Physiological indicators of performance in squash.

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Physiological indicators of performance in squash

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CANDIDATE STATEMENT

I declare that the studies presented in this thesis were conceived by myself and executed on my own unless otherwise indicated below:

The incremental squash test described in chapters four and five
was designed by Damon Leedale-Brown.
I received advice from Damon Leedale-Brown in the design of the fitness test described in chapter six and assistance in data collection from Andrew Sutherland, an undergraduate student at Northumbria University.
Assistance with data collection for the study described in chapter seven was provided by Andrew McCord, an undergraduate student of Northumbria University.
Northumbria University research assistants Mark Stone and Kevin Thomas and Matt Cooke of the England Institute of Sport assisted data collection for the studies reported in chapters eight and nine respectively.

The content of this thesis has not been in whole or in any part submitted in the past, or is being, or is to be submitted for a degree at Sheffield Hallam or any other University.

This thesis is presented in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

Signed:________________________

Date: 11·3·09

ABSTRACT

The aim of this thesis was to develop and validate squash-specific fitness tests to identify physiological determinants of repeat-sprint ability and performance in sub-elite and elite-standard squash players.

Study one examined the validity of a squash-specific test of endurance capability and $\dot{V}O_{2max}$. Trained squash players and runners completed squash-specific and treadmill incremental tests to exhaustion. Squash players achieved greater $\dot{V}O_{2max}$ on the squash-specific than the treadmill test while runners did not differ. Squash players exercised longer than runners on the squash-specific test despite similar $\dot{V}O_{2max}$. The squash test discriminated endurance capability between squash and non-squash players of similar fitness and elicited higher $\dot{V}O_{2max}$ in squash players. The results suggest that it is a valid test of aerobic fitness in squash players.

Study two assessed the reproducibility of physiological and performance measures from the squash specific test in county-standard players. Test-retest variability was low for all measures (Typical error < 5%) though the magnitude varied depending on the metric used.

Studies three and four examined the validity and reproducibility of squash-specific tests of change-of-direction speed and multiple-sprint ability. County-standard squash players and footballers completed squash-specific and equivalent non-specific tests on separate days. Performance time was recorded. Participants repeated the tests seven days later to assess reproducibility. Squash outperformed non-squash players on the squash-specific tests despite similar non-specific capabilities. Squash-specific tests discriminated squash player rank while non-specific tests did not. Test-retest variability was low (Typical Error < 3%) for both tests. Squash-specific tests predicted ability in squash players and discriminated between squash and non-squash players of equal non-specific fitness. The findings suggest that the squash-specific tests are valid for the assessment of high-intensity exercise capabilities in squash players.

Studies five and six explored correlates of multiple-sprint ability and performance in sub-elite and elite squash players. Squash-specific and general tests were performed by regional league players ranging from division three to premier standard and elite players on three tiers of a national performance program. In sub-elites, multiple-sprint ability and endurance capability discriminated performance and multiple-sprint ability was related to change-of-direction-speed, $\dot{V}O_{2max}$ and endurance capability. In world-ranked men and women, the ability to perform and sustain rapid changes of direction correlated with multiple-sprint ability and together with multiple-sprint ability discriminated performance. Aerobic fitness was not related to performance or multiple-sprint ability in elite players. Senior elites performed better than players on the talented athlete scholarship scheme (TASS) on all tests except $\dot{V}O_{2max}$ and counter-movement jump. Drop-jump power and reactive strength discriminated senior and transition level from TASS players and indices from the multiple-sprint test discriminated seniors from transition and TASS players.

This thesis has validated squash-specific tests of endurance and high-intensity exercise capabilities. These tests have shown that high-intensity exercise capabilities determine performance in elites while sub-elite performance is determined by multiple-sprint ability and endurance capability. The findings can be used to improve assessment of training effects and to inform the design of effective training methods.

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LIST OF PUBLICATIONS

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Wilkinson, M., Cooke, M., Murray, S., Thompson, K. and Winter, E.M. Physiological correlates of multiple-sprint ability and performance in international-standard squash players. *International Journal of Sports Physiology and Performance.*

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1 INTRODUCTION.

The physiology of exercise can be defined as the study of how the body responds and adapts to exercise. An important aspect of this study is the development of appropriate tests capable of quantifying exercise responses in specific sporting activities. Squash is a game that imposes extreme and diverse physiological stresses on the performer and challenges conventional test procedures to replicate the specific demands and movements of the sport.

The development of appropriate test procedures to quantify exercise necessitates an understanding of exercise and how it can be quantified. Exercise has been defined as any and all skeletal muscle activity (Knuttgen, 1978; Knuttgen and Kraemer, 1987). It should however be acknowledged that cardiac and smooth muscle are also important for generating and distributing the circulation of oxygen and nutrient carrying blood. However, for quantifying exercise, the focus is generally on skeletal muscle because of its force generating capability that can (but does not always) result in movement when applied to the skeletal system.

Measurement of force, torque, mechanical work, power, impulse, metabolic cost and rate of progression are common methods for quantifying exercise though the selection of an appropriate metric can be problematic and necessitates an understanding of the limitations and correct application of each (Winter, 1990, 1991, 2005). These challenges are particularly evident when attempting to quantify the exercise intensity of sports and in particular variable-direction, multiple-sprint sports such as squash. Knowledge of the intensity of exercise in sports can be used to characterise the activity and in turn inform the development of specific testing and training with the goal of enhancing sports performance (Müller *et al.*, 2000).

1.1 Applied physiology of exercise – the historical perspective

Quantifying the acute demands placed upon the body during exercise and the adaptations to chronic exercise exposure means that the physiology of exercise can explain rather than simply describe aspects of exercise performance (Winter *et al.*, 2007). As such, an exercise physiologist is ideally placed to assist sports performers attain their goal of performance improvement. Indeed, the application of physiology to the enhancement of athletic endeavour has long been recognised. Greek and Roman physicians of antiquity had keen interests in the benefits of exercise for health and the prevention of disease (McArdle *et al.*, 2007) and also applied this knowledge to the enhancement of sports performance. The Roman physician Galen (cAD 129-216) in addition to his duties as personal physician to emperor Marcus Aurelius, also attended to the medical needs of gladiators training at schools part-funded by the emperor and advised other staff on issues of diet, training and therapeutic massage (Porter, 1999). The primary goal of this involvement was the improved performance of the gladiators that fulfilled secondary goals of an improved spectacle for the crowds and a subsequent increase in the political image of the ruling emperors (Winter, 2008). The Greek physician Hippocrates (c460-370BC) fulfilled an identical role with athletes competing in the ancient Olympic games. In modern times, English physiologist and Nobel laureate Archibald Vivien Hill made landmark discoveries about factors limiting exercise tolerance in high-intensity running that withstood refutation for more than eighty years (Hill *et al.*, 1924) and informed the training of athletes he worked with.

The current model for the scientific support of sport in the UK is in essence identical to that described above, with state-funded training facilities and specialists in physiology, performance analysis, conditioning, nutrition and physiotherapy striving to optimise athlete performance through characterisation of sports performance and subsequent specific testing and training. Despite two and half thousand years of evolution, the optimisation of sports performance remains a challenge. This is particularly the case in multiple-sprint activities like squash that impose diverse physiological demands.

