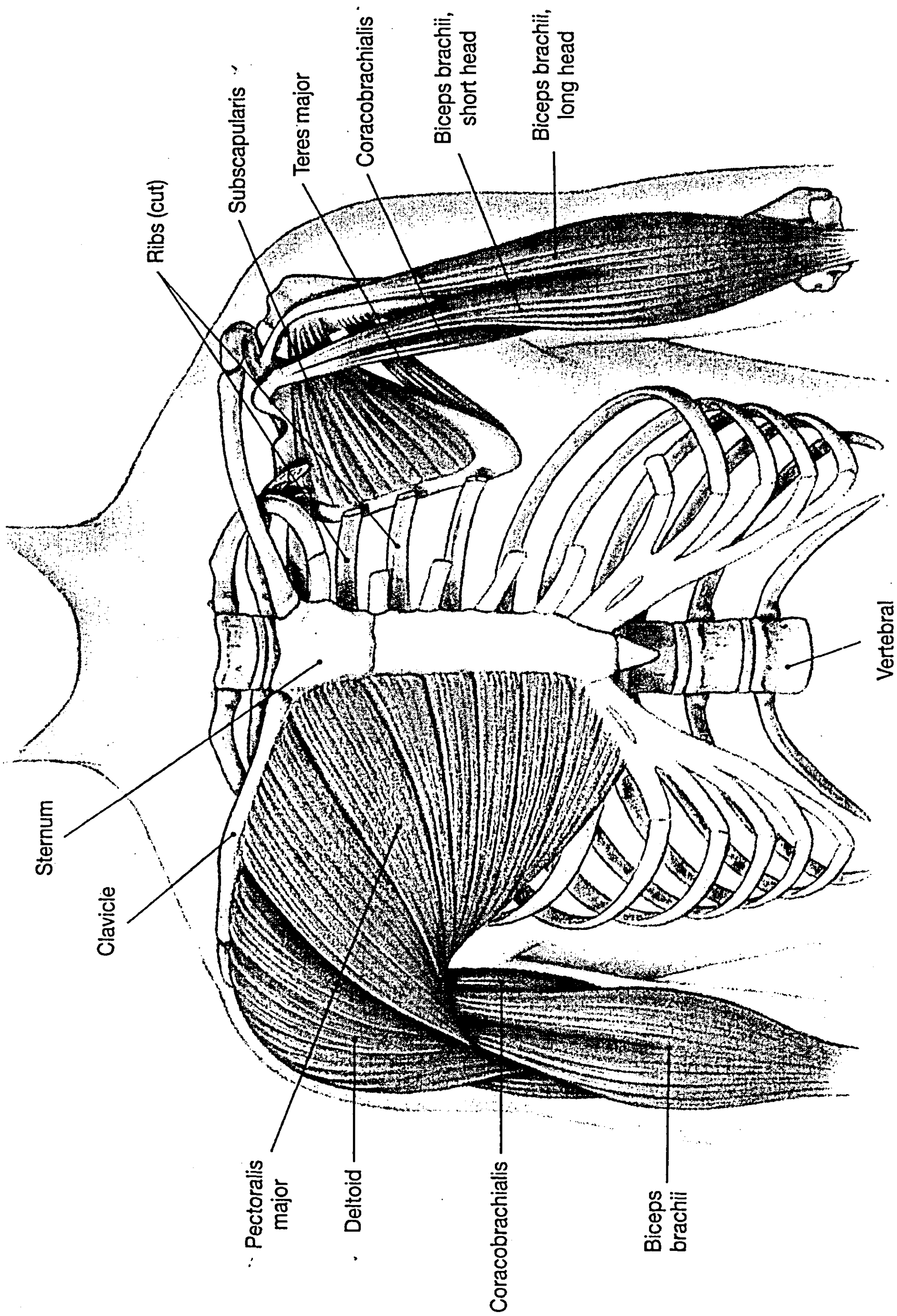


Figure 3.4. Anterior view of the upper body and shoulder highlighting the location of the Deltoid, subscapularis, pectoralis major and coracobrachialis muscle groups.

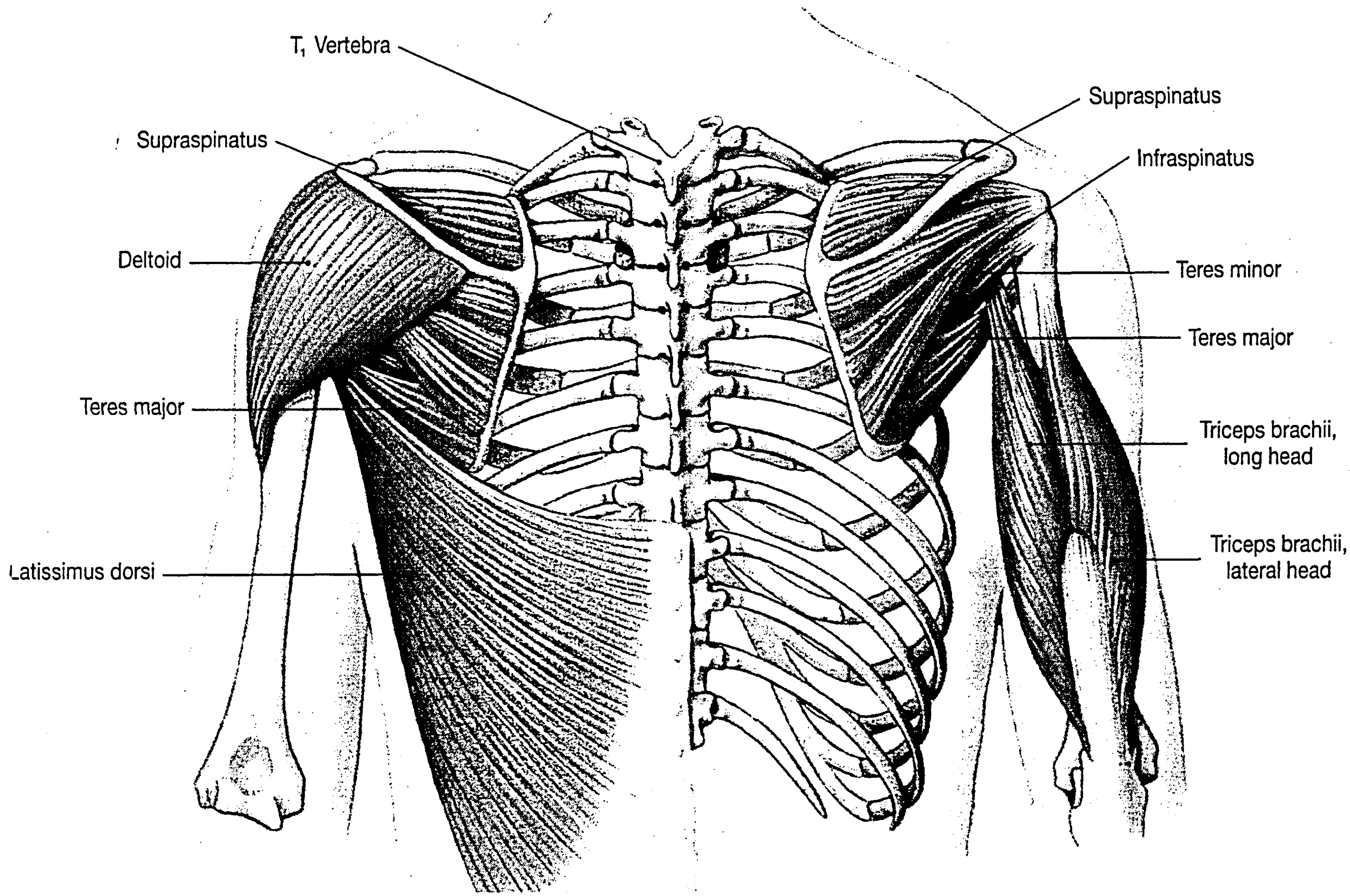


Figure 3.5. Posterior view of the upper body and shoulder highlighting the location of the supraspinatus, infraspinatus and teres minor muscles.

3.2.2. Selection of a mode of strength testing

Having considered the factors and principles involved with sport specific testing and having identified the muscle actions of concentric abduction and eccentric adduction, it was decided to use isokinetic assessment for this study. This mode of assessment has been widely used to measure strength in sport performance (Hoffman et al. 1991, Chandler et al. 1992 and Koutedakis et al. 1992). It enables the maximal force production of a given joint to be assessed throughout a range of motion during both concentric and eccentric contractions and at a prescribed velocity of movement (Mayer et al. 1994(i), Mont et al. 1994). Isometric testing was not considered to be appropriate since the rugby tackle primarily involves dynamic contractions. Isotonic (1RM and isotonic dynamometry) testing was considered unsuitable as the maximal force is limited by the weakest point in the range of motion and therefore, does not enable assessment of maximal strength throughout the range of motion of the sport specific movement. Isoinertial testing was considered unsuitable because of the high risk of injury.

Isokinetic testing is usually carried out at either low, mid or high speed velocities according to the action being considered. A high speed assessment was decided against, as the likelihood of sustaining injury is higher with high speed eccentric contractions. It was therefore decided to test at two velocities 1.08 rad•s^{-1} and 2.16 rad•s^{-1}. This covers both slow and mid speed assessment. It was not possible to identify the exact velocity at which the shoulder moves during the action of a rugby tackle as no studies were found that examined this area. It is likely that the shoulder travels at a varying velocity whilst performing a tackle and the speeds of 1.08 rad•s^{-1} and 2.16 rad•s^{-1} were felt to be a fair representation of these speeds.

3.3. Isokinetic dynamometry: Methodological considerations

The way in which an isokinetic dynamometer works is fundamentally simple. In the concentric mode the limb or body part starts and accelerates to engage the resistance mechanism of the dynamometer. Once this contact is made, the speed of the limb may exceed the pre-set velocity. The dynamometer then applies resistance to the limb to slow the movement down until the pre-set velocity is attained. This process takes a fraction of a second, after which constant velocity is maintained until the limb is slowed down and stopped at the end of the prescribed testing range of motion.

The isokinetic dynamometer available for this study was the Kinetic Communicator 500H, Chattanooga Group, Inc., Hixon, Tennessee (Kin Com®) (Figure 3.6). It permits testing to be performed by using isokinetic, isometric, isotonic or passive contractions and can be used for both concentric and eccentric muscle actions. It can assess a limb or body part at speeds between 0 and 4.5 rad•s^{-1} and permits the use of gravity correction.

There are several key components to the Kin Com® which enable it to work effectively. They are as follows:

1. The load cell. This is positioned at the end of the lever arm and it indicates the direction and the amount of force that is being applied by the subject. The load cell can accurately measure from 1 N to 2000 N.

2. The lever arm is the mechanical axis on which the load cell is positioned.

3. The potentiometer constantly measures the exact angular position of the lever arm.

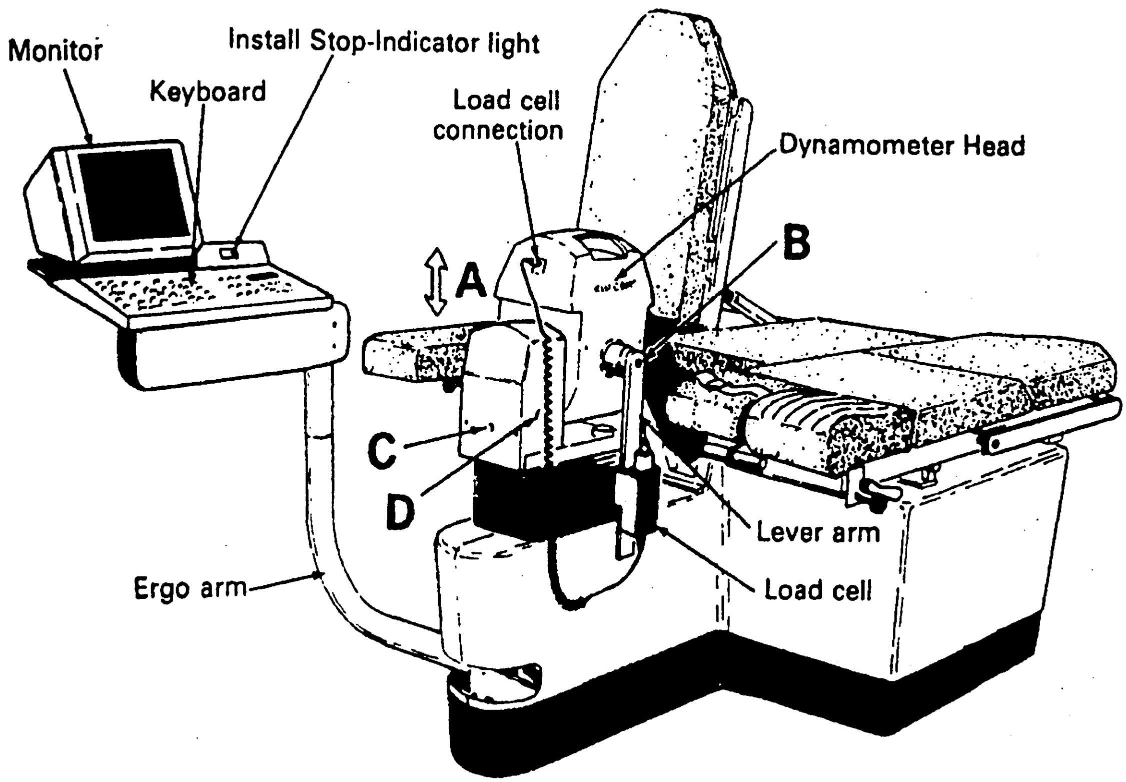
4. The tachometer measures and controls the rotational velocity of the lever arm during any activity, from 0 to 4.5 rad•s^{-1}.

Data is sampled from the load cell, the potentiometer and the tachometer every 0.01 second.

3.3.1. Reliability of isokinetic dynamometry

Many studies have been conducted that examine the accuracy and repeatability of isokinetic dynamometry (Malerba et al 1993, Frisello et al. 1994 and Mayer et al. 1994(ii)) and several have specifically examined the performance characteristics of the Kin Com® dynamometer. One such study (Mayhew et al. 1994), made comparisons between measurements of force, angle and velocity obtained by the Kin Com® and measurements acquired by an external recording system of known weights, angles and user set velocities. The reliability of the measurements was also scrutinised by conducting repeated tests on consecutive days. The repeatability of the measurement were shown to be high ($r > 0.99$).

Figure 3.6. The Kinetic communicator 500H Isokinetic dynamometer



When repeated measures of any variable are being made, there are several factors that influence and therefore, affect the reliability of the results obtained.