1.2 Squash

Squash is believed to have started at Harrow public school where boys waiting their turn for the rackets court warmed-up using a soft, hollow ball rather than the bouncier solid rackets ball, though there are historical references and evidence to suggest that the game might have originated at the London debtors prison (Bellamy, 1987). The dimensions of a standard-singles court (shown in Figure 1) and game rules were formalised in 1911.

Singles squash is played between two players with the most basic rule being that the ball must be struck alternately to hit and rebound off the front wall above the tin and below the out-of-court line before it bounces twice. The ball can hit the front wall directly or via the side or back walls. A point is won when a shot is so placed that the opponent cannot satisfy these two requirements. In elite-standard squash a point is scored at the conclusion of every rally with the winner of the rally gaining a point and the right to serve (or retain serve) to begin the next rally. Games are won by the first player to reach eleven points and matches comprise the best of five games. Squash is unique from the other major racket sports (tennis and badminton) because players share the same territory. This requires unique movement patterns to avoid interference with the swing of the opponent's racket and the incoming player's view of and path to and from the ball. Rules regarding interference and associated penalties are complex and result in many heated debates between players and referees and markers during match play.

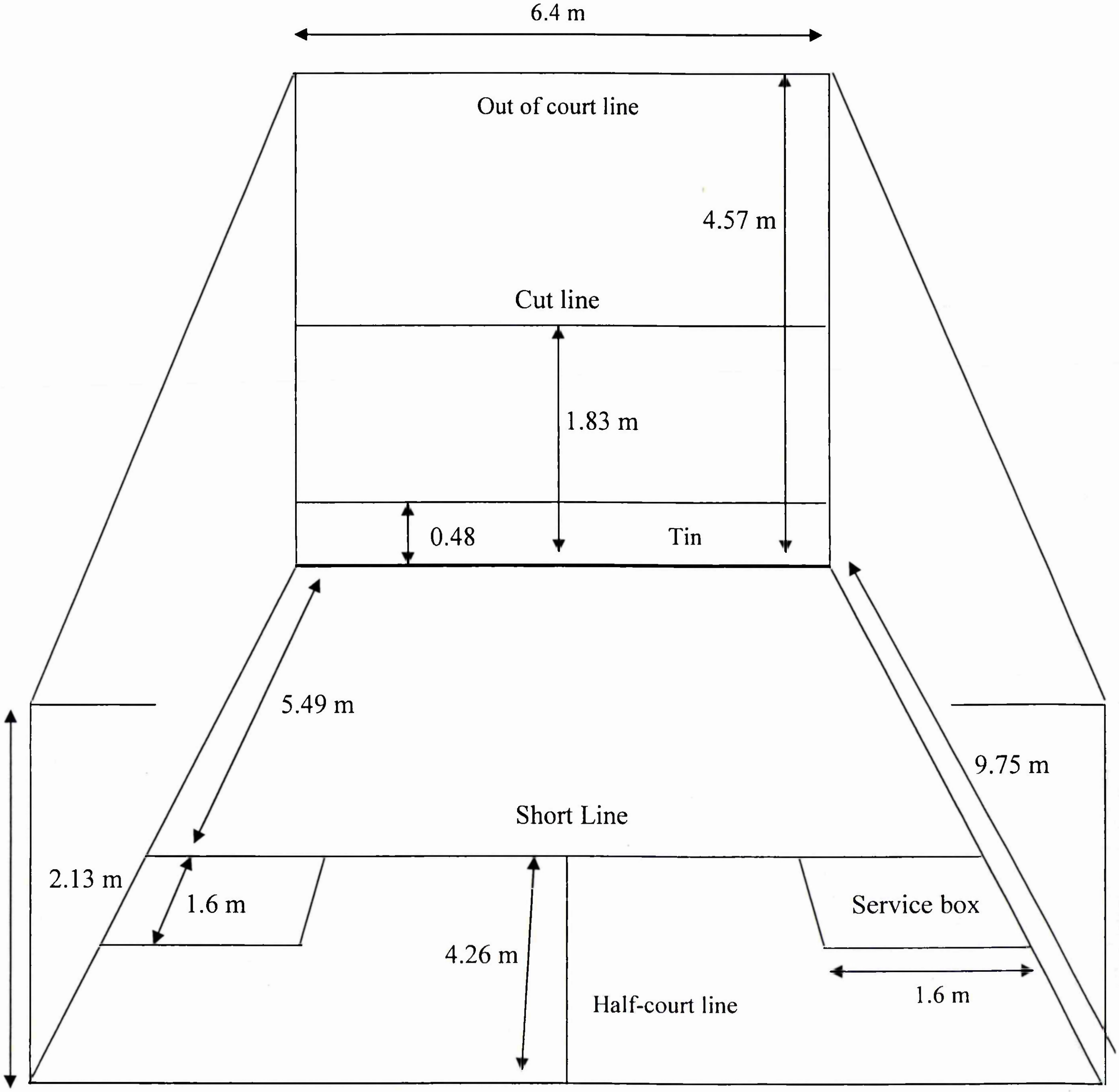


Figure 1. Dimensions of a standard-singles squash court.

1.3 Physiological responses to squash play

Squash is characterised by an intermittent activity pattern where the physiological demand is largely determined by the activity of the opponent, the exercise-to-rest ratio and environmental factors (Lees, 2003). However, physiological demands on players can be modified by the application of particular tactics (Sharp, 1998). Match play imposes diverse physiological demands on cardio-pulmonary endurance, muscle endurance, explosive strength, speed, and flexibility (Sharp, 1998). At elite standard, squash is a high-intensity intermittent activity with mean rally lengths of 16-21 s and recovery times of 8 - 12 s between rallies (Montpetit, 1990; Hughes and Robertson, 1998; Girard *et al.*, 2007). Professional matches can last for 3 hr during which players are active for up to 70% of the time (Girard *et al.*, 2007; Montpetit, 1990). This makes marked challenges to energy supply.

Data from elite match play show heart rate quickly reaches a steady state equivalent to $\geq$ 90% of predicted maximum (Brown and Winter, 1995; Girard *et al.*, 2007). Mean oxygen uptake values of 54 $ml \cdot kg^{-1} \cdot min^{-1}$ ($\approx$86 $\%\dot{V}O_{2max}$) and mean lactate concentrations of 8.3 $mmol \cdot L^{-1}$ have been recently reported (Girard *et al.*, 2007). These data suggest that elite match play places high demands on aerobic and glycolytic energy supply. The $\dot{V}O_{2max}$ values of 62 – 66 $ml \cdot kg^{-1} \cdot min^{-1}$ and Wingate peak powers of 12.5 – 13.5 $W \cdot kg^{-1}$ in elite male players confirm the importance of both high aerobic and non-oxidative power for successful performance (Chin *et al.*, 1995; Brown *et al.*, 1998; Girard *et al.*, 2007).

The specific movement patterns and physiological demands of squash challenge the requirements for sport-specific fitness assessment (Winter *et al.*, 2007). Previous tests developed to assess specific fitness in squash, while addressing some of the criteria for sport-specific procedures, have focussed on maximum and sub-maximum cardio-pulmonary responses and have involved movement patterns that, although specific to squash, are performed at intensities to assess aerobic capabilities. Furthermore, the complexity of existing squash-specific tests is likely to limit their widespread use for the tracking of training-induced adaptations.

Despite the multiple-sprint nature of squash and the documented importance of qualities such as explosive strength and speed and the rapid accelerations, decelerations and direction changes that characterise squash movement (Vučković *et al.*, 2004), there appear to be no published squash-specific tests of multiple-sprint capabilities or change-of-direction speed. This is surprising as the specificity of change-of-direction speed has been demonstrated (Young *et al.*, 1996; Young *et al.*, 2001) and a sport-specific test of multiple-sprint capability has been shown to discriminate ability in a field-based multiple-sprint sport (Boddington *et al.*, 2004).

In summary, squash is a sport where multiple-sprint, endurance and high-intensity exercise capabilities are challenged within unique movement patterns. However, it is unclear which of these factors best relate to performance or which fitness components relate to squash-specific multiple-sprint capability. Links between endurance capability and performance have been explored but need to be re-explored in light of recent changes to scoring and court dimensions. The importance of this and other fitness factors to performance needs to be explored using sport-specific procedures.

1.4 Broad Aims and importance of achieving aims

The aim of the thesis is to develop and validate squash-specific procedures to examine indicators of performance and multiple-sprint capability in sub-elite and elite-standard squash players. It is hoped that achieving this aim could lead to more effective training methods and assessment of the effects of training. It is intended that the development of sport-specific procedures will improve the practices of players and coaches in this regard.

1.5 Research questions

1. Which measures of fitness are most related to squash performance?
2. What are key indicators of squash-specific multiple-sprint capability?

2 REVIEW OF LITERATURE.

2.1 Exercise

Exercise has been defined as any and all skeletal muscle activity (Knuttgen, 1978; Knuttgen and Kraemer, 1987). A notable feature of this definition is that movement is not a necessary outcome of the muscular activity for exercise to be performed. As skeletal muscle activity constitutes exercise in this definition, a thorough understanding of skeletal muscle function is an appropriate starting point from which to derive appropriate means of quantifying muscle activity and thus exercise.

2.1.1 The role of muscle in exercise

It is commonplace in physiological literature to see the purpose of muscle labelled as contraction. Indeed, many classic exercise physiology texts define muscle function in this way (Woledge *et al.*, 1985; Åstrand and Rodahl, 1986; Brooks *et al.*, 1996). The literal meaning of the word contract in the context of skeletal muscle activity is "to make or become smaller; to draw together" implying a reduction in volume and a shortening in length (HarperCollins, 1998). The use of the term "contraction" to describe skeletal muscle activity is widespread and deeply entrenched. It is however inappropriate for describing what an activated skeletal muscle actually does (Knuttgen, 1978; Cavanagh, 1988; Winter, 1990). Experiments as early as the mid-seventeenth century provided clear evidence that muscle volume does not change upon activation. Danish anatomist Jan Swammerdam and later English physician John Goddard, both demonstrated no alteration in the volume of activated muscle using *in vitro* and *in vivo* methods respectively as described by Needham (1971).

Further evidence for the unsuitability of the term contraction can be seen when it is applied to the description of different types of muscle activity. Knuttgen (1978) stated that when a muscle cell is stimulated, the interaction of actin and myosin filaments produce a force that acts to shorten the muscle cell along its longitudinal axis. Whether the muscle actually shortens depends on the relationship between the opposing force resulting from activation and the force acting on the muscle's attachments through a joint lever system. Depending on this balance, the muscle cell might shorten (muscle force > external force), lengthen (muscle force < external force), or have no change in length (muscle force = external force). To describe the active state of muscle as a "contraction" (implying shortening) when the muscle might be shortening, lengthening, or remaining at a constant length is clearly inappropriate and inaccurate. Knuttgen (1978) offers a more accurate and logical description of muscle function suggesting that when stimulated, muscle produces force and does so by attempting to shorten. The outcome of this attempt might be shortening, lengthening or no change in length. Cavanagh (1988) offers a solution by proposing the term "muscle action" to describe the process of muscle activation and subsequent force production.

2.1.2 Quantifying Exercise

2.1.2.1 Force

So far it has been established that exercise refers to skeletal muscle activity, and that the outcome of muscle activation is force. It follows then, that the measurement of skeletal muscle force provides at least one means of quantifying exercise. Force is defined as "that which changes or tends to change the state of rest or motion in matter" (Knuttgen and Kraemer, 1987) and is measured in newtons (N). As it is difficult to assess the actual force produced by an active muscle *in vivo*, it is common instead to quantify the effect of the application of the muscular force on the motion of a body part or other external object. A simple example of this is the lifting of a free weight by an athlete. The mass of the object is acted upon by gravity, and the force developed by the involved muscle groups is accepted as that which is necessary to oppose the gravitational force on the object's mass with the outcome normally reported in units of mass (kg) of the object moved. This immediately poses a problem, as a measure of the force produced should always be quantified in newtons. Furthermore, there are confounding factors in interpreting the outcome of such a test as a true representation of the actual forces generated *in vivo*. Specifically, 1) the force required to accelerate the involved limbs and the mass lifted at the beginning of the movement is not accounted for (Knuttgen, 1995); and 2) the changing mechanical advantage of the joint or joints involved, because of alterations in the angle and distance of the point of force action to the axis of rotation, and length – tension relations are also not accounted for (Knuttgen, 1978).

2.1.2.2 Torque

In most cases, the force generated by an activated skeletal muscle results in movement of skeletal parts about a joint and torque is generated. The prime purpose of an intact skeletal muscle is indeed to generate torque about the joint of the skeleton over which it is inserted (Knuttgen, 1995). Torque is defined as "a measure of the tendency of a force to produce rotation of an object about an axis" (Knuttgen and Kraemer, 1987) and is the product of force and the perpendicular distance in meters from the line of action of the force to the axis of rotation (newton-meter, N·m) . If the torque results in skeletal movement, the muscle activity is said to be dynamic (Knuttgen, 1978). To describe the dynamic activity, the type of muscle action must also be specified as either a shortening or lengthening action for reasons outlined previously.