The factors that could affect the reliability of this and other studies of this nature are outlined by Dvir (1995) as having five potential sources.

1. Machine linked inconsistencies.

   For any measurement to have meaning, it must firstly be ascertained that the measurement is accurate. This involves the calibration of any equipment being used. Calibration is the process by which the system measured quantities are compared with a standard and if necessary, corrected. In the case of the Kin Com®, the dynamometer's ability to accurately assess a force applied to the load cell is checked by hanging a weight of known mass from the load cell. The ability of the Kin Com® to judge the angle at which the lever arm is positioned is also checked and both, can be adjusted if necessary. The Kin Com® undergoes a self-calibration test each time the machine is powered up and therefore only periodic manual calibration is required.

2. Subject linked inconsistencies.

Subject linked inconsistencies are more difficult to control. A test administrator relies upon their subjects to prepare for assessment in the correct manner, however precise instructions are necessary to ensure that the subject knows what is required of them. The time of day at which a test is performed can cause performance to vary. There is evidence (Reilly 1987) of rhythmicity in hormonal secretions at rest that affect metabolism and so have a potential impact during exercise. As such it is important that when a subject is re-tested that the assessment is conducted at a similar time to any previous assessments.

3. Testing procedure linked errors.

Error can be introduced to the results by failing to maintain standards in the testing procedure. Failure to ensure that the subject is suitably stabilised during testing can cause errors. Stabilisation has two purposes: to maintain, as closely as possible, the length-tension relationship of the muscles under consideration and to maintain, at a minimal level, or even exclude, contributions from other muscles. Other factors to be considered in this section are the test range of motion, subject positioning in relation to the isokinetic dynamometer, the angular velocities used and the alignment of biological and mechanical axes of rotation.

4. Protocol linked variations.

The decision on whether to incorporate visual and / or verbal feedback is a contentious issue. The effect of visual feedback during isokinetic assessment has been the subject of several studies. Figoni and Morris (1984), Hald and Bottjen (1987) and Baltzopoulos et al. (1991) have all reported increases in torque production when subjects were made aware of their results during slow speed isokinetic assessment. It has been shown that verbal instructions and encouragement during the testing protocol can also have an influence on torque production (Perrin 1993). However, due to an inability to ensure exactly the same level of motivation and encouragement between subjects and between tests, it is recommended that no encouragement be given during the test.

Other factors that may affect reliability are:

- The choice of a unidirectional vs. a bi-directional movement, e.g. extension only or extension followed by flexion.
- The choice of contraction mode, e.g. concentric contraction/s only, or concentric – eccentric sequence.
- Inter-contraction pause (if any and how long).
- Number of contraction repetitions and the number of sets.
- Inter-set pause.
- Test-retest interval.

These factors and others must be maintained to exactly the same setting as previous tests, if retest reliability is to be maintained.

5. Data processing linked factors – e.g. smoothing.

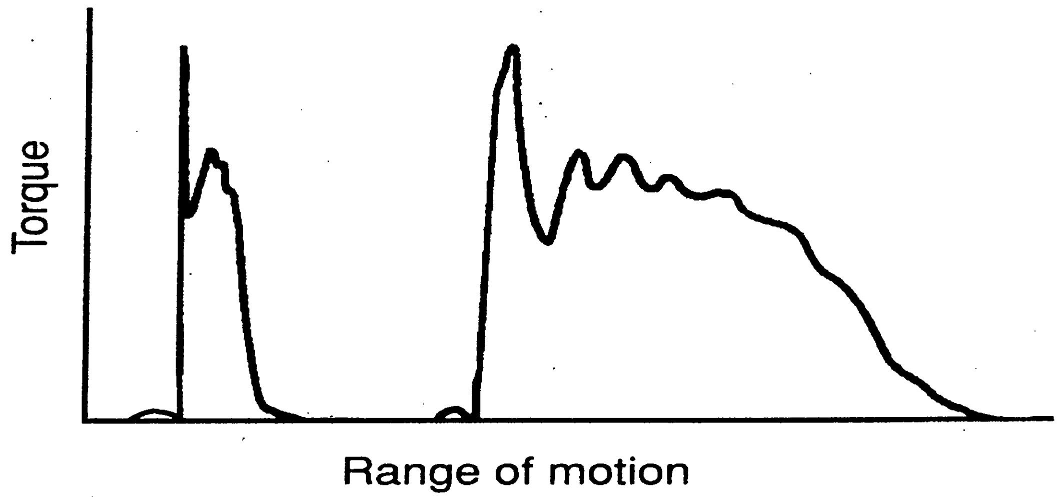
If data is to be manipulated in any way (such as data smoothing), a consistent approach must be adopted to ensure all data are treated in the same way.

There are also several factors that can affect the validity of data obtained through isokinetic assessment, which are specific to this form of dynamometry.

3.3.2. Torque overshoot

When engaging the lever arm of an isokinetic device such as the Kin Com® it is necessary to initially accelerate the limb being assessed to the predetermined test velocity. The deceleration of the overspeeding limb and lever arm results in a characteristic spike or peak known as the 'overshoot' phenomenon (Sapega et al. 1982). Figure 3.7. illustrates the 'overshoot' phenomenon. This phenomenon if ignored, would result in exaggerated reports of peak isokinetic torques, as the peak is produced by the Kin Com® reacting to the accelerating limb and is not representative of the muscle's true capacity to produce maximal force.

Figure 3.7. A curve illustrating the effect of torque 'overshoot'. From "The nature of torque 'overshoot' in Cybex isokinetic dynamometry" by A.A. Sapega, J.A. Nicholas, D Sokolow and A Saraniti, 1982, Medicine and science in sports and



To compensate for this deceleration mechanism, manufacturers have incorporated 'pre-load' features on their equipment (also referred to as 'damp' or 'ramp' on different dynamometers) in an effort to reduce the impact torque. This feature has been scrutinised to assess its effect on the torque values produced and studies have concluded that pre-load had no effect upon peak torque, but did have a significant effect upon average torque, whereby an increase in pre-load resulted in an increase in average torque (Kramer et al. 1991, Jensen et al. 1991, Tis et al. 1993).

The Kin Com® also provides three acceleration and deceleration rates (low, medium and high) to control the movement of the limb being assessed. This feature controls the rate of acceleration of the limb and therefore, allows a smoother transition from the acceleration to the constant velocity phase during the contraction (Baltzopoulos and Brodie 1989). In a study conducted by Rathfon et al. (1991), thirty one subjects completed concentric and eccentric contractions of the knee extensors at 1.62 $rad \cdot s^{-1}$ at each of the three acceleration and deceleration speeds. The study concluded that the acceleration and deceleration rate significantly affected the average velocity curve over the entire range of motion. It also had some effect on the average torque over the acceleration and deceleration phases, but had no significant effect on the average or peak torque of the whole curve. It was concluded that any of the acceleration and deceleration rates could be used without significantly affecting the results.

To combat the problems created by this 'overshoot' phenomenon it has been suggested that torque results only be taken from the portion of the curve which is truly isokinetic; therefore ignoring the acceleration and deceleration phases in the movement (Sapega et al. 1982). It was also suggested that when using the Cybex II isokinetic dynamometer that the damping be set to 0. The equivalent setting on the Kin Com® is the pre-load and this value should be kept as low as possible.

3.3.3. The gravity correction feature on isokinetic dynamometers

Gravity effect torque (GET) is the torque resulting from the effect of gravity upon the combined weight of the limb being assessed and the weight of the dynamometer lever arm. If this factor is ignored when assessing actions that involve movement of a limb through gravity dependent positions, then erroneous conclusions could be made. An example of how GET can effect results is particularly evident during the assessment of the quadriceps and hamstring muscle groups (Bohannon and Smith 1989, Perrin et al. 1991). In the case of the quadriceps, the total work may be underpredicted by four to forty three percent, consequently, the hamstring muscles total work may be overpredicted by between fifteen and five hundred and ten percent (Winter et al 1981, Nelson and Duncan1983).

A study that evaluated the effectiveness of the gravity correction feature on the Kin Com® concluded that the dynamometer accurately recorded the rotational component of gravitational forces (Finucane et al. 1994). It recommended that when selecting a joint angle at which to complete the gravity correction procedure, that the limb is not positioned so as to put two joint muscles in a stretched position, as this would cause inaccurate measurement of the gravitational forces acting upon the limb.

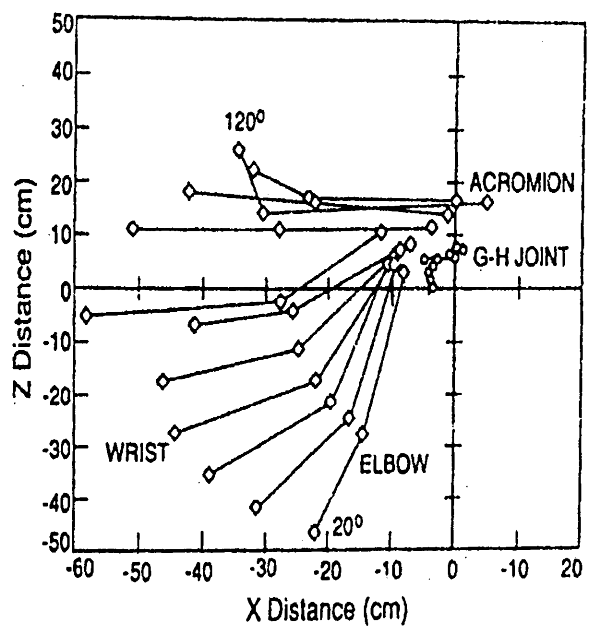
3.3.4. Isokinetic assessment of the shoulder

Using the Kin Com isokinetic dynamometer the shoulder strength can be assessed by shoulder abduction / adduction in the coronal plane or by internal / external rotation in the horizontal plane. Since the shoulder movement in the rugby tackle involves primarily shoulder abduction and adduction in the coronal plane this testing position was selected as the action best representing the tackle. Measurement of shoulder strength during movement across two planes was not possible with the equipment available.

A methodological problem specific to the assessment of shoulder abduction / adduction is the alignment of the axis of rotation in the glenohumeral joint with that of the dynamometer. During the action of abduction / adduction there is a significant movement of the scapula after the first 30° of movement. The next 150° of abduction and adduction occur as a combination of movement between the glenohumeral joint and the shoulder girdle joints. A relationship then exists between the humerous and the scapula whereby every 2° of movement of the humerous is achieved by a concomitant movement of 1° in the scapula.

A study which examined the movement of the axis of rotation of the glenohumeral joint during the abduction and adduction movement concluded that the axis of rotation moved by approximately eight centimetres from the beginning to the end of the range of motion (Walmsley 1993). Figure 3.8. shows the tracing of various reference points during the movements of abduction and adduction. It can be clearly seen that to allocate a single axis of rotation for assessment, (as is necessary when using an isokinetic device) is a compromise. Care needs to be exercised to ensure that this position is as close to the majority of the true axis of rotation as possible. Based on Walamsley's (1993) data the axis of rotation was set six centimetres in from the distal point of the acromion process.

Figure 3.8. Relative positions of the wrist, elbow, acromion process and the glenohumeral joint during shoulder abduction from 20° to 120° of movement. Pooled data (n=7) viewed on the X-Z plane. Taken form Walmsley 1993.



3.4. Experimental aims of the study

The experimental aims of this study were:

1. To assess the reliability of various test measures of shoulder strength during the isokinetic assessment of shoulder abduction / adduction.
2. To use the most reliable test to measure the shoulder strength of rugby union players during a period covering the pre-season training and competitive playing season.

Chapter 4

Methodology

4.1. The isokinetic dynamometer

The Kinetic Communicator 500H, Chattanooga Group, Inc., Hixon, Tennessee (Kin Com®) was used in evaluation mode to measure maximal isokinetic strength during concentric abduction and eccentric adduction of the shoulder. The shin pad was attached to the load cell and the moveable chair was used to position the subject next to the dynamometer head (Figure 4.1).

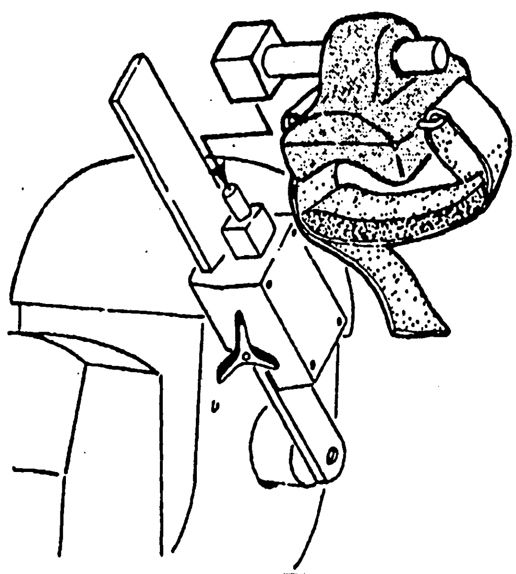


Figure 4.1. The shin pad is attached to the load cell, which in turn is located upon a moveable vice to allow movement along the length of the lever arm. The positioning of the load cell is measured against a scale which is marked on the outside edge of the lever arm.

4.1.1. Calibration of the isokinetic dynamometer

Before the study began the Kin Com® was calibrated by an qualified engineer from the Chattanooga group. All facets of the operation of the machine were checked and found to be correct. Subsequent calibration was performed as part of the start up procedure of the Kin Com®, with self checks of velocity, angle and force registering components of the equipment. The machine was re checked at the end of the study by a laboratory technician and again, no alteration of the equipment was necessary.

4.1.2. The isokinetic dynamometer settings

4.1.2.1. Range of movement

The range of movement was set at 20° to 130° using the electrical stops. The subject was initially set-up with their arm abducted to 90°, this was measured using a goniometer. The dynamometer was calibrated and the range of motion was set from this. To prevent injury in the event of an electrical failure, the mechanical stops were positioned to ensure that the movement of the lever arm was restricted to this range of movement (Figure 4.2).

4.1.2.2. Acceleration and deceleration rates

Acceleration and deceleration rates were set to "high".

4.1.2.3. Preload

A preload setting of 50 N was used for the reproducibility study. This was increased to 120 N for the main study.