2.1.2.3 Mechanical work.

Where torques about joints result in movement of body parts or external objects, then mechanical work is done. Mechanical work is the product of force expressed and the distance of displacement of an object, with no consideration of time. The unit of work is the joule (J) which is equivalent to one newton causing a displacement of one meter. Mechanical work is often said to be interchangeable with energy and heat (Knuttgen and Kraemer, 1987; Knuttgen, 1995). Whilst there are relationships between the three variables, the concept of work and energy being synonymous can be misleading. The misapplication of the mechanical principles underlying the relationships has been reported in key exercise physiology texts. For example "energy is the capacity to do work" (Brooks *et al*., 1996). This innocuous statement is in fact incorrect and as recognised by Winter (1990) poses real problems in the case of static muscle actions where no displacement occurs i.e. force × 0 m = 0 J of mechanical work. If work is synonymous with energy, then in this example, a high-force static muscle action appears to require no energy. A further misapplication of this mechanical principle is that mechanical work is often used to quantify exercise intensity (Knuttgen, 1978). The problem here is that exercise might involve in isolation or in combination shortening, lengthening, and static muscle actions. So the muscle could produce external mechanical work (shortening), have work performed on it (lengthening), or produce no external mechanical work (static) a situation which is clearly confusing and inappropriate (Knuttgen, 1978). Furthermore, there is no limitation on time inferred in the expression of mechanical work which does not lend itself to most sporting or exercise testing situations. As such, the use of the term work to quantify exercise has been recognised as inappropriate (Knuttgen, 1978; Knuttgen and Kraemer, 1987; Winter, 1990). In fact when the term work is used to describe an exercise intensity over a particular duration, what is really of interest is the rate of work production or absorption i.e. power.

2.1.2.4 Power

Power is the rate of doing mechanical work, or alternatively the rate of transformation of metabolic energy to work and / or heat (Knuttgen, 1995). It is expressed in watts (W) with one watt equal to one joule of work being performed in one second. Power has been considered to be the most important concept determining sports performance as it is the interaction of muscle force, displacement, and time that determine success in many athletic performances (Knuttgen, 1995). However, Winter (1990, 1991) points out that unless the performance in question can be quantified in watts, which necessitates some measure of external work done per unit of time, it cannot be expressed in terms of power.

2.1.2.5 Impulse / momentum

Exercise tasks of an explosive nature such as throwing and jumping activities and the explosive bursts of movement characteristic of multiple sprint sports are often discussed in terms of power. High-intensity, short-duration exercise like this is however better described by Newton's second law of motion (Winter, 1990). Newton's second law shows that the change in momentum of an object (calculated as final velocity minus initial velocity multiplied by the mass of the body) is proportional to the impulse applied to it. Impulse is the product of force and the time for which the force is applied (Ft). Maximising the impulse will in turn produce the largest change in momentum of the object (i.e. maximise the object's velocity) and this is independent of power output (Winter, 1990). This being the case, it is more accurate to describe an explosive sprint start in terms of the impulse generating capability of the muscle rather than its capacity for producing power. Start or take-off velocity is the decisive quality that influences explosive maximal and high-intensity exercise (Winter, 2005). As it is a vector, velocity applies also to rapid changes-of-direction that are common in field and racket sports. One caveat to this is that impulse is not easily measured as the necessity for accurate readings of force imparted and duration of force application generally require the use of force platforms or other similar transducers. Nevertheless, it is important to be aware of the correct way in which various forms of exercise should be described as accuracy, clarity, and precision are cornerstones of scientific measurement (Knuttgen, 1978).

2.1.2.6 Rate of progression, velocity and performance time.

All forms of exercise involving locomotion (such as running), do not lend themselves easily to accurate calculations of external mechanical work because of complications of combinations of muscle action types and difficulty calculating the displacement of all moving body parts. Similarly, accurate real-time measurements of force make calculations of impulse and torque problematic. In such cases, exercise performance can be more simply expressed as rate of progression (speed) in $m \cdot s^{-1}$, or velocity if direction is important (Winter, 1990). Where the exercise tasks involves frequent changes in speed or velocity whereby neither mean nor peak values accurately represent the exercise intensity, time taken to complete a set distance can be used to indicate the intensity of exercise.

2.1.2.7 Metabolic cost.

The production of force, work and power all require energy. The energy requirement of a task is a combination of the intensity (rate of ATP supply needed) and the duration of muscular activity. As such all tasks can be placed on a spectrum of metabolic cost from very high ATP demand for a short time (anaerobic systems) to low ATP demand for extended duration (aerobic).

The ATP regenerating pathways that respond to the range of energy demands from skeletal muscle ensure that muscle [ATP] remains remarkably constant and allow for an extended duration of energy supply to continue muscle activity. Two important features of these energetic processes are the maximum rate at which ATP can be regenerated (power of the process) and the amount of ATP that can be produced (capacity of the process) (Sahlin, 1996). The three major ATP regenerating pathways differ markedly in their powers and capacities for ATP supply. The energy pathways differ on a spectrum from the high power, very low capacity hydrolysis of phosphocreatine (PCr) to the low power, very high capacity oxidation of carbohydrate (CHO) and triacylglycerols (TAG). The anaerobic and incomplete breakdown of CHO to lactate and associated protons termed glycolysis provides an intermediate pathway for ATP regeneration both in terms of power and capacity. The differences in power and capacity of the three pathways are illustrated in Figure 2.

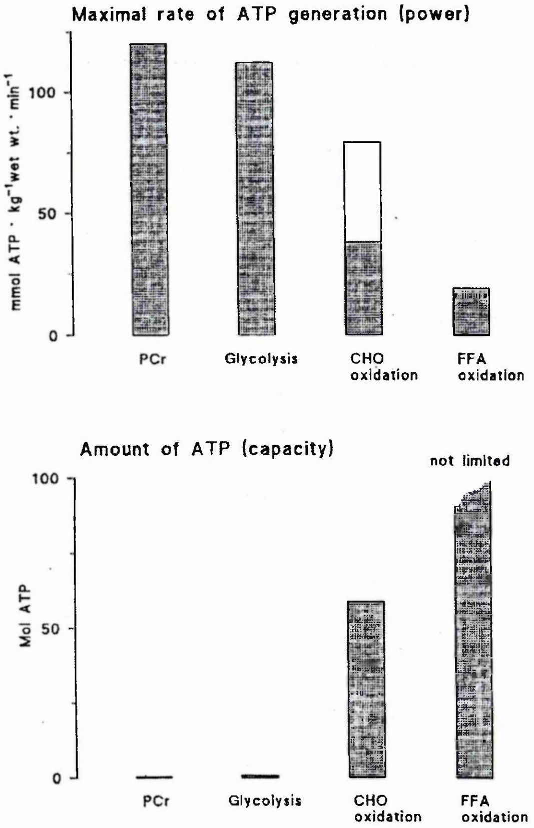


Figure 2. Power and capacity of energy yielding processes in human skeletal muscle. Power values are based on observations in the following conditions: PCr breakdown, 1.3 s electrical stimulation; glycolysis, 10 s cycling; CHO oxidation (filled bar), calculated from O_2 extraction during two-leg cycling assuming 72% of $\dot{V}O_{2max}$ is utilised by a 20 kg mass of active muscle; CHO oxidation (unfilled bar), one-leg knee extension; FFA oxidation, assumed to be 50% of that of CHO oxidation. Capacity values have been derived from muscle content of PCr, glycogen, maximal muscle lactate accumulation and an exercising muscle mass of 20 kg (Sahlin, 1996).