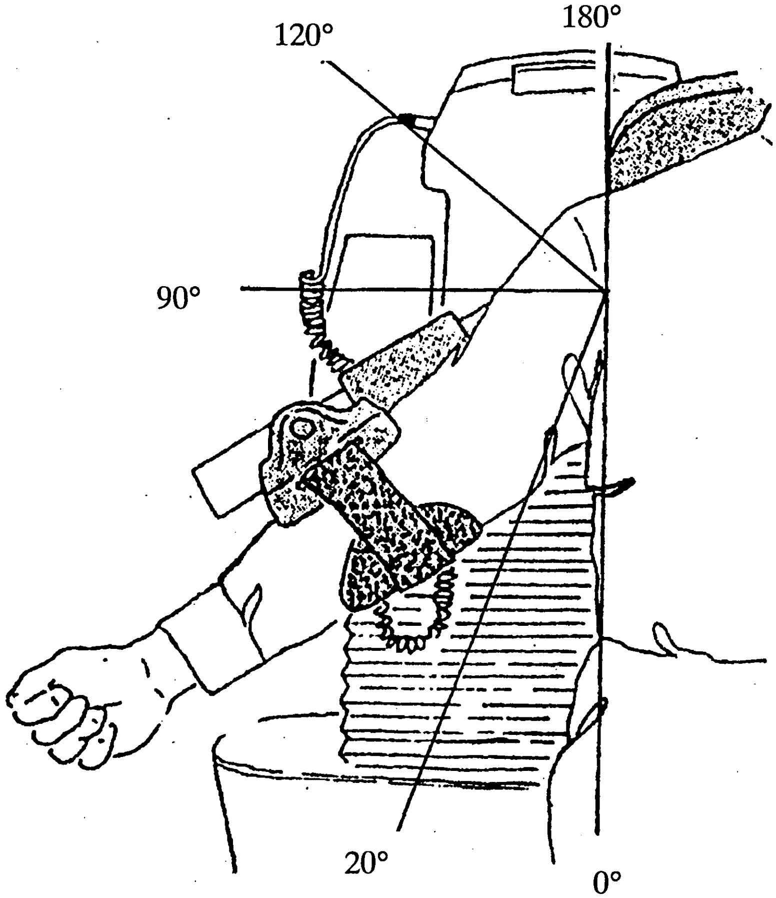


Figure 4.2. Range of motion for the isokinetic assessment of shoulder abduction and adduction on the Kin Com ® isokinetic dynamometer.

4.1.2.4. Speed of movement

Subjects were tested at two velocities, 1.08 rad•s^{-1} and 2.16 rad•s^{-1}.

4.1.2.5. Gravity correction

The gravity correction option was selected, the lever arm was moved to the horizontal position and the limb weighed.

4.1.3. Subject positioning

The subject was seated in the testing chair. The axis of rotation of the glenohumeral joint was identified by taking a point six centimetres in from the tip of the acromium process (see section 3.3.4.). This was aligned with the mechanical axis on the Kin Com by moving both the chair and the dynamometer head. The chair was secured by applying the rubber stops on each wheel. The seat position, seat height and dynamometer head height were recorded and subsequently used for further tests. The subject was stabilised in the testing chair with the use of velcro straps. One strap was placed across the waist and a second, from the waist diagonally across the torso and over the shoulder not being tested. A third strap was placed across the thighs and under the seat of the chair to restrict lower limb movement. The pad on the lever arm was positioned over the elbow joint with the wrist rotated so that the palm of the hand faced forward. The pad was secured using velcro strapping. The length of the lever arm was measured as the distance between the load cell and the mechanical axis of rotation. In subsequent tests using the same subject, the lever arm length was checked to ensure that the value did not change, due to incorrect positioning of the subject (Figure 4.3).

4.1.3.1. Identifying the subjects dominant limb.

Each subject was asked to identify their dominant shoulder. This was identified by the subject as being the shoulder with which they preferred to tackle.

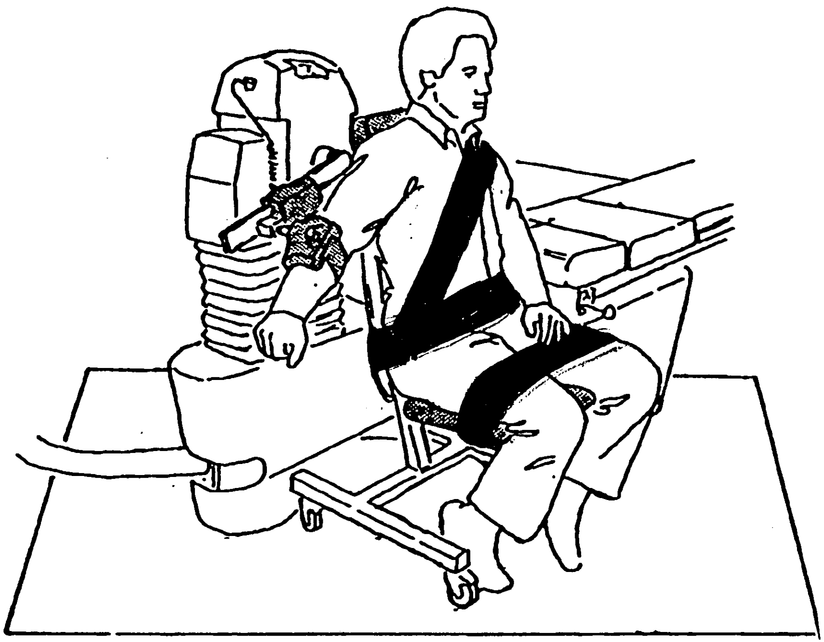


Figure 4.3. Subject positioning and stabilisation whilst being assessed for the concentric abduction and eccentric adduction on the Kin Com® isokinetic dynamometer.

4.1.4. Test protocol

The test protocol is described in Table 4.1. Testing was initially carried out at 1.08 rad•s^{-1} followed by 2.16 rad•s^{-1} with approximately six minutes rest between speeds. A contraction cycle consisted of a concentric abduction followed fifteen seconds later by an eccentric adduction. At each test speed, the subject performed a warm up which comprised of three submaximal and one maximal contraction cycles. This was followed by four maximal contraction cycles. Contractions were performed every fifteen seconds with each contraction cycle lasting thirty seconds. No verbal or visual feedback was given during the testing protocol, however verbal instructions were given to begin each contraction.

Table 4.1. Protocol timing and contraction types

Velocity = 1.08 rad•s^{-1}								
Time (min : sec)	0:00	0:15	0:30	0:45	1:00	1:15	1:30	1:45
Contraction type	W/u con	w/u ecc	w/u con	w/u ecc	w/u con	w/u ecc	m.v.c. w/u con	m.v.c. w/u ecc
Time (min : sec)	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45
Contraction type	m.v.c. con	m.v.c. ecc	m.v.c. con	m.v.c. ecc	m.v.c. con	m.v.c. ecc	m.v.c. con	m.v.c. ecc
REST								
Velocity = 2.16 rad•s^{-1}								
Time (min : sec)	10:00	10:15	10:30	10:45	11:00	11:15	11:30	11:45
Contraction type	w/u con	w/u ecc	w/u con	w/u ecc	w/u con	w/u ecc	m.v.c. w/u con	m.v.c. w/u ecc
Time (min : sec)	12:00	12:15	12:30	12:45	13:00	13:15	13:30	13:45
Contraction type	m.v.c. con	m.v.c. ecc	m.v.c. con	m.v.c. ecc	m.v.c. con	m.v.c. ecc	m.v.c. con	m.v.c. ecc

con = concentric **ecc = eccentric**
w/u = warm-up **m.v.c. = maximal voluntary contraction**

4.1.5. Subject familiarisation

The subjects were familiarised with the equipment and the test protocol. The nature of the contraction cycle was explained and several practices were allowed, to ensure that the subjects could perform concentric and eccentric contractions successfully.

4.1.6. Data analysis

Data from the last four contraction cycles were used to assess isokinetic strength at each test velocity.

4.1.6.1. Range of true isokinetic movement

The true range of isokinetic movement was taken as the range over which constant velocity was achieved for each contraction type by all subjects. The constant velocity was defined by 1.08 $rad{\bullet}s^{-1} \pm 0.018$ and 2.16 $rad{\bullet}s^{-1} \pm 0.036$. Data recorded over this range was then used in subsequent analysis.

4.1.6.2. Isokinetic strength indices

Three indices of strength were derived from the data generated from each contraction type. These are:

1. Average torque.
2. Average peak torque.
3. Peak torque.

The average torque was calculated as the mean value of all four contractions. The average peak torque was calculated as the mean of the peak torque values from each contraction. Peak torque was taken as the highest torque value from any one of the four contractions.

4.2. Anthropometric measures

At the initial testing session all subjects had their height and weight measured using a balance scale and stadiometer. On subsequent assessments subjects had their weight measurement reassessed.

4.3. Pre-testing questionnaire.

All subjects completed a medical questionnaire prior to examination (appendix 2). This questionnaire was used to identify any medical conditions, which would preclude the subject from examination on the basis of this or previous injuries.

Chapter 5

The reliability of isokinetic testing of shoulder abduction and adduction.

5.1. Introduction

A pilot study was conducted to assess the reliability of the isokinetic assessment of concentric abduction and eccentric adduction of the shoulder.

Reliability is the repeatability, or consistency in the repetition of a measurement process. There are a variety of methods that have been used to assess the reliability of test results.

Analysis of variance (ANOVA) or t-test (Malerba et al. 1993) are used to assess whether or not there is a significant difference between test-retest measures. The assessment of the reliability of the measure, or more importantly the correlation between the two measures (Tredinnick and Duncan 1988, Kramer 1990, Tis et al. 1993, Frisiello et al. 1994, Finucane et al. 1994) is completed using one (or more) of several tests. Pearson correlation is sometimes incorrectly used to assess the test-retest reliability. Pearson compares deviations from the mean in two measures, but is not sensitive to the changes in the means of the scores. If the fluctuations in the results between test 1 and test 2 all occur in a systematic manner (they all go up or down by the same amount) the order and deviation will remain unchanged and the correlation high, however the two means may differ significantly. This may lead to erroneous conclusions. The intraclass correlation coefficient (ICC) overcomes this problem, as it is sensitive to both changes in the order and the magnitude (mean differences) of the repeated measures. Both Pearsons and ICC produce their results in the form of a r value and subsequently give little information as to the variability of a score (Vincent 1995, Hopkins 1997). Two tests used to show within-subject variation are standard error of measurement (SEM) and limits of agreement. SEM is essentially the standard deviation of the measurement. This is essentially the within-subject variation in the measurement, after changes in the mean have been accounted for. It allows the variability in the measurement to be presented as a unit (N•m) or as a percentage of the strength value. Limits of agreement presents a value, which is the 95% likely range for the differences between a subject's score in two tests. This is presented as the measured value. The majority of the literature within the field of isokinetics refers to ICC and SEM values. Therefore for ease of comparisons these statistical methods were employed for analysis of the results.

ICC coefficients greater than 0.8 indicate acceptable level of test-retest reliability (Shrout and Fleiss 1979, Denegar and Ball 1993 and Vincent 1995). In the isokinetic assessment of shoulder rotation ICC values between r = 0.44 - 0.94 have been reported (Malerba et al. 1993, Frisello et al. 1994, Keskula and Perrin 1994). This wide range in ICC values reflects how various factors in these studies can affect reliability. Lower reliability has been found with eccentric compared with concentric contractions (Malerba et al. 1993) and in continuous compared with interrupted protocols (Keskula and Perrin 1994). The speed of contraction has also been shown to affect the reliability of the measure (Osternig 1986). The assessment of more stable limbs such as the knee results in greater reliability of measurement. Gleeson and Mercer (1992) produced ICC results ranging between r = 0.94 and r = 0.97 for gravity corrected peak torques resulting from the isokinetic flexion and extension of the knee. Molczyk et al 1991 examined the reliability of the knee flexor and extensor strength in the dominant limb at 1.08 $rad{\bullet}s^{-1}$, 3.24 $rad{\bullet}s^{-1}$ and 5.4 $rad{\bullet}s^{-1}$ and presented ICC values of $r = 0.95$, $r = 0.92$ and $r = 0.95$ respectively.

ICC identifies the reliability of a measurement but does not give an indication of the precision of the measurement. To identify this the, standard error of the measurement may be calculated (Denegar and Ball 1993). Gleeson and Mercer (1992) examined the flexion and extension strength of the knee in male sprinters and distance runners. The reproducibility of knee extension and flexion peak torque produced ICC results of r = 0.91 – 0.96 and the SEM% ranged between ±3.2% and ±11.2%.

Since there is little information on the reliability of the isokinetic measurement of muscle strength during shoulder abduction and adduction, the aim of this chapter is to investigate the variability of these measurements.

5.2. Methodology

5.2.1. Subjects

Ten male subjects participated in the reproducibility study. Subject details are given in Table 5.1. These subjects were all senior rugby union players who were competing in the 1995/1996 season. All the players were engaged in regular training programmes for fitness and skills involved in the game of rugby union and were playing in competitive matches weekly (subject to selection and injury).

Table 5.1. Subject details (Mean ± standard deviation).

N	Age (years)	Height (m)	Mass (kg)
10	25.7 ± 2.0	183.7 ± 8.4	93.2 ± 19.1

All the subjects had been free from upper body injuries during the previous year and were asked to complete an additional medical questionnaire, to screen for musculo skeletal disorders (see appendix 2). They were informed of the procedures to be used and made aware of the inherent risks of participation in such a study. The subjects were then asked to sign a consent form before participating in any of the tests (see appendix 3).

5.2.2. Measurement of isokinetic strength

Isokinetic strength of the shoulder was assessed using the Kinetic Communicator 500H, Chattanooga Group, Inc., Hixon, Tennessee (Kin Com®) as described in Chapter 4. Average torque, peak torque and average peak torque were recorded.

5.2.3. Testing procedure

Isokinetic strength was assessed on two occasions with seven days separating the tests. Both test and retest were conducted at the same time of day for each subject. The subjects were instructed to maintain their regular programme of training and competition during this week. The laboratory temperature and humidity were recorded before each testing session. The subject positioning in relation to the machine, the alignment of the axis of rotation and gravity correction were individual to each subject and these factors were kept constant between tests.

Shoulder abduction and adduction were tested at two velocities 1.08 rad $\bullet s^{-1}$ and 2.16 rad $\bullet s^{-1}$ over the range of motion of 20 to 130 degrees. All subjects were initially tested at the slower velocity (Wilhite et al. 1992), however the starting limb was chosen at random. The subject was then re-tested on the opposing limb and the same procedure was followed. Data was taken from the true isokinetic range of motion as described in section 4.1.6.1.. Therefore, the range of motion for the purpose of data analysis is shown in Table 5.2..

Table 5.2. Limit of constant velocity motion for concentric abduction and eccentric adduction of the shoulder.