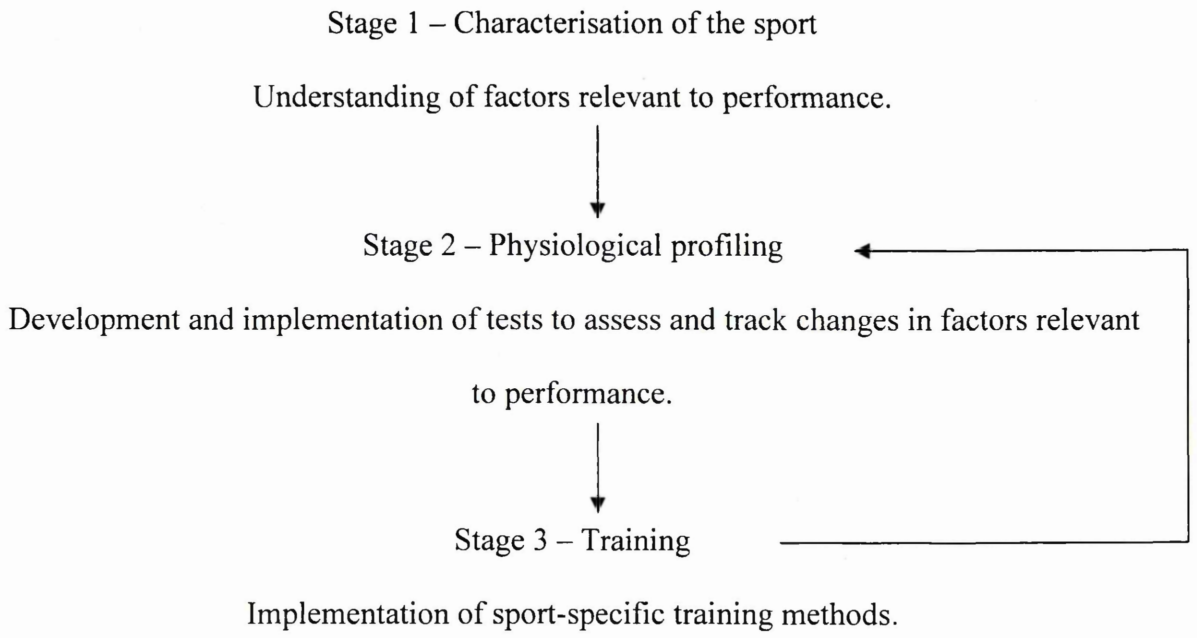
2.2 Applications of the physiology of exercise.

Understanding the acute demands placed upon the body during exercise and how the body adapts to chronic exercise exposure means that the physiology of exercise can explain rather than simply describe aspects of exercise performance (Winter *et al.*, 2007). As such, a practitioner is ideally placed to assist sports performers attain their goal of performance improvement. Indeed, the application of physiology to the enhancement of athletic endeavour has long been recognised. The central role of athletics in the culture of ancient Greece produced specialists in exercise training, diet and massage therapy who worked with the early Olympians (Porter, 1999). Early versions of state-funded sport-science support schemes were evident in the gladiator training schools of Rome as depicted in recent modern box office films and acknowledged in text books on the history of science (Sarton, 1944).

As standards of performance in sport continue to rise, greater emphasis is placed on the optimisation of athlete training and preparation. Only when training is optimised can physiological adaptations be maximised while incidences of injury and mal-adaptation are reduced. The study of the physiology of exercise provides the knowledge and understanding of physiological demands placed on performers and of mechanisms that underpin improvements in performance with training that can be used to move towards optimisation of training (Winter *et al.*, 2007).

2.3 Physiological profiling.

The following model of the development of optimal training for performance improvement has been proposed by Müller *et al.*(2000):



Stage 1 – Characterisation of the sport

Understanding of factors relevant to performance.

Stage 2 – Physiological profiling

Development and implementation of tests to assess and track changes in factors relevant to performance.

Stage 3 – Training

Implementation of sport-specific training methods.

For the purpose of this review, only stages one and two will be considered further.

2.3.1 Stage 1- Characterisation of the sport

Advances in technology have resulted in subjective observations and interpretations of the coach (once common-place at this stage of the process) being replaced by objective recordings of performance and physiological responses to match play. The evolution of computerised notational analysis systems has resulted in rapid and accurate statistical analyses of performance parameters. The four main objectives of notational analysis are (Hughes, 1997):

- Analysis of movement – type, velocity / speed, acceleration, patterns, time-motion.
- Tactical evaluation.
- Technical evaluation.
- Statistical compilation.

Similarly, technological developments have resulted in real-time collection of heart rate and oxygen uptake responses by light-weight, portable analysers that transmit telemetrically to computers for immediate analysis. Fast-response, hand-held electrochemical analysers have also facilitated the collection of blood-borne markers of metabolism.

Together, analyses of these data can provide a detailed picture of the physiological demands experienced by the performer and thus the factors that determine performance.

2.3.2 Stage 2 – Physiological testing

The general purpose of physiological assessment is to understand human exercise capabilities (Winter *et al.*, 2007). Specifically, according to Bird and Davison (1997), physiological testing aims to:

1. Evaluate strengths and weaknesses of performers in relation to the factors known to be important for performance.
2. Evaluate the effectiveness of training interventions.
3. Evaluate the health status of an athlete.
4. Provide a source of motivation for the performer in the form of short-term goals for improvement before re-testing and positive feedback of improvements in fitness since a prior assessment.
5. Assist in talent identification or demonstrate readiness to recommence training following injury or layoff.
6. Provide knowledge and understanding of a sport to assist coaches, athletes and scientists.
7. Provide data that can be used to address research questions.

The extent to which physiological assessment can achieve these benefits depends heavily on the selection of appropriate test procedures. Criteria have been published to guide both the choice of appropriate tests from existing batteries and the development of new procedures (N.C.F., 1995; Winter *et al.*, 2007).

2.4 Criteria for sport-specific tests.

It is acknowledged that tests should be specific, valid, reproducible and sensitive enough to detect meaningful changes in performance that result from training-induced adaptations (Winter *et al.*, 2007; Müller *et al.*, 2000; N.C.F., 1995). This presents severe challenges particularly in multiple-sprint activities such as squash.

2.4.1 Specificity.

Multiple-sprint sports such as squash challenge tests to replicate the specific and varied movements and changes-of-direction and speed that characterise match play. This necessitates the development of valid and reproducible sport-specific procedures capable of assessing fitness components important for performance. Factors for consideration in the design of such tests (Winter *et al.*, 2007) are:

1. Muscle groups involved, types of muscle action and range of motion required.
2. Intensity and duration of activity.
3. Energy systems recruited.
4. Resistive forces encountered.

These requirements question the utility of laboratory-based exercise testing for sports such as squash because of difficulties in characterising the movement patterns. This suggests a move away from laboratory-based procedures to those that are field-based and specific to sport-related activities (N.C.F., 1995). However, it must be noted that there is usually a trade-off between increased specificity and reduced precision and control that must be carefully considered in test selection (Winter *et al.*, 2007).