	Limit of motion (degrees)	
Concentric 1.08 rad $\bullet s^{-1}$	38	130
Concentric 2.16 rad $\bullet s^{-1}$	59	130
Eccentric 1.08 rad $\bullet s^{-1}$	104	20
Eccentric 2.16 rad $\bullet s^{-1}$	103	20

5.2.4. Statistical analysis

5.2.4.1. Anova

A four factor ANOVA (General Linear Model) with repeated measures on all factors was conducted to identify any differences in the strength measure between the two tests and also, differences due to the speed of contraction, arm dominance and contraction type. The factors and levels for the test are shown in Table 5.3. The level of significance was set at $P \leq 0.05$.

Table 5.3. Factors and levels for the GLM ANOVA.

Factor	Level 1	Level 2
Test	First	Second
Speed	1.08 rad $\bullet s^{-1}$	2.16 rad $\bullet s^{-1}$
Arm	Dominant	Non Dominant
Contraction type	Concentric	Eccentric

5.2.4.2. Intraclass correlation

The intraclass correlation coefficient was calculated for each test measure using a one way ANOVA according to the formula given by Vincent (1995).

5.2.4.3. Standard error of measurement

Standard error of measurement was calculated from the data using the following formula:

$$SEM = s \sqrt{(1-r)}$$

where s is the standard deviation of the measurement and r is the ICC (Denegar and Ball 1993).

5.3. Results

The mean strength values (mean ± SD) recorded during the test and re-test are shown in Table 5.4. below. Analysis of variance (GLM model) for each measure of strength (average torque, average peak torque and true peak torque) identified that there were no significant differences in values due to test number, speed of contraction, or arm dominance. A significant difference was identified between concentric and eccentric values in all three strength measures ($P < 0.01$).

Table 5.4. Mean torque values (mean ± SD) for isokinetic concentric abduction and eccentric adduction of the shoulder joint at 1.08 rad•s^{-1} and 2.16 rad•s^{-1}. Values are presented for the dominant and non-dominant arms.

	Average torque (N•m)			
	DOM		NON DOM	
	Test 1	Test 2	Test 1	Test 2
C1.08	61 ± 17.4	60 ± 12.7	58 ± 17.6	59 ±13.0
C2.16	57 ± 18.3	58 ± 15.4	56 ± 17.1	57 ± 14.4
E1.08	88 ± 29.3	90 ± 23.5	82 ± 23.6	88 ±19.4
E2.16	93 ± 26.5	96 ± 21.5	88 ± 18.7	95 ± 19.9
	Peak torque (N•m)			
	DOM		NON DOM	
	Test 1	Test 2	Test 1	Test 2
C1.08	75 ± 22.3	74 ± 15.7	72 ± 23.2	72 ± 15.4
C2.16	66 ± 18.7	67 ± 15.9	65 ± 18.0	66 ± 13.7
E1.08	108 ± 31.2	109 ± 29.2	101 ± 27.0	111 ± 32.3
E2.16	115 ± 31.4	114 ± 23.6	108 ± 24.0	114 ± 27.6
	True peak torque (N•m)			
	DOM		NON DOM	
	Test 1	Test 2	Test 1	Test 2
C1.08	80 ± 22.9	80 ± 21.2	77 ± 25.4	78 ± 17.8
C2.16	70 ± 18.3	74 ± 17.8	70 ± 18	70 ± 15.2
E1.08	117 ± 29.6	120 ± 36.4	109 ± 30.1	118 ± 37.4
E2.16	126 ± 34.7	125 ± 28.5	116 ± 26.4	121 ± 29.0

C1.08 = concentric 1.08 rad •s^{-1}. E1.08 = eccentric 1.08 rad •s^{-1}
C2.16 = concentric 2.16 rad •s^{-1}. E2.16 = eccentric 2.16 rad •s^{-1}.
DOM = dominant NON DOM = Non dominant

The values obtained for ICC are shown in Table 5.5. All the values were greater than 0.8 indicating an acceptable level of reproducibility. Values for the dominant arm were generally higher than for the non-dominant arm. Values for the dominant arm ranged from r = 0.91 - 0.97 and between r = 0.80 - 0.95 for the non-dominant arm. The lowest ICC values were recorded for eccentric adduction in the non-dominant arm.

Table 5.5. Intraclass correlation coefficients (*r*) derived from test re-test strength measures for the concentric abduction and eccentric adduction of the shoulder.

	Dominant	Non Dominant
Average		
C1.08	.93	.93
C2.16	.96	.95
E1.08	.95	.85
E2.16	.97	.86
Average Peak		
C1.08	.91	.89
C2.16	.97	.93
E1.08	.95	.81
E2.16	.95	.85
True Peak		
C1.08	.94	.91
C2.16	.95	.95
E1.08	.93	.80
E2.16	.95	.91

C1.08 = concentric 1.08 rad $\bullet s^{-1}$. E1.08 = eccentric 1.08 rad $\bullet s^{-1}$
C2.16 = concentric 2.16 rad $\bullet s^{-1}$. E2.16 = eccentric 2.16 rad $\bullet s^{-1}$.

5.3.1. Standard Error of Measurement (SEM).

The SEM was calculated for all test variable types and each contraction type. The results can be seen in Table 5.6. and range from ±3.2 N•m - ±8.2 N•m for average torque, ±3.8 N•m - ±13.0 N•m for average peak torque and ±3.9 N•m - ±14.9 N•m for peak torque.

Table 5.6. SEM for each contraction type and test variable. All values shown in N•m.

	Dominant N•m			Non Dominant N•m		
	Average	Average peak	True Peak	Average	Average peak	True peak
C1.08	± 3.9	± 5.7	± 5.0	± 4.0	± 6.4	± 6.5
C2.16	± 3.2	± 3.8	± 3.9	± 3.6	± 4.0	± 3.9
E1.08	± 5.6	± 5.0	± 8.9	± 8.2	± 13.0	± 14.9
E2.16	± 4.2	± 6.1	± 7.2	± 7.1	± 9.8	± 8.2

5.4. Discussion

The isokinetic strength of rugby players was found to be considerably higher than previously reported normative data (Mayer 1994(f)) which was collected from a population of 51 untrained men and women.

The strength values for concentric abduction and eccentric adduction at 1.08 rad•s^{-1} produced from the assessment of rugby union players are compared to the results of Mayer's male normative population in Table 5.7.

Table 5.7. Concentric abduction and eccentric adduction of the shoulder, comparisons of average peak torque (APT) values at 1.08 rad•s^{-1} between rugby union players and a normal male population (Mayer 1994).

	Rugby players N= 10	Normative data N= 32	Rugby players N= 10	Normative data N= 32
	Dominant		Non dominant	
Concentric Abduction (APT).	75 ± 19 N•m	38 ± 7 N•m	72 ± 19 N•m	38 ± 7 N•m
Eccentric Adduction (APT).	109 ± 29 N•m	55 + 11 N•m	106 ± 29 N•m	55 ± 10 N•m

The results suggest that the rugby union player is significantly stronger than the 'normal' population. This can be attributed to either the training involved in preparation for rugby union, or, the training effect of match play itself. What is more likely is that it is a combination of these factors, over a period of time, which enhances the strength of individuals who play rugby. The rugby players are significantly larger than the population studied by Mayer et al. (1994(f)) and this will also contribute to their greater strength.

The subjects in the pilot study were a mixture of forwards and backs. Even within the forward population large differences in size and strength were evident. Consequently, the SD of the data ranged from 12.7 N•m to 25.4 N•m for concentric contractions and 18.7 N•m to 37.4 N•m for eccentric contractions. The range of the actual values for concentric and eccentric contractions were 42.8 N•m to 110 N•m and 61 N•m to 132 N•m respectively.

Analysis of the test re-test data identified that there was no significant difference between test 1 and test 2 in any of the test measures.

The ICC values were above 0.8 for all test measures, indicating an acceptable level of repeatability. The large standard deviation within the data would however influence this. There are no reported figures for ICC of the abduction or adduction of the shoulder; however, Mayer et al. (1994(ii)) has reported variability of peak torque test re-test measures for a variety of shoulder movements including abduction and adduction. Variability of abduction and adduction measures is less than that for internal / external rotation. Studies of the internal / external rotation of the shoulder produced ICC results of r = 0.75 - 0.86 (Frisiello et al. 1994) and a study conducted by Malerba et al. (1993), produced ICC results of r = 0.62 - 0.95 for concentric peak torque and r = 0.44 - 0.90 for eccentric peak torque. In studies which examine the extension of the knee ICC results of r = 0.86 - 0.91 (Kramer 1990), r = 0.87 - 0.97 (Gross et al. 1991), r = 0.92 - 0.95 (dominant) and r = 0.95 - 0.98 (non-dominant) (Molczyk et al. 1991) have been reported. The reason why higher ICC results are obtained for examination of the knee is related to the anatomy of the joint. The knee allows movement in one plane, unlike the shoulder, which allows free movement in all planes. Equally important is the axis of rotation. The knee is far easier to align accurately and the axis of rotation is fundamentally fixed, whereas the axis of rotation in the shoulder moves quite considerably after the first 15° of abduction, as the relationship of movement between the scapula and the humorous begins to take affect. A study by Walmsley (1993) showed that the axis of rotation during shoulder abduction and adduction moved by 8cm during the full range of motion. It therefore necessitates a compromise axis of rotation to be adopted for analysis to take place. These two basic differences between the joints result in the shoulder being a far more complex joint to assess accurately. This results in a greater variability in test retest measures of the shoulder and therefore lower ICC values are recorded. Despite this, the method used in this study to position the subject and align the axis of rotation has resulted in reproducible measures.

The range of SEM values recorded for concentric actions was ±3.2 - ±6.5 N•m (±5.4% - ±8.8%) and for eccentric actions was ±4.2 - ±14.9 N•m (±4.5% - ±13.2%). Values for concentric actions fall within the range of ±3.2% - ±11.2% reported for concentric knee flexion and extension (Gleeson and Mercer 1994).

Torque values produced by both dominant and non-dominant limbs were assessed; however, no significant difference existed between them. Previous studies have identified that in sports such as tennis, which predispose the participant to prefer one limb, there are significant differences in contralateral strength (Ellenbecker 1991, Chandler et al. 1992, Pedegana et al. 1982). Although the rugby players identified their preferred tackling shoulder, this was not reflected by increased isokinetic strength measurements in the dominant shoulder.

The results showed the expected trends of a decrease in concentric torque values and an increase in eccentric torque values at the higher velocity, however this was not significant.

The variability of the strength measurements of the non-dominant shoulder was greater than the dominant shoulder and this was reflected in both the ICC and SEM values. It was noticeable that there was little difference in reliability between concentric - eccentric measures of strength in the dominant limb, whereas in the non-dominant limb eccentric actions displayed greater variability. Previous studies on the reliability of the isokinetic assessment of the shoulder have consistently demonstrated greater variability for eccentric actions (Malerba 1993 and Mayer et al. 1994(ii)). The similarity in the reliability of concentric and eccentric actions in the dominant arm in rugby players suggests that the nature of the sport has resulted in more consistent eccentric actions in this limb.

In conclusion, inspection of the ICC and the SEM values for the various test measures indicate that the greatest reliability (as indicated by ICC values) and repeatability (as indicated by the SEM) occurs in the average torque values at 2.16 rad•s^{-1} in the dominant arm. Although the ICC values for these measures are high (r = 0.96 -0.97), the range of SEM values (±3.2 - ±5.6 N•m) would not allow confident interpretation of changes in isokinetic strength of the shoulder in individuals. However, these measures may be used to identify changes in strength in groups of individuals in response to an intervention.

The minimum mean test re-test difference that could be detected by the test with 80% power and α = 0.05 is 4.04 N•m and 4.98 N•m for concentric abduction and eccentric adduction at 2.16 rad•s^{-1} respectively. This was calculated according to Portney and Watkins (1993). In this group this would represented a change in strength of approximately 6%. This is well within the expected increase in strength following a strength training programme.

Chapter 6

A seasonal assessment of isokinetic concentric abduction and eccentric adduction of the shoulder in Rugby Union players.

6.1. Introduction

The aim of this study was to measure the isokinetic shoulder strength of rugby union players during the season to provide a sport specific assessment of fitness in this sporting group.

A year in rugby has three distinct phases to it. These are:

1. Off-season
2. Pre-season
3. Playing season.

During the off season, which normally begins in May and continues until the end of June or the beginning of July, players rest. This time is used to enable the players to fully recover from any injuries sustained during the previous season and to prepare themselves both mentally and physically for another year of competitive play.

During the pre-season phase of the year (June/July up to the end of August) players should undertake very high levels of muscular and cardiovascular conditioning work and increases in both muscle strength and aerobic capacity might be expected to be seen during this phase.

During the playing season, the aim of training is to maintain levels of muscular strength and cardiovascular fitness and to improve game related skills. The training volume is lower than in the pre-season phase to account for the preparation required for competitive matches.

A study which examined the number of weight training sessions and the improvements in strength suggested that training 5 days a week gave significantly greater improvements in strength that training fewer days (McKenzie Gillam 1981). In addition to this there is evidence that suggests that upon beginning a training programme improvements in strength are made rapidly as the neurological system is stimulated more efficiently, therefore allowing greater muscle fibre recruitment (Fox et al. 1993, Perrin 1993).

Key physiological variables e.g. aerobic capacity and muscle strength, have been shown to change during the season (Allen 1989, Koutedakis et al. 1992). These changes would be expected to match the activity associated with the phase of the season. During the off-season phase a reduction in $\dot{V}O_2max$ from 55.80 $ml \cdot kg^{-1} \cdot min^{-1}$ to 48.98 $ml \cdot kg^{-1} \cdot min^{-1}$ was identified in six professional rugby league players. During the same period, average body weight dropped from 79.75 kg to 76.04 kg and the total skinfold measures of six sites remained relatively constant at 55.04mm and 53.65mm, indicating a loss in muscle mass (Allen 1989). Muscular strength was not measured in this study but would be expected to decrease if players had ceased training entirely (Graves et al. 1988). Deterioration of physiological variables during the off-season has been observed in other sports. In rowing an 18% reduction between in-season and off-season $\dot{V}O_2max$ was reported for nine US Olympic oarsman (Hagerman and Staron 1983).

During the competitive season, training is aimed at maintaining physical fitness, however, some studies have shown that fitness may deteriorate during this time. Eighteen International British downhill, free-style and speed skiers were subjected to tests to assess muscular and cardiovascular fitness at the beginning, middle and end of the skiing competitive season (October – June). There was a significant reduction in mean $\dot{V}O_2$ max between the beginning and end of season tests ($P< 0.05$). This was accompanied by significant reductions in isokinetic mean peak torques for the knee extensors measured at the end of the season, compared with both the start ($P< 0.01$) and the middle ($P< 0.05$) of the season (Koutedakis et al. 1992). The decrease in fitness was attributed to a lack of appropriate training during the competitive season. Such a decrease in fitness would be expected to have a negative effect on performance, however a training schedule that is too demanding may result in overtraining and similarly, decrease fitness/performance (Callister et al. 1990, Fry et al. 1994).