2.4.2 Validity

Validity is defined as "the extent to which a test, measurement or other method of investigation possesses the property of actually doing what it has been designed to do" (Kent, 1994). The validation of tests can be a complex task and that might explain why many field-based sports tests have not been scientifically validated. However, the

National Coaching Foundation (N.C.F.) (1995) offers useful criteria with which the validity of field-based tests can be established. A test procedure can be deemed valid if it demonstrates:

1. Logical or face validity
2. Criterion validity
3. Construct validity

2.4.2.1 Logical validity

Logical validity is demonstrated when the test procedure is capable of assessing key physiological components known to be of importance for performance. For example a test of vertical jump height would be a logically valid test for a rugby line-out.

2.4.2.2 Criterion validity

Criterion validity is usually assessed by comparison of the new test procedure to an established and recognised *gold standard* test procedure. If there is agreement between the test scores, or the tests are correlated, the new test is said to possess criterion validity. An example of this approach is the validation of the 20-m Multiple Shuttle Test (Leger and Lambert, 1982) to predict maximal oxygen uptake ($\dot{V}O_{2max}$). This test was validated against directly determined $\dot{V}O_{2max}$ from a laboratory-based treadmill incremental test.

2.4.2.3 Construct validity

Construct validity is demonstrated by the ability of a test to discriminate between groups of performers from sports with different characteristics or between abilities within a group of performers. An example here would be the ability of a twelve-minute-run test to discriminate between a group of distance runners and a group of sprinters. It would be anticipated that distance runners would out-perform sprinters on this test. Similarly, elite-standard distance runners would probably out-perform non-elite distance runners (N.C.F., 1995).

2.4.3 Reproducibility and sensitivity

A reproducible test is one that produces similar results on two or more occasions in the absence of any change in fitness (Kent, 1994) and is an important requirement for data to be considered meaningful (Winter *et al.*, 2007). The variability present in all measurements (Hand, 2004) is a combination of systematic and random error components. The former encompasses learning effects and the accuracy and precision of instrumentation and its operation, whereas the latter comprises random and cyclical biological fluctuations (Winter *et al.*, 2007). Accurate interpretation of test results is dependent on quantifying the error inherent in the measurement.

Precisely which metric of reproducibility to use is the subject of enthusiastic debate because each has its detractors and supporters (Atkinson and Nevill, 1998; Hopkins, 2000a). However, a factor common to all metrics is that their interpretation requires the scientist to judge (based on proposed use of the test) whether or not the test-retest error is small enough for the test to be of practical use (Atkinson and Nevill, 1998). To make this judgement, the researcher must possess knowledge of the smallest worthwhile change in a performance or physiological variable, then assess the extent to which the test is sensitive enough to detect such a change (Hopkins, 2000a).

2.5 Physiological demands of squash play

Squash is characterised by an intermittent activity pattern where the physiological demand is largely determined by the activity of the opponent, the exercise-to-rest ratio and environmental factors (Lees, 2003). However, physiological demands on players can be modified by the application of particular tactics (Sharp, 1998). In common with multiple-sprint activities such as soccer, basketball and other racket sports, specific movement patterns and demands of squash provide a unique challenge to physiologists in their attempts to produce valid and reliable assessments of physiological factors relevant to squash performance. The challenge is to combine the control of laboratory procedures with the ecological validity of tests carried out in the specific movement patterns of the sport.

2.5.1 Characterising squash

Recent changes in rules (2007) have resulted in a change to scoring in elite-standard men's competitions from point-a-rally to fifteen points (PAR – 15), to PAR to eleven points (PAR -11), with matches still comprising the best of five games. In addition, senior-male elite-players compete on courts with a tin height of 43.18 cm rather than the standard 48.26 cm tin used at all other standards of play. These points are raised because data from the studies that follow were largely collected from male players prior to these rule changes. To-date, only one study has reported the nature of play and physiological demands of elite-standard squash played with PAR - 11 and the lower tin of professional events (Girard *et al.*, 2007).

2.5.2 Time and motion analysis.

Analyses of time-motion characteristics of a sport can be used to estimate the physical demands of match play (Montpetit, 1990) and in tandem with measures of physiological responses, guide the selection of appropriate fitness tests. Table 1 summarises the available published temporal data for elite squash.

Table 1. Temporal structure variables for elite squash match play. Values are mean ± SD (where reported).

Reference	Standard	Sex	N	Mean game duration (min)	Active time (%)	Rallies / game	Shots / rally	Mean rally time (s)	Mean rest time between rallies (s)	Total playing time (min)
Monpetit (1990)	Professional	M		11.6	60.1	30.5	4.8	13.6	9.0	
Montpetit (1990)	'A' grade amateurs	M		12.3	67.5	30	6.0	16.6	8.0	
Gillam *et al.* (1990)	Nationally ranked	M F	7 6		74 66			17.3 ± 4.8 12.5 ± 2.4	6.1 ± 1.0 6.6 ± 1.2	
Hughes and Robertson (1998)	World top 20	M				26		21.0	10.0	
(Vučković *et al.*, 2004)	Professional	M	8	11.6 ± 4.1	59.5 ± 5.7	25 ± 7.5		16.4 ± 13.2	11.6 ± 5.4	
Girard *et al.* (2007)	Professional	M	7	7.9	69.7 ± 4.7			18.6 ± 4.6	8.0 ± 1.8	25 ± 4

Despite the time span over which the data were collected and the accompanying advances in equipment and scoring system changes, the temporal nature of squash appears largely unchanged at the highest standards of play. The intermittency of play is clearly depicted and is characteristic of racket sports in general (Lees, 2003). In contrast with other racket sports, mean rally duration and effective playing time in squash are longer (4-5 s, 35% and 4-8 s, 10-30% in badminton and tennis respectively) (Pluim, 2004). Mean recovery times between rallies are similar in squash and badminton (6-11 s), but recovery durations in tennis are greater (15-25 s) (Pluim, 2004).

Studies characterising the movement patterns of squash are limited. Vučković *et al.* (2004) stated that movements can be characterised in terms of quantity and intensity. The former is measured as distance covered (m) for cyclic movements, or frequency of execution for acyclic movements (such as lunge, side-step, turn etc.). The latter is measured as speed of movement ($m \cdot s^{-1}$) or frequency of movements for cyclic and acyclic movements respectively. As the playing area in squash is small, movements in one direction are short and acyclic movements are frequent (Vučković *et al.*, 2004). Mean distances per rally of 12 m (Hughes, 1998) and 26 m (Vučković *et al.*, 2004) have been reported for good club-players and national-standard players respectively though distances of 152 m in a single rally have been recorded (Vučković *et al.*, 2004). Most movements occur within 1 m of the central T position and players can cover up to 2 km in a single game (Vučković *et al.*, 2004).

Only one study has attempted to characterise types and frequencies of movement that occur in squash play. Using fourteen county-and regional-standard players, Eubank and Messenger (2000) reported 2866 ± 464 steps per match and 580 ± 104 steps in rallies per game. A high percentage of these movements (74.4%) included a flight phase leading the authors to conclude that this dynamic nature indicated the high-intensity nature of squash. Table 2 displays the variety and frequency of steps used and Table 3 shows common double-and triple-step patterns recorded (Eubank and Messenger, 2000).

Table 2. Percentage breakdown of steps made during squash matches (italics represent the mean number of a particular movement per match) (Eubank and Messenger, 2000).

	Forward Step	Sidestep	Crossover	Cut	Stretch	Lunge
Total %	70.1	10.6	4.3	10.8	2.8	0.05
N	*1386*	*207*	*84*	*211*	*55*	*11*
Straight	78.1	88.5	80.3	79.1		
90°	20.2	11.1	18.9	18.3		
180°	1.7	0.0	1.0	2.5		
Forward					65.1	100
Sideways					34.9	

Table 3. Commonly occurring double-and triple-movement links in squash (Eubank and Messenger, 2000).

Move 1	Move 2	Move 3	Occurrence (%)
Step with 90° turn	Forward step		26
Sidestep	Forward step		22
Cut	Forward step		8
Forward step	Sidestep	Forward step	19
Forward step	Step with 90° turn	Forward step	11
Forward step	Crossover sidestep	Forward step	7

In summary, the temporal and movement pattern data show that squash is characterised by repeated high-intensity movements over short distances and short durations in different directions, with short recovery periods between rallies and a high percentage of effective playing time. This analysis justifies claims that squash is the most demanding of the racket sports (Lees, 2003; Pluim, 2004) and emphasises the importance of fitness at elite standards of play.

2.5.3 Physical and physiological characteristics of elite squash players.

Time-motion data suggest that aerobic and high-intensity exercise capabilities are important characteristics for elite squash players (Eubank and Messenger, 2000). Anthropometric and physiological data from elite standard squash players can be used to support this assumption. Available data are summarised in Tables 4 and 5 and the following text.

Table 4. A summary of characteristics for senior, elite-standard squash players. Values are mean ± SD (where reported).

Reference	Sex	*n*	Age (yrs)	Stature (m)	Body Mass (kg)	Body fat (%)
Mercier *et al.* (1987)	M	5	28 ± 4	1.78 ± 0.05	80.7 ± 9.6	16.8 ± 4.1
Gillam *et al.* (1990)	M	7		1.74	72.2	8.6
	F	6		1.62		18.1
Chin *et al.* (1995)			21 ± 3	1.73 ± 0.04	67.7 ± 6.9	7.4 ± 3.4
Brown *et al.* (1998)	M	5	25 ± 0.6	1.80 ± 0.03	73.5 ± 3.6	10.2 ± 0.7
	F	7	26 ± 1.7	1.68 ± 0.01	64.2 ± 1.3	24.7 ± 1.2
St Clair Gibson *et al.* (1999)	M	10	22 ± 2	1.79 ± 0.03	73.4 ± 7.2	12.5 ± 4.7
Girard *et al.* (2005)	M	7	25 ± 4	1.77 ± 0.06	72.1 ± 6.1	

With the exception of the data of Mercier *et al.* (1987), the characteristics of male elite players appear consistent across studies with regard to body mass and low percentage body fat. As squash is a weight bearing activity, low body mass and body fat are desirable characteristics particularly as the movement patterns and intermittent activity profile require repeated, rapid acceleration and deceleration (see section 2.5.2). The elite players in the study of Mercier *et al.* (1987) comprised three French national standard and two others classed as 'high-standard'. The two high-standard players might not have been of comparable ability to the national players in the study or in the other studies reported. As such, their results could have affected the group mean and might account for the discrepancies between studies.

Table 5. A summary of aerobic physiological profile data for senior elite-standard squash players. Values are mean ± SD (where reported).

Reference	Sex	*N*	$\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	Maximum heart rate ($beats \cdot min^{-1}$)	Lactate Threshold (% $\dot{V}O_{2max}$)	Test Method
Mercier *et al.* (1987)		5	56 ± 6.1	182 ± 11		ICT
Steininger & Wodick (1987)	M + F	13	58.5 ± 8.1	195 ± 6		ITT
Gillam *et al.* (1990)	M	7	57.8	190	86	ITT
	F	6	53.8	188	88	
Chin *et al.* (1995)		10	61.7 ± 3.4	191 ± 7	80 ± 4.9	ITT
St Clair Gibson *et al.* (1998)	M	10	63.4 ± 6.1	188 ± 5		ITT
Girard *et al.* (2005)	M	7	54.9 ± 2.5	195 ± 9	83.2 ± 8.3	ITT
			63.6 ± 3	193 ± 8	84.5 ± 5.7	IST

ICT, incremental cycle test; ITT, incremental treadmill test; IST, incremental squash-specific test.

The data in Table 5 show that elite squash players possess moderate to high maximal oxygen uptakes that are greater than those reported in elite badminton players (51.5 $ml \cdot kg^{-1} \cdot min^{-1}$) (Hughes, 1995) but comparable with elite tennis players (54 – 65 $ml \cdot kg^{-1} \cdot min^{-1}$) (Christmass *et al.*, 1995; Bernardi *et al.*, 1998). Lactate thresholds are generally high and comparable to trained distance runners (Midgley *et al.*, 2006). Comparable data from other racket sports are not available.

Brown *et al.* (1998) reported the $\dot{V}O_{2max}$ of senior male (n = 5) and female (n = 7) players from England's national squads. However, the data were expressed in litres per minute (4.86 ± 0.16, 3.50 ± 0.12 for males and females respectively) and relative to body mass as a power function ratio standard, with body mass raised to the power 0.67 (274 ± 4, 215 ± 5 for male and female players). This facilitated comparison with the $\dot{V}O_{2max}$ of elite junior players who were also tested but makes comparison with data from other studies difficult. Nevertheless, the study provided a useful cross-sectional comparison showing elite senior players had a 7 – 9 % greater aerobic power than elite juniors and suggesting that, in addition to differences in technical and tactical skills, physiological factors also determine successful transition to senior elite-standard.

Data profiling the high-intensity exercise capabilities of elite squash players are limited. This is surprising as time-motion analysis identifies short-duration, explosive activity as a key feature of match play. The lack of data from measures of high-intensity exercise capability might reflect the fact that characterisation of these elements of match play has not been undertaken until recently (Eubank and Messenger, 2000; Vučković *et al.*, 2004).

Grip strength is a commonly reported factor in the studies that have measured high-intensity exercise capabilities and has obvious value in relation to racket control. Sharp (1998) reported values as high as 600 N in male elite players while scores from other studies are comparable but lower than this (507 ± 16 N, Todd and Mahoney (1994); 493 N, Gillam *et al.*(1990); 479 ± 56 N, Chin *et al.*(1995)). In female players, values ranging from 300 – 450 N have been reported (Sharp, 1998; Gillam *et al.*, 1990). Sharp (1988) suggested that grip strength scores ranging from 400 – 450 N and 300 – 350 N for males and females respectively are required to ensure racket control during match play. These ranges were derived from extensive testing of elite-standard players.