The game of rugby union has changed from an amateur to a professional status. This has placed increased demands on players in terms of the number of matches played and the training required. This would be expected to increase the overall levels of fitness in the game, but the increased demands during the competitive season may result in overtraining and consequently a decrease in performance.

Previous studies have shown that forwards are significantly stronger than backs when strength is assessed in absolute terms (Tong and Mayes 1995). During a game and therefore a playing season the demands placed upon a forward are very different to that of a back player. Subsequently, the training stimulus that the two player groups are exposed to may vary significantly; this difference may be sufficient to create a training effect in one group and not the other.

The measurement of shoulder abduction/adduction provides a test of shoulder strength which is specific to rugby. Testing at specific points during the season (pre-season, start of season and mid-season) will provide a profile of shoulder strength in rugby players and will allow changes in strength during the pre-season phase and the competitive phase to be assessed.

The results of the pilot study showed that when measuring the action of shoulder abduction/adduction, average torque at 2.16 rad•s^{-1} in the dominant arm provided the most reliable results.

The aim of this study therefore, is to measure isokinetic shoulder strength in the dominant arm of rugby union forwards and backs, both concentrically and eccentrically, at a velocity of 2.16 rad•s^{-1}, at three stages of the season. These three stages are during the pre – season training phase (PS), at the start of the competitive playing season (SS) and mid way though the competitive league season (MS). Changes in strength will be correlated to initial strength and training load.

6.2. Methodology

6.2.1. Subjects

Twenty-nine male subjects (eighteen forwards and eleven backs) volunteered to take part in the study and their details can be seen in Table 6.1. The subjects were all rugby union players who were participating in the national leagues of the 1996/1997 season. The majority of the players were competing in the Allied Dunbar 2nd division (formerly known as the Courage League 2nd division). The players were participating in regular training programmes for fitness and skills involved in the game of rugby union and were playing in competitive matches weekly (subject to selection and injury). All the subjects had been free from upper body injuries during the previous twelve months. All subjects completed a medical questionnaire (appendix 2), they were informed of the procedures to be used and made aware of the inherent risks of participating in such a study. The subjects were then asked to sign a consent form (appendix 3).

Table 6.1. Subject details for all participants (Mean ± SD).

	N	Age (years)	Height (m)	Mass (kg)
Forwards	18	26.98 ± 4.38	1.85 ± 0.08	104.37 ± 11.06
Backs	11	27.13 ± 4.53	1.79 ± 0.04	83.05 ± 8.09
Total	29	27.03 ± 4.53	1.83 ± 0.08	97.26 ± 14.32

In the event of injury the players were considered fit for examination if they were participating in squad training or competitive matches.

During the course of the main study, the subjects who participated were to only have their dominant shoulder assessed, this was as a result of the pilot study which identified that there was no significant difference between the dominant and non dominant shoulders ($P<0.05$). In the event of a subject injuring their dominant shoulder during the course of the study and being unable to complete the assessment, their non dominant arm would be tested.

6.2.2. Training logs

Each subject completed a questionnaire on their training and playing schedule on a fortnightly basis (appendix 4). The questionnaire was used to determine the number of club training sessions (fitness or squad) and weight training sessions undertaken.

6.2.3. Measurement of isokinetic strength

Isokinetic strength of the shoulder was assessed using the Kinetic Communicator 500H (Kin-Com©, Chattecx Corp., Chattanooga, TN) as described in section 4.1. except for pre-load setting. This was increased from 50 N to 120 N to prevent the early activation of the lever arm, which had sometimes occurred with the larger and stronger subjects (see section 4.1.2.3).

6.2.4. Testing procedure

Isokinetic strength was assessed on three occasions which coincided with the beginning of pre-season training (PS) during July, the start of the competitive playing season (SS) during September and mid way through the league season (MS), which is at the end of November and the beginning of December. There were approximately nine weeks between each testing session and test sessions were conducted at the same time of day for each subject. The laboratory temperature and humidity were recorded before each testing session. The subject positioning in relation to the machine, the alignment of the axis of rotation and gravity correction was individual to each subject and these factors were kept constant between tests.

Shoulder concentric abduction and eccentric adduction of the dominant arm were tested at 2.16 rad•s^{-1} over the range of motion of 20° to 130°. The procedure for testing is detailed in section 4.1.4..

6.2.5. Data analysis

Average torque was taken as the measure of isokinetic strength as described in section 4.1.6.2..

6.2.6. Statistical analysis

The data was initially assessed using a two way ANOVA with repeated measures to assess variation due to contraction type (concentric/eccentric) and time of testing. The data were then split to analyse the data from the forwards and the backs separately. A two way ANOVA with repeated measures was used to identify variation attributed to contraction type and the time of the test during the season. Significant differences between forwards and backs were identified by unpaired t-tests. Due to the unbalanced nature of the study (12 forwards and 7 backs completing all assessments), it was not possible to use ANOVA for this analysis, hence necessitating the use of unpaired t-tests.

Pearson product moment correlation (r) was used to assess a) the relationship between the number of weight training sessions and subsequent changes in strength and b) the initial strength and changes in strength.

Analyses were performed using SPSS for Windows and Minitab for Windows statistical analysis software. The level of significance was set at $P < 0.05$.

6.3. Results

6.3.1. Adherence

Of the twenty-nine subjects who completed the first test, twenty-three completed the second test and twenty-four completed the third and final test. Nineteen subjects (twelve forwards and seven backs, see Table 6.2) completed all three of the tests and consequently, it was the results from this group of players which were subsequently used for the purposes of data analysis. This group of nineteen players will now be referred to as the study group.

Table 6.2. Subject details for those completing all three tests – The study group (Mean ± SD).

	N	Age (years)	Height (m)	Mass (kg)
Forwards	12	24.7 ± 3.0	1.85 ± 0.1	106.8 ± 11.9
Backs	7	28.5 ± 5.3	1.79 ± 0.1	85.2 ± 7.4
Total	19	25.9 ± 3.7	1.83 ± 0.9	98.9 ± 14.8

Details of the ten subjects (five forwards and five backs) who were unable to complete the second or third test can be seen in Table 6.3.

Table 6.3. Subject details for those unable to complete all three tests (Mean ± SD).

	N	Age (years)	Height (m)	Mass (kg)
Forwards	5	28.5 ± 5.3	1.87 ± 0.1	99.0 ± 8.6
Backs	5	24.0 ± 5.6	1.80 ± 0.1	82.8 ± 11.4
Total	10	26.3 ± 5.6	1.83 ± 0.6	90.9 ± 12.8

These subjects were not injured but were unable to complete all the necessary tests due to work and personal commitments.

6.3.2. Training and playing activities

The training and playing activities conducted by all the players during the testing period were monitored. The time between the tests conducted at the beginning of pre-season (PS) and the start of season (SS) was 61 days ± 9 days. During this time players on average participated in 1 ± 1 match, 9.7 ± 5.3 fitness sessions, 10.4 ± 5.9 squad training sessions and 12.8 ± 12.3 weight training sessions. On a weekly basis this amounts to 1.1 fitness session, 1.2 squad sessions and 1.5 weight training sessions.

The training and playing activities between the SS and mid-season (MS) tests was 8.2 ± 3.2 games, 8.5 ± 3.2 fitness sessions, 16.6 ± 5.6 squad training sessions and 12.6 ± 11.3 weight training sessions. The time between tests was 72 ± 8 days, therefore the average weekly activity was 0.8 games, 0.8 fitness sessions, 1.6 squad sessions and 1.2 weight training sessions.

6.3.3. Isokinetic shoulder strength at pre – season, start of season and mid season

A two way ANOVA with repeated measures showed that there were no significant differences between any of the PS, SS or MS tests. It did however identify that there was a significant difference between concentric and eccentric measures ($P < 0.001$). Table 6.4 shows the torque values for the study group.

Table 6.4. Average torque values (N•m) for concentric abduction and eccentric adduction at 2.16 rad•s^{-1} (mean ± SD, n=19). PS = pre-season, SS = start of season and MS = mid-season.

	Average torque (N•m)			
	PS	SS	MS	Mean PS/SS/MS ***
Concentric	61.9 ± 13.5	60.9 ± 11.8	61.0 ± 11.3	61.3 ± 12.0
Eccentric	104.8 ± 21.4	101.5 ± 19.8	102.7 ± 16.8	103.0 ± 19.1

***** significant difference between concentric and eccentric contractions P <0.001**

6.3.3.1. Change in strength in relation to training load and initial strength

The strength data was further analysed to see if there was a relationship between individual changes in strength during the season and either the number of weight training sessions completed or the initial strength of the subject.

The change in strength (PS to SS and SS to MS) was positively correlated with the number of weight training sessions completed, however this was not significant. A negative correlation was found between the initial strength and the change in strength, which was significant for concentric contractions between PS and SS and eccentric contractions between SS and MS. The correlation coefficients can be seen in Table 6.5..

Table 6.5. Pearson rank correlation coefficients (r) for i) the relationship between the change in torque and the number of training sessions and ii) the relationship between the change in torque and the initial torque. Values are given for concentric and eccentric contractions for the PS to SS data and the SS to MS data. PS = pre-season, SS = start of season and MS = mid-season.

	Correlation coefficient (r)	
	i) Change in strength versus the number of training sessions between tests	ii) Change in strength versus the initial strength
PS – SS Concentric	0.26	-0.48*
PS – SS Eccentric	0.43	-0.39
SS – MS Concentric	0.24	-0.39
SS – MS Eccentric	0.34	-0.53*

*** = p<0.05**

6.3.3.2. Strength values in forwards and backs

The group was then split into two, based upon playing position to assess the shoulder strength in forwards and backs during the season (Table 6.6.).

Table 6.6. Average torque values (N•m) for forwards (n=12) and backs (n=7) performing concentric abduction and eccentric adduction at 2.16 rad•s^{-1} (mean ± SD). PS = pre-season, SS = start of season and MS = mid-season.

		Average torque (N•m)			
		PS	SS	MS	Mean PS/SS/MS
Forwards n=12	Concentric	66.3 ± 12.0	63.7 ± 13.4	64.5 ± 11.5	64.8 ± 12.0 *
	Eccentric	113.3 ± 17.8	108.9 ± 19.7	111.2 ± 14.6	111.1 ± 17.1 ***
Backs n=7	Concentric	54.5 ± 13.3	56.0 ± 6.8	55.0 ± 8.6	55.2 ± 9.5
	Eccentric	90.3 ± 20.2	88.9 ± 13.0	88.2 ± 8.2	89.2 ± 13.9

* Significant difference between forwards and backs (P<0.05)
*** Significant difference between forwards and backs (P<0.001)

A two way ANOVA with repeated measures was used to analyse the data for the forwards and the backs separately. It was identified within the forward population that there was no significant difference with the time of testing, however there was a significant difference between concentric and eccentric contractions ($P < 0.001$). The same relationships were found in the back population, with no significant difference found between time of test and a significant difference ($P < 0.001$) between concentric and eccentric contractions. Unpaired t-tests showed a significant difference between forwards and backs for both concentric ($P<0.05$) and eccentric ($P<0.001$) average torque values.

The average strength levels produced for the concentric abduction and eccentric adduction of the shoulder at 2.16 rad•s^{-1} for forwards and backs in the study group relative to body weight are detailed in Table 6.7 below.

Table 6.7. Average torque values relative to body weight (N•m•kg^{-1}) produced by rugby union forwards (n=12) and backs (n=7) for concentric abduction and eccentric adduction at 2.16 rad•s^{-1} (mean ± SD).
PS = pre-season, SS = start of season and MS = mid-season.

	Average torque (N•m•kg^{-1}) concentric abduction			
	PS	SS	MS	Mean PS/SS/MS
Forwards	0.62 ± 0.08	0.60 ± 0.10	0.61 ± 0.10	0.61 ± 0.09
Backs	0.63 ± 0.11	0.66 ± 0.04	0.65 ± 0.09	0.65 ± 0.08
	Average torque (N•m•kg^{-1}) eccentric adduction			
	PS	SS	MS	Mean PS/SS/MS
Forwards	1.06 ± 0.13	1.02 ± 0.16	1.05 ± 0.13	1.04 ± 0.14
Backs	1.05 ± 0.17	1.05 ± 0.14	1.04 ± 0.12	1.05 ± 0.13

There was no significant difference between time of testing (PS/SS/MS) or between forwards and backs when strength was expressed relative to body weight.

6.3.4. Normative data

The mean of the PS, SS and MS measures of shoulder strength in the whole group and in the forwards and the backs are summarised in Table 6.8.

Table 6.8. Average torque values presented as absolute (N•m) and relative to body weight (N•m•kg^{-1}) produced by a rugby union population (n=19), forwards (n=12) and backs (n=7) for concentric abduction and eccentric adduction at 2.16 rad•s^{-1} (mean ± SD).

	Absolute (N•m)		Weight relative (N•m•kg^{-1})	
	Con	Ecc	Con	Ecc
Whole group n = 19	61.3 ± 12.0	103.0 ± 19.1	0.62 ± 0.09	1.04 ± 0.14
Forwards n = 12	64.8 ± 12.0	111.1 ± 17.1	0.61 ± 0.09	1.04 ± 0.14
Backs n = 7	55.2 ± 9.5	89.2 ± 13.9	0.65 ± 0.08	1.05 ± 0.13

6.4. Discussion

6.4.1. Adherence

The overall adherence rate for attending testing sessions was 87%. In spite of the backing and support from the management and coaching staff of the various teams, the players participating in the study were part time and some were unable to attend all three testing sessions. This reduced the adherence rate for the whole study to 66% over the six month period. In addition, two of the subjects who dropped out of the study had moved clubs and were no longer living in the area. It is possible that higher adherence rates may have been achieved if professional players had been used as subjects with the backing of their club management. High drop out rates might be expected in longitudinal studies using a volunteer population as subjects.

6.4.2. Pre-season to start of season (PS –SS)

During the PS – SS period of the study there was no overall change in strength observed for the group as a whole. When the forwards and backs where observed separately there was still no significant change.

The pre-season training period which leads up to the start of the competitive season has been described as representing the most important period of training to improve the physical capacity of athletes involved in competitive sport (Häkkinen and Sinnemäki 1991, Rebelo and Soares 1995). It is therefore expected that significant changes in the physiological conditioning and performance of athletes would be observed during this period.

Pre-season fitness gains depend upon the type of training undertaken, for example, during the six week pre-season period of an English professional football team, it was observed that players increased their cardiovascular fitness, reduced their blood pressure and reaction times (Reilly and Thomas 1977). In contrast, the muscular strength and power of the players decreased during the same time period. This was attributed to an emphasis being placed upon cardiovascular fitness during pre-season training and the fact that there had been no provision for strength training as part of the programme.

The effect of pre-season training on a number of physiological parameters was monitored in the Welsh national rugby union (Tong and Mayes 1995). The results from the first testing session provided baseline data and enabled the training programmes for individuals to be tailored to their specific needs. Training was designed to increase strength and aerobic capacity. The results from the second test sessions showed that both the forwards and the backs improved their strength and flexibility, however, only the backs made improvements to their aerobic performance.

Analysis of the training data which was gathered from the training diaries completed throughout the PS – SS period by the players involved in this study, indicated that the forwards were completing on average 1.6 weight training sessions per week and the backs were doing 1.4 weight training sessions per week during pre-season training. This frequency of training has been shown sufficient to maintain strength over a period of time, however, a minimum of two weight training sessions per week were proved to be sufficient to increase muscular strength (Graves et al. 1988). This may account for the lack of overall change in strength during pre season training. It might be expected that there would be a correlation between the number of weight training sessions performed and changes in isokinetic strength. Since poor correlations were found for both concentric ($r = 0.26$) and eccentric ($r = 0.43$) contractions, this might suggest that the pre season training was ineffective which may be attributed to the lack of individually tailored training programmes as suggested by Tong and Mayes (1995). It may also be that the training completed by individuals was not specific to the abduction adduction action, therefore not being detected by the test. Also the test itself may not have been sufficiently sensitive to detect small changes in strength. Some of the variation in the results may be due to a greater increase in strength in players whose initial strength is low. The significant correlation between initial strength and changes in concentric strength suggest that this may be the case.

6.4.3. Start of season to mid – season (SS – MS)

A similar pattern of results occurred during the period between the start of season and mid season with no overall change in strength.

It has been possible to show an increase in muscular strength and power over the period of a playing season in an English professional soccer team (Thomas and Reilly 1979). This improvement in the test results was attributed to the training effect of match play itself and the lack of strength and power training during the pre-season build up, which meant that players were starting the season with sub-optimal levels of strength and power. Increases in strength have also been observed during the competitive season of elite varsity wrestlers (Song and Cipriano 1984). Despite having no established weight training programme for the wrestlers, strength values increased and it is suggested that the isometric contractions performed on a regular basis as part of the wrestlers training were sufficient training stimulus to increase strength (Song and Cipriano 1984).

Other studies have observed significant reductions in both muscular strength and aerobic capacity during the competitive period of the season. A significant reduction in aerobic capacity and isokinetic knee flexion and extension torque values were found during the season in elite male skiers (Koutedakis et al. 1992). Reductions in the isokinetic concentric and eccentric quadriceps and hamstring torques were observed in an amateur ice hockey team during their competitive season (Posch et al 1989). Both aerobic capacity and isokinetic torques produced by knee flexion and extension were reduced during a season for épée fencers (Koutedakis et al 1993). During the competitive season of elite bandy players minor reductions in maximal oxygen uptake were observed. Although isometric strength remained constant, the time to produce a maximal contraction increased significantly over the playing season (Häkkinen and Sinnemäki 1991). All the above studies identified reductions in fitness parameters which they attributed to insufficient training intensity or volume.

In this study, no consistent effect of match play could be discerned during the first half of the competitive season, however, in some players the addition of match play might increase strength, particularly if no strength gains had been made in the pre season period.

Players were considered fit for testing if they were fit enough to play competitively. Minor injuries, resulting from match play or training activities, whilst not being sufficient to prevent play, may account for the decrease in strength recorded in some subjects.

6.4.4. Normative data for shoulder strength in rugby union players

Since no seasonal differences in shoulder strength were identified in either the whole group or in the forwards or backs separately, the mean of the PS, SS and MS measures can be used to provide normative data for shoulder strength in rugby union players. Shoulder abduction and adduction has not been used previously to assess strength in rugby players or in other sporting groups, therefore, no comparative data is available.

Analysis of shoulder strength according to positional role showed significant differences in absolute, but not relative strength, between forwards and backs. This suggests that the greater shoulder strength in forwards is related to their greater body mass, rather than a specific training effect associated with training drills or match play.

6.5. Conclusion

In conclusion, the use of a sport specific test of upper body strength has provided normative data for rugby union players. No consistent changes in strength attributable to seasonal variations could be demonstrated. Although changes could be observed in individual rugby players there was no overall effect of either pre season training or match play.

More research would be needed to clarify the effects of specific training procedures for rugby players.

6.6. Future recommendations

It is recommended that future studies that examine the shoulder strength in a sporting population try and reduce the variability in the measure. This may be achieved by allowing more familiarisation time for the subjects at the start of each examination and possibly looking at the various playing positions separately, therefore removing the large standard deviation in the strength values.

It would also be beneficial to develop the test for repeated measures of an individual. This also would improve the reliability and allow more accurate assessment of change to be assessed for individuals as opposed to the population. This would enable the test to be accurately used for the assessment of individual shoulder strength during rehabilitation, therefore monitoring progress.

Finally, it is suggested that individuals who are being assessed as part of a longitudinal study should ensure that the muscle groups being examined in the tests are receiving sufficient training stimulus. During this study several of the subjects were completing weight training sessions 3 or more times a week. However only a small percentage of these subjects were training the shoulder abductors specifically. This study was looking at concentric shoulder abduction and eccentric adduction. Side lateral raises using dumbbells or cable pulls simulate these actions. Either of these exercises completed 3 or more times a week would ensure that the correct muscle groups being examined were receiving sufficient training stimulus to improve strength. Had this been done then the results of this study may have been different.

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Appendices

Appendix 1 Anthropometric and physiological profiles of senior rugby union players produced by Rigg and Reilly 1988 and Quarrie et al. 1995

Anthropometric, anaerobic and physical work capacities (mean values ± SD) for 1st Class (n=24) and 2nd Class players (n=24) (Taken from Rigg and Reilly 1988)

Test		Front Row	Second Row	Back Row	Half – Backs	Backs
Height (cm)	1st Class	176.7±3.7	196.7±6.1*	184.8±5.9*	172.8±5.4	180.4±4.8
	2nd Class	176.2±2.7	185.3±2.1	176.1±4.1	172±2.2	179.6±4.6
Mass (kg)	1st Class	89.2±3.7	100.8±6.7*	86.5±6.8	77.0±5.8	80.2±4.6
	2nd Class	80.0±8.1	86.7±8	80.9±2.5	72.0±8.9	77.3±5.2
Body fat (%)	1st Class	13.6±2.1	11.1±1.2*	11.5±2.5	12.1±1.2	10.4±1.5
	2nd Class	12.4±3.4	13.3±1	12.3±2.1	11.7±1.3	11.0±2.9
Peak power (W)	1st Class	-	914±46	1071.0±108*	858.0±32	888.0±46
	2nd Class	937.0±79	861.0±84	878.0±121	809.0±47	941.0±142
Mean power (W)	1st Class	-	797.0±70	903.0±39*	618.0±32	767.0±68
	2nd Class	755.0±103	699.0±47	735.0±118	674.0±73	656±237
Peak power ($W \bullet kg^{-1}$)	1st Class	-	7.9±1.1	10.6±1.2*	8.0±0.4**	9.68±0.18
	2nd Class	9.3±1.3	8.2±0.2	8.6±0.9	9.4±0.3	9.9±1.4
PWC_{170} (W)	1st Class	210.0±37	246.0±22	258.0±38*	204.0±37	238.0±61*
	2nd Class	210.0±35	210.0±9	186.0±40	180.0±11	174.0±20

* = significant difference p<0.05 ** = significant difference p<0.01

Fitness performance profiles (mean ± SD) for 1st Class (n=24) and 2nd Class players (n=24) (Taken from Rigg and Reilly 1988)

Test		Front Row	Second Row	Back Row	Half – Backs	Backs
Press–ups	1st Class	41.2±8.6 *	31.8±18.6	38.4±8.8	39.0±3.2*	33.8±3.9**
	2nd Class	26.0±3.4	17.3±3.1	42.0±22.1	28.5±6.6	24±4.5
Sit-ups	1st Class	79.4±50.1	63.3±9.7	71.6±22.2	87.5±2.5*	95.7±24.5**
	2nd Class	56.3±2.9	55.0±5.0	85.2±75.4	51.8±7	57.9±17.1
Vertical Jump (cm)	1st Class	50.0±7.0	52.0±3.0*	53.0±5*	55±3	57±2
	2nd Class	45.0±4.0	52.0±3.0	46.0±5	51±3	51±7
Broad Jump (m)	1st Class	2.12±.05*	2.24±0.5	2.27±23	2.4±19	2.30±20
	2nd Class	2.00±0.92	2.25±5	2.22±13	2.3±17	2.30±17
40 m sprint (s)	1st Class	6.38±0.5	6.28±0.22	6.12±0.2	5.82±0.2	5.8±0.4
	2nd Class	6.7±0.2	6.5±0.1	6.16±0.2	6.0±0.2	6.1±0.2
W.M.A. (s)	1st Class	17.9±0.7	18.5±0.6	17.2±0.7	17.0±0.4	16.9±0.8
	2nd Class	18.6±6.9	18.8±0.1	17.7±0.6	17.3±0.4	17.4±0.9
Sit and reach (cm)	1st Class	10.2±4.7*	5.9±4.3	11.7±5.5*	4.3±6.5	9.8±4.8
	2nd Class	0.63*7.5	8.2±5.5	3.7±4.3	5.8±3	8.1±4.6
Dynamic flexibility	1st Class	23.2*5.5	20.8±2.1	19.6±5.6	23.2±3.8	21.3±4.3
	2nd Class	20.8±1.7	16.0±9.6	23.2±0.8	21.3±2.2	23.9±2.8

* = significant difference p<0.05 ** = significant difference p<0.01

Rugby injury and performance project cohort pre – season 1993. Anthropometric characteristics of male players (taken from Quarrie et al. 1995)

		Grade							
		Senior A		Senior B		Under -21		Under – 19/18	
		n		N		n		n	
Age (years)	Forwards	50	22.7	20	25.5	33	18.9	29	16.7
	Backs	44	21.9	19	22.5	32	18.9	25	17.1
Height (cm) *	Forwards	50	186.0	20	181.5	33	183.3	29	180.2
	Backs	44	177.8	19	176.5	32	177.5	25	175.4
Mass (kg) ***	Forwards	50	98.5	20	88.1	33	89.4	29	82.6
	Backs	44	81.8	19	77.3	32	75.5	25	72.0
Neck circumference (cm) ***	Forwards	47	42.7	19	40.3	33	40.8	29	39.3
	Backs	39	39.6	19	38.6	32	38.6	25	37.6
Endomorphy	Forwards	47	3.7	19	3.2	33	3.6	28	3.4
	Backs	41	2.5	19	2.9	32	2.4	25	2.2
Mesomorphy *	Forwards	47	6.5	18	6.0	33	5.9	25	5.6
	Backs	39	6.2	17	5.3	32	5.4	23	5.5
Ectomorphy	Forwards	50	1.1	19	1.4	33	1.5	28	2.0
	Backs	44	1.4	19	1.8	32	2.2	25	2.3

* = Senior A players were significantly taller and more mesomorphic P<0.05
*** = Senior A players were significantly heavier and possessed larger necks P<0.001

Rugby injury and performance project cohort pre – season 1993. Physical performance characteristics of male players (taken from Quarrie et al. 1995)

		Grade							
		Senior A		Senior B		Under -21		Under – 19/18	
		n		n		n		n	
Aerobic shuttle (No)	Forwards	50	108.6	19	114.3	32	104.6	29	100.2
	Backs ***	43	127.4	19	115.2	29	118.4	24	105.0
Vertical jump (cm)	Forwards	50	59.7	17	55.2	32	58.4	29	56.8
	Backs***	44	63.2	18	60.3	29	61.8	24	62.9
Push ups (No)	Forwards	44	25.6	18	26.6	33	22.1	28	24.5
	Backs***	36	32.3	19	29.2	29	27.3	24	24.9
Agility run (s)	Forwards	50	12.2	18	12.4	33	12.3	29	12.2
	Backs***	42	11.5	19	11.9	29	11.9	24	12.0
30 m sprint standing start (s)	Forwards	45	4.5	12	4.8	33	4.5	29	4.6
	Backs***	37	4.3	12	4.5	29	4.4	24	4.4
Momentum ($kg{\bullet}m{\bullet}s^{-1}$)	Forwards	45	654	12	570	33	603	29	535
	Backs***	37	573	12	530	29	522	24	496
30 m sprint running start (s)	Forwards	45	4.0	12	4.1	33	4.0	28	4.1
	Backs***	37	3.7	12	3.9	29	3.8	24	3.9
Fatigue index	Forwards	49	49.0	18	55.9	32	57.7	28	56.8
	Backs	41	47.9	19	68.3	28	59.7	23	70.2

*** = Backs performed significantly better than the forwards P<0.001

Appendix 2 Health medical history questionnaire

Health Medical History Questionnaire

N.B. All information on this form will remain completely confidential and is only used to assess your suitability for testing.

<u>Health / Fitness History</u>

1. Are you currently involved in a regular exercise programme? Yes No
   If Yes, please list activity, duration, frequency and intensity.
   ____
   ____

2. Do you now or have you ever smoked? Yes No
   If you previously smoked, how long did you smoke, how often, and when did you quit.______________________________
   If Yes how many do you smoke each day?____________________

3. Has your doctor ever told you that you have any of the following?

Coronary heart disease	Yes	No
Epilepsy	Yes	No
Irregular heart beats	Yes	No
Hypertension	Yes	No

Please give details:______________________________________
____
____
____
____

4. Do you suffer from any of the following?

Back pain	Yes	No
Joint, tendon or muscle pain	Yes	No
Lung disease (asthma, emphysema, other)	Yes	No

Please give details:______________________________________
____
____
____
____

5. Are you currently taking any medication. Yes No

Please give details:______________________________________
____
____

6. Has anyone in your immediate family (father, mother, brother or sister) had a heart attack or other heart-related problems before the age of 50. Yes No

Please give details:____

7. Do you have any medical conditions for which a physician has ever recommended some restriction on activity (including surgery)?
Yes No

Please give details:____

9. Have you ever broken or dislocated any bone or joint Yes No

Please give details:____

Appendix 3 Subject Consent Form

The purpose of the study that you are agreeing to participate in is to assess the strength in the shoulder using Isokinetic Dynamometry. You will be required to perform a test which involves two types of contraction (concentric and eccentric) and this test will need to be repeated three times during the 1996 / 1997 season. As a result of the tests you may have some discomfort in the muscles of your shoulder. This will be similar to the feeling you get after a weight training session (the test consists of 8 warm up reps and 8 maximum reps on each arm.). There is however a risk that you may incur an injury to either your muscle, ligament or tendon as a result of the test. This risk is minimal and all steps will be taken to reduce the likelihood of it happening. You are at liberty to stop the test at any time if you feel uncomfortable or unhappy in any way. You are also at liberty to withdraw from the study at any time if you wish.

I _______________ hereby agree to participate in the research study into isokinetic strength in the upper body. I realise that my participation in this activity involves risks of injury and possible discomfort to the body parts being tested. I am aware that I can withdraw at any stage without reason or recourse.

I have had an opportunity to ask questions. Any questions I have asked have been answered to my complete satisfaction. I understand the risks of my participation in this study, and knowing and appreciating these risks I voluntarily choose to participate.

_______________________ _______________________

Witness Participant
Dated

Notes of questions and answers. ________________________________

____

____

____

____

This is, as stated, a true and accurate record of what was asked and answered.

____

Participant

To be checked by test administrator.

		Checked	Initials
1.	Risks were orally discussed.	______	______
2.	Questions were asked, and the participant indicated understandings of the risks.	______	______
3.	Questions were not asked, but an opportunity to ask questions was provided and the participant indicated complete understanding of the risks.	______	______
4.	A medical history questionnaire was completed.	______	______

Appendix 4 Questionnaire completed by players on their training and playing schedule

Name:
Position:
Number of games played
Since last diary update:
Have you been injured: **Yes/No**
If yes please give details of injury:

If yes have you missed any training as a result of the injury: **Yes/No**

NB All information relating to the training you have undertaken during the last two weeks must be entered on the training diary updates to enable realistic conclusions to be made from the strength data gathered. If attending squad (S) or fitness (F) training sessions organised by your club please identify with the appropriate letter. If you have undertaken any fitness training in your own time please indicate using 'PF' and outline the type of training that you have completed. Finally weight training should be identified with the letters 'WT' and a description of the training programme you use submitted. This should include the types of exercise you do and the number of sets and repetitions.

MONDAY ______________________________
TUESDAY ______________________________
WEDNESDAY ______________________________
THURSDAY ______________________________
FRIDAY ______________________________
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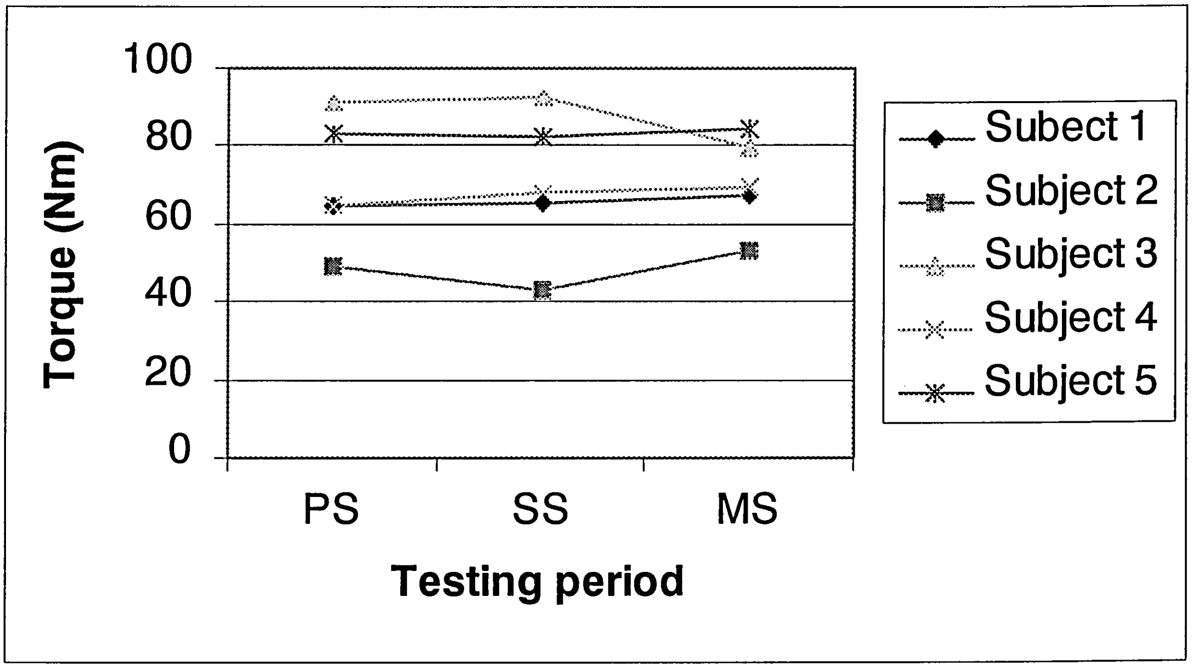
SATURDAY	____________________
SUNDAY	____________________

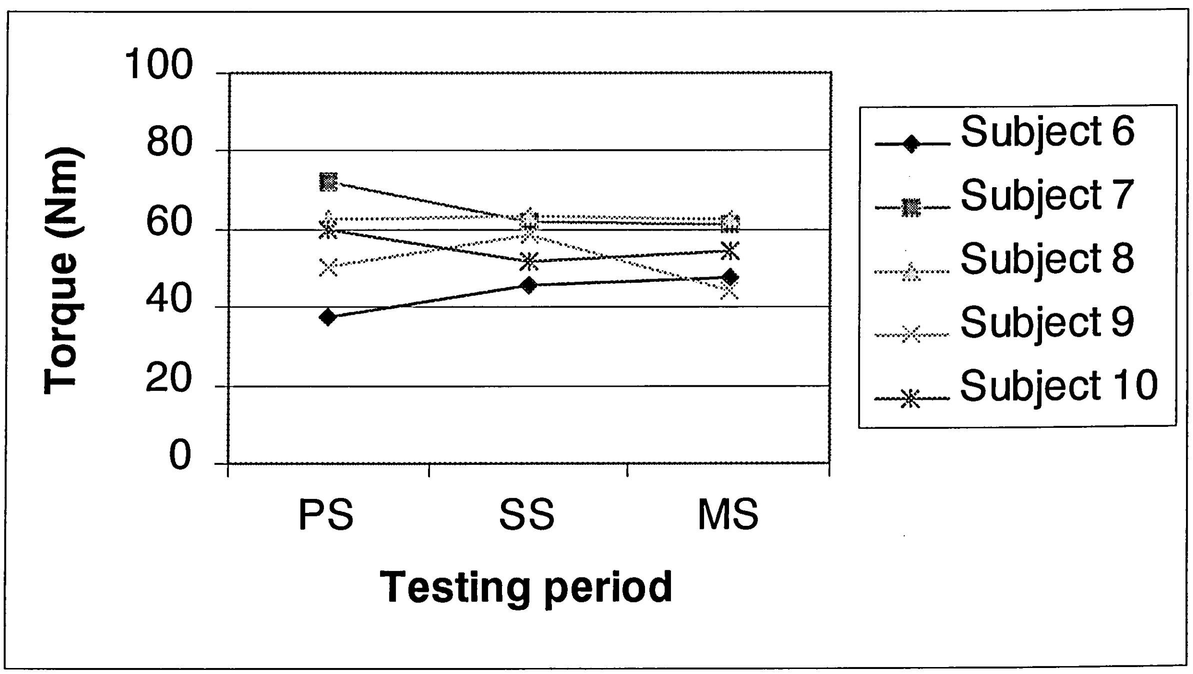
Thank you for your co-operation in this matter.

If you have any additional information please give details below.

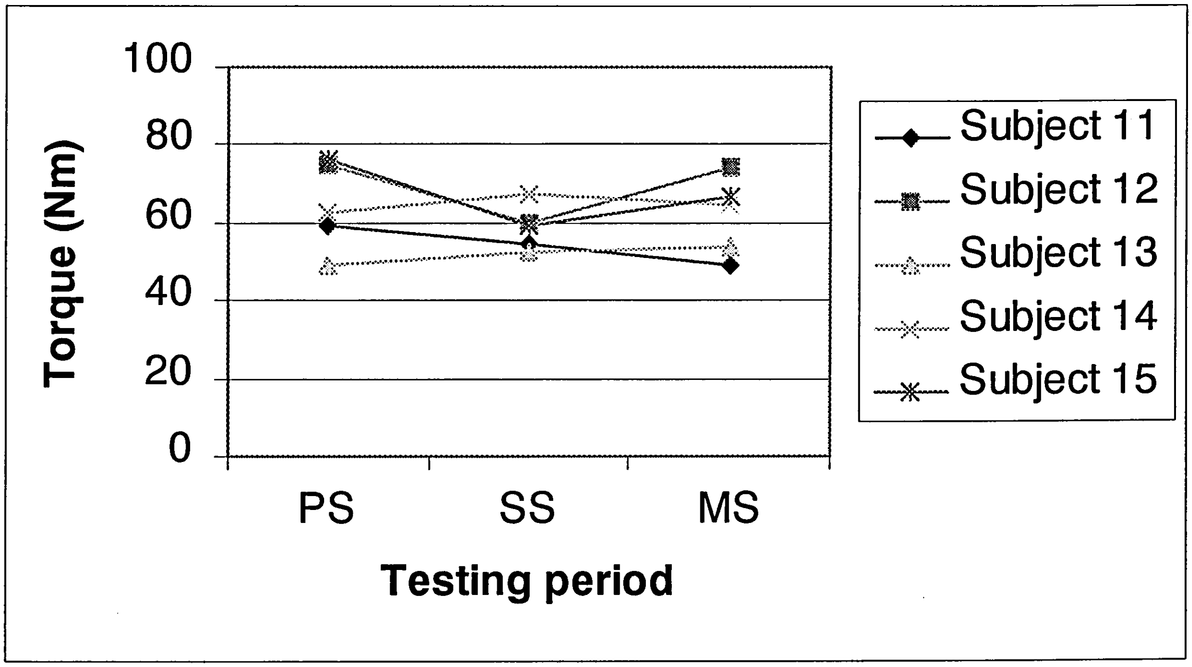
Appendix 5 Individual strength curves for the period PS, SS and MS

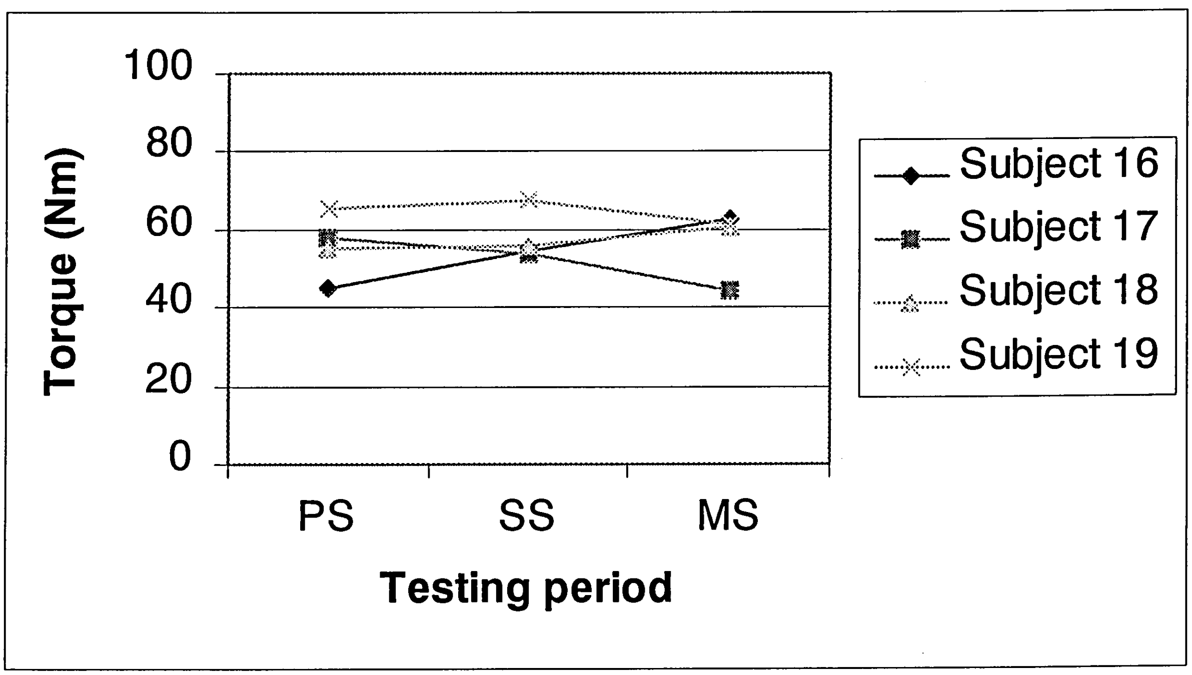
Subjects 1-10 Concentric abduction of the dominant shoulder at 2.16 rad•s^{-1}. Torque (N•m) trends for PS, SS & MS periods. PS = Pre-season, MS = Mid-season, SS = Start of season



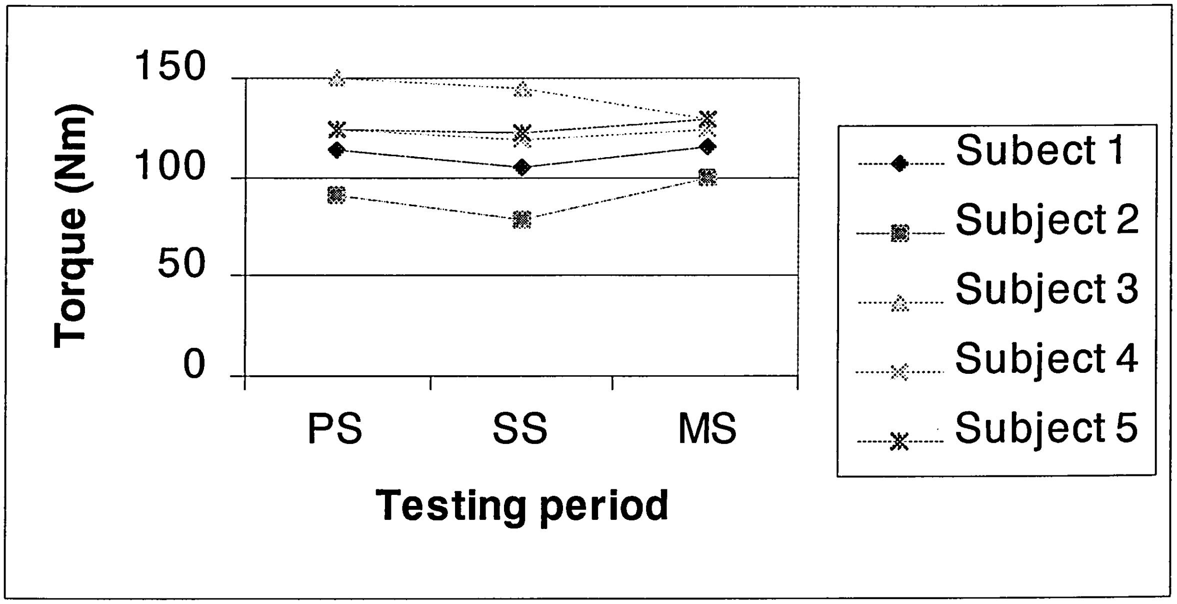


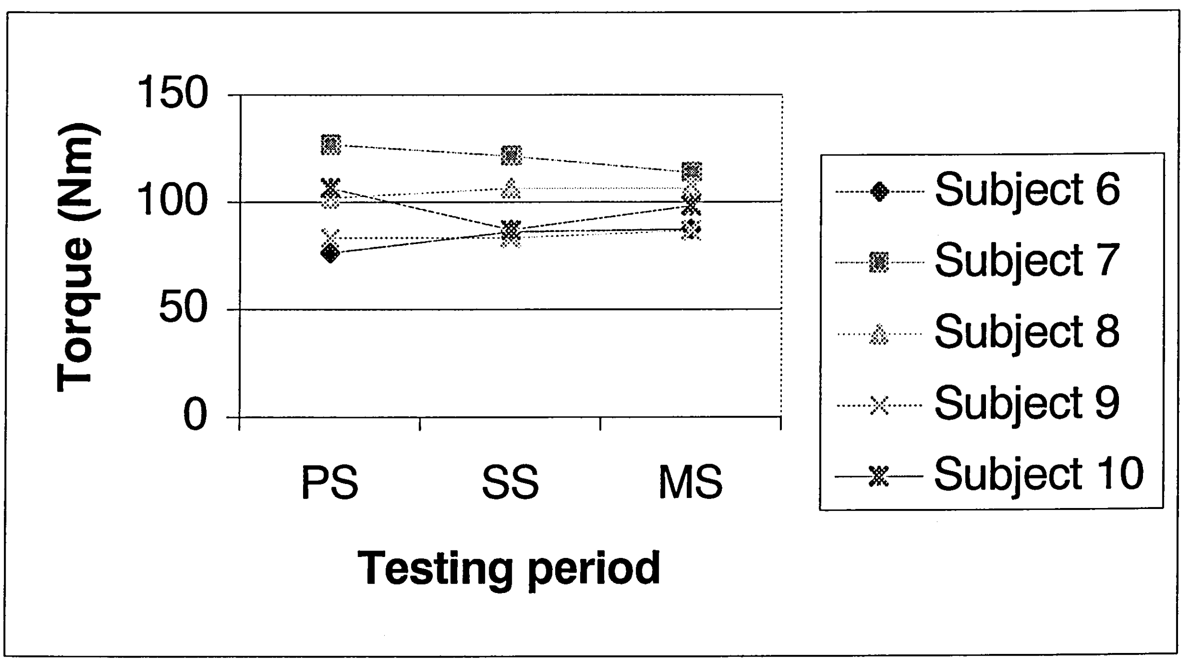
Subjects 11-19 Concentric abduction of the dominant shoulder at 2.16 rad•s^{-1}.
Torque (N•m) trends for PS, SS & MS periods.
PS = Pre-season, MS = Mid-season, SS = Start of season





Subjects 1-10 Eccentric adduction of the dominant shoulder at 2.16 rad•s^{-1}.
Torque (N•m) trends for PS, SS & MS periods.
PS = Pre-season, MS = Mid-season, SS = Start of season





Subjects 11-19 Eccentric adduction of the dominant shoulder at 2.16 rad•s^{-1}.
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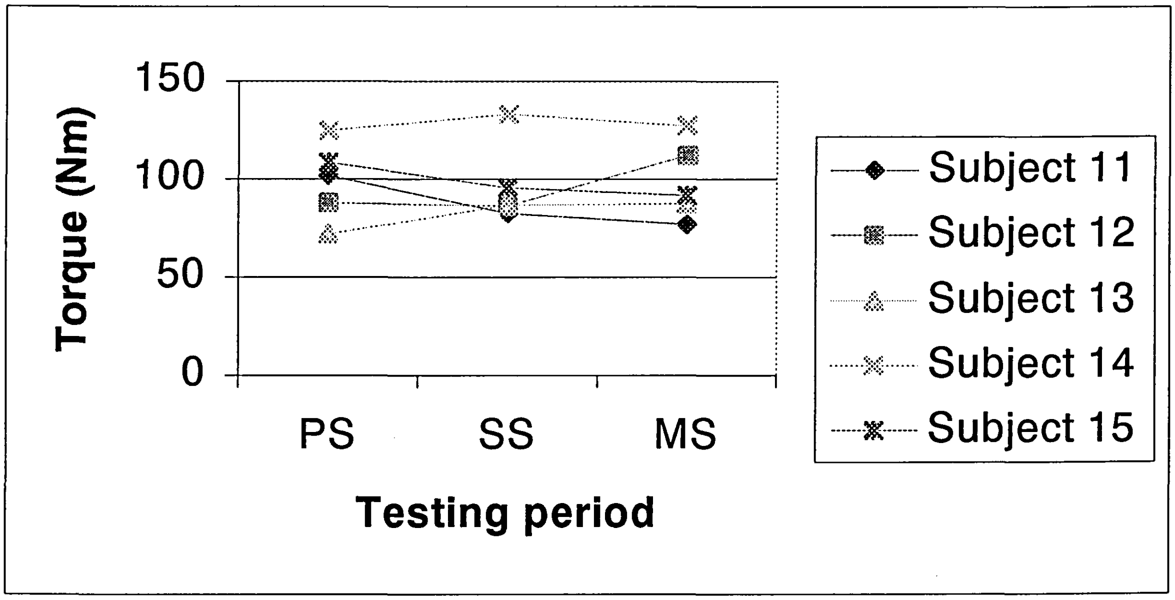
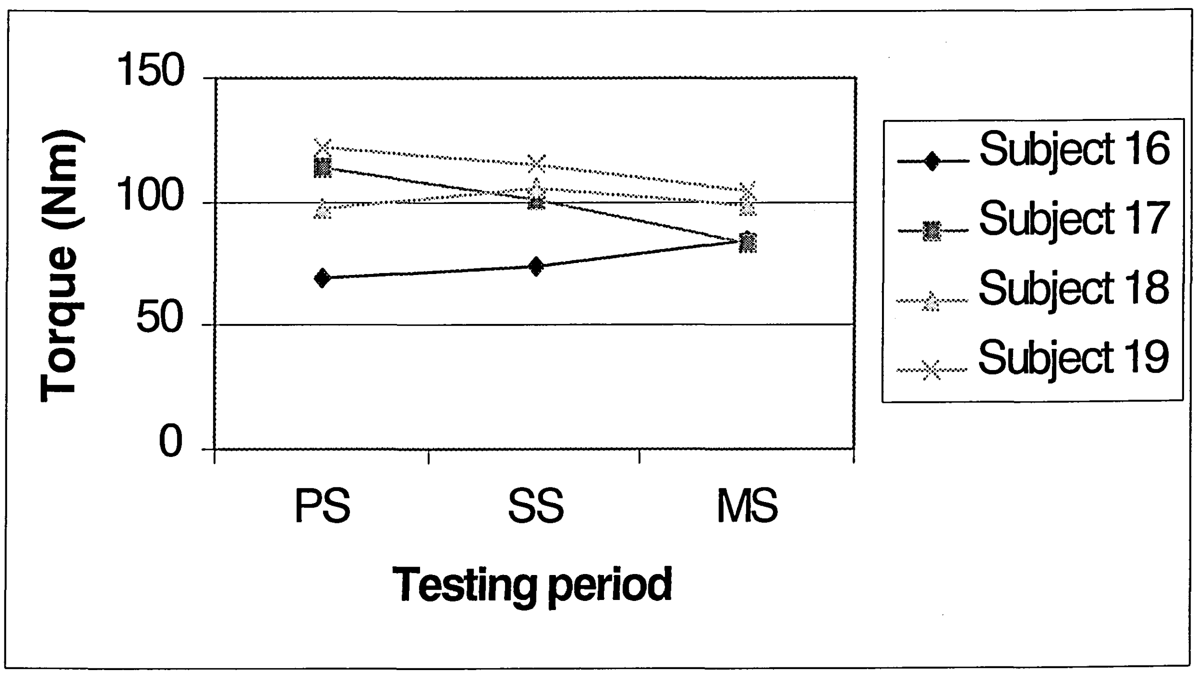




Appendix 6 Abstract from the second annual congress of the European College of Sports Science in Copenhagen 1997

THE ISOKINETIC ASSESSMENT OF MUSCLE STRENGTH IN RUGBY UNION PLAYERS.

Ian Kearney, Mary Fysh, Janet Chapman.

School of Leisure Management, Sheffield Hallam University, Sheffield, UK.

INTRODUCTION

Strength is an important requirement in the game of Rugby Union. Activities such as tackling, scrummaging, rucking, mauling and lifting in the line out make upper body strength essential for success at the higher levels of competition

Isokinetic dynamometry has been used to determine upper body strength for several sports (Ellenbecker 1991; Aldernick and Kuck 1986), however, despite the importance of strength to performance, few studies have employed isokinetic dynamometry to assess upper body strength in rugby players.

The advantage of using isokinetic dynamometry in the assessment of muscle strength is that the muscle groups being assessed can be exercised to their maximal potential throughout a range of motion.

The purpose of this study was to develop a test to assess the upper body strength of senior Rugby Union players over a six month period. Shoulder abduction and adduction were chosen as these actions are similar to those involved in a rugby tackle.

METHOD

The subjects were male Rugby Union players (12 forwards and 7 backs) who were competing in the English Courage League 2nd division 1996/1997 season (Table 1).

Table 1 Subject details (Mean ± standard deviation).

	N	Age (years)	Height (m)	Weight (Kg)
Forwards	12	25.5 ± 3.1	1.85 ± 0.096	106.8 ± 11.9
Backs	7	28.6 ± 4.0	1.79 ± 0.048	85.2 ± 7.4

Strength measurements were made using a Kin Com® 500H Isokinetic Dynamometer. The dominant shoulder was tested concentrically and eccentrically at two different speeds: 60°/s and 120°/s. The range of motion for concentric abduction and eccentric adduction was 15° to 130°. The mean peak torque (corrected for gravity) was calculated from the peak torque of four repetitions at both velocities.

The tests were carried out over the first half of the competitive season. The first test (T1) was carried out at the beginning of pre-season training after the players had rested over the off season. The second test (T2) was conducted at the beginning of the competitive season and the final test (T3) half way through the league fixtures. Assessment of changes in strength and differences between forwards and backs were made using a one way analysis of variance technique (ANOVA). Statistical significance was set at $P< 0.05$. Results are expressed as mean peak torque ± standard deviation.

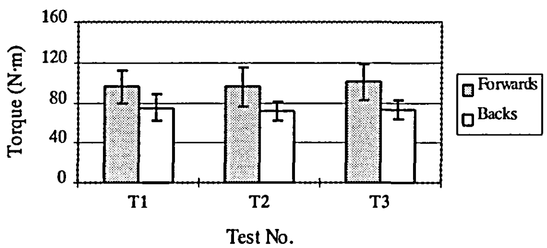
RESULTS

Values for isokinetic shoulder strength were higher in the rugby players than in the normal population and the forwards were significantly stronger than the backs (Table 2). There was no statistically significant variation in strength for either the forwards or backs over the period of the study (Graphs 1-4).

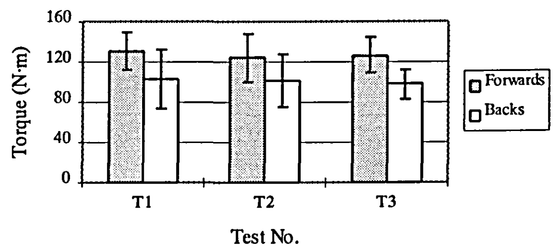
Table 2. Shoulder abduction and adduction torque values at 60°/s for forwards and backs compared with the normal population (Mayer et al. 1994). *Significant difference between forwards and backs $P < 0.05$.

Speed 60°/s	Forwards	Backs	Normal
Concentric abduction N•m	97 ± 17.6*	73 ± 10.3	38 ± 7
Eccentric adduction N•m	127 ± 20.1*	101 ± 23.4	55 ± 11

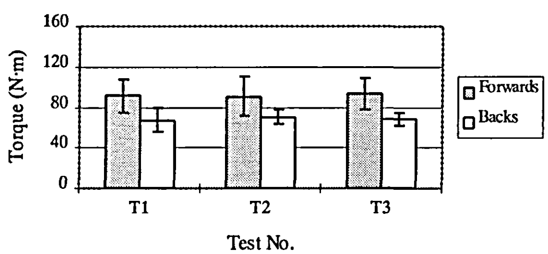
Graph 1. Concentric shoulder abduction torque values in forwards and backs at 60°/s.



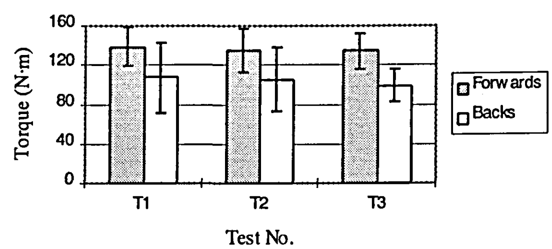
Graph 2. Eccentric shoulder adduction torque values in forwards and backs at 60°/s.



Graph 3. Concentric shoulder abduction torque values in forwards and backs at 120°/s.



Graph 4. Eccentric shoulder adduction torque values in forwards and backs at 120°/s.



DISCUSSION

This study has provided normative data for the isokinetic assessment of shoulder strength in Rugby Union players. Shoulder strength was significantly higher in forwards when compared with the backs. This difference can be partially explained by the larger body mass of the forwards, but is also a reflection of the higher strength requirements of the playing position.

The shoulder strength of players remained constant throughout the period of study. Without more comparative data it is impossible to say if this level of strength was optimal. The lack of increase during the pre-season training is however a cause for concern.

Further investigation is necessary to identify the specific strength requirements of each playing position, and also to establish appropriate pre-season training regimes to meet these demands.

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