Because of the repeated short-duration, high-intensity movements involved in match play (Eubank and Messenger, 2000; Vučković *et al.*, 2004), high-intensity exercise capabilities of the lower limbs are important factors determining court coverage (Behm, 1992). In a study with county-standard squash players, Brookes and Winter (1985) compared performance in two types of vertical jump and the Wingate cycle test. Jump heights of 0.5 ± 0.057 m and 0.3 ± 0.075 m and peak power of 11.94 ± 1.07 $W{\cdot}kg^{-1}$ (924 ± 178 W) were reported for the Sargent jump, Power jump and Wingate tests respectively. Vertical jump height data have been reported by Gillam *et al.*(1990) and Todd and Mahoney (1994) where mean values of 0.47 and 0.56 m respectively were produced by elite-standard-male players. However, the precise methods for the jump tests used by Gillam *et al.*(1990) and Todd and Mahoney (1994) are unclear which makes comparisons between studies problematic. In contrast, Chin *et al.* (1995) reported mean Wingate peak power of 15.5 ± 1.8 $W{\cdot}kg^{-1}$ for ten male elite Asian players offering a direct comparison with the Wingate peak power scores reported by Brookes and Winter (1985). The higher scores reported by Chin *et al.* (1995) might reflect the difference in standard of players between the two studies, though Todd and Mahoney

(1994) reported mean Wingate peak power similar to Brookes and Winter (1985) in 12 elite Irish squash players (898 ± 36.1 W).

Other measures of lower limb high-intensity exercise capabilities reported include isokinetic peak torque (Chin *et al.*, 1995), 30-m sprint and 10 × 5-m sprint times (Todd and Mahoney, 1994). Unfortunately, there are no comparable data for these tests.

2.5.4 Physiological responses to match play in squash.

The evaluation of squash player performance in general tests of sub-maximal and high-intensity exercise capabilities is useful for cross-sectional and longitudinal comparison. However, for physiological assessment to be valid and specific and for interpretation to be meaningful, tests should attempt to mimic the demands of match play. Moreover, specific training should aim to impose similar physiological stress on the player to that experienced in actual play. To achieve this, physiological responses to match play must be characterised. Table 6 summarises the available physiological response data from elite players collected during match play. In this context, elite refers to players of county / regional standard up to international.

Table 6. Physiological responses to match play in elite squash players.

Reference	*N*	Mean HR (beats·min^{-1})	Mean HR_{max} (beats·min^{-1})	% HR_{max}	% HRR	Mean $\dot{V}O_2$ (ml·kg^{-1}·min^{-1})	% $\dot{V}O_{2max}$	Mean blood lactate (mmol·l^{-1})
Blanksby *et al.*(1973)	25	150	163	84[b]				
Blanksby *et al.*(1980)	9		167		74[b]			
Docherty (1982)	3			82[b]				
Mercier *et al.* (1987)	5	153 ± 9	187[d]	84[a]				2.9 ± 1.5
Montpetit *et al.* (1987)	16	147 ± 18		72[a]			57[e]	
Gillam *et al.* (1990)	2	150 ± 17		79[a]		42.5 ± 5.5	73[e]	1.3 ± 0.7
Girard *et al.* (2007)	7	177 ± 10		92[c]		54.4 ± 4.8	86[f]	8.3 ± 3.4

[a] HR_{max} directly determined from laboratory test; [b] HR_{max} age-predicted; [c] HR_{max} directly determined from squash-specific incremental test; [d] value higher than mean HR_{max} measured in laboratory test; [e] $\dot{V}O_{2max}$ directly determined from laboratory test; [f] $\dot{V}O_{2max}$ directly determined from squash-specific incremental test.

Telemetric measurement of on-court heart rate is common to all of the studies in Table 6 and mean heart rates are comparable between studies with the exception of Girard *et al.* (2007). Similarly, relative exercise intensity expressed as percentage of maximum heart rate is comparable between studies with the exception of Montpetit *et al.* (1987) whose players were at the lower end of the elite category and Girard *et al.* (2007) whose data were collected during match play with current lightweight rackets, the PAR – 11 scoring system and a lower tin height.

Only two studies report measurements of on-court $\dot{V}O_2$ and discrepancies between them are large. Gillam *et al.* (1990) used Douglas bags mounted on the backs of two players to collect expired air for subsequent analysis of volume and fractions of expired CO_2 and O_2. Following a thirty-minute warm-up, one-to two-minute samples were taken when player heart rates reached their usual playing range. However, to adjust for the effect of the equipment on mobility and peripheral vision, game rules were modified to allow the ball to bounce twice thus altering the nature of play. As such, the oxygen cost calculated is unlikely to reflect that of play under normal rules. Furthermore, the responses of two players might not be representative of the population of elite-standard players. In contrast, Girard *et al.* (2007) were able to make use of recent technological advances collecting breath-by-breath data with a light-weight portable, telemetric system worn by players in a small shoulder harness. Participants played three competitive games against an opponent of similar standard under Professional Squash Association rules with PAR – 11 scoring and the lower tin height used in professional men's competition. The participants were members of the French national men's squad and included the world number one and reigning world champion (at the time of data collection). The higher oxygen cost reported by Girard *et al.* (2007) is more likely to represent demands of modern match play because of the methods, equipment and players used and the rules applied in data collection. Notably, the post-game blood lactate concentrations reported in the recent study of Girard *et al.* (2007) are higher than those in earlier studies despite similar methods applied to collection and analysis. This suggests that advances in racket and ball technology, combined with scoring and court changes, have increased the intensity of exercise in match play. The higher mean heart rate and relative $\dot{V}O_2$ scores reported by Girard *et al.* (2007) support this. It is notable that the relative exercise intensity in this study was expressed as a percentage of maximum heart rate and maximal oxygen uptake derived from an incremental test performed on-court using squash-specific movement patterns at controlled speeds, adding to the value of the study's findings.

2.5.5 Summary of important physiological factors for squash.

The data presented show that squash is a high-intensity, multiple-sprint sport involving explosive movements over short distances with frequent directional changes. Time-motion analyses, physiological profiling data and responses to match play confirm the importance of endurance capability and high-intensity exercise capabilities, in particular, explosiveness of the lower limbs and change-of-direction-speed.

2.6 Specific fitness testing in squash.

Specificity, validity, reproducibility and sensitivity are the criteria that fitness tests should satisfy (Winter *et al.*, 2007; Müller *et al.*, 2000; N.C.F., 1995). Sport-specific procedures should reflect intensities of exercise and their duration, involved muscles, muscle activity, forces and metabolic demands of match play (Winter *et al.*, 2007). Use of non-specific procedures can produce inaccurate physiological profiles and misinterpretations of strengths and weaknesses.

The importance of sport-specific testing of physiological factors relevant to squash has been previously demonstrated. St Clair Gibson *et al.* (1998) reported that maximal oxygen uptake estimated from a field-based 20-m shuttle test correlated more highly with laboratory-determined $\dot{V}O_{2max}$ in runners ($r = 0.71$, $P < 0.05$), than in squash players ($r = 0.61$, $P < 0.05$) indicating sport-specific differences in the prediction of $\dot{V}O_{2max}$. The test specificity of $\dot{V}O_{2max}$ in squash players has also been demonstrated elsewhere. Two studies compared responses of elite squash players in squash-specific incremental tests and laboratory-based treadmill incremental tests and showed that higher $\dot{V}O_{2max}$ was achieved by squash players on the squash-specific tests (Steininger and Wodick, 1987; Girard *et al.*, 2005).

The use of on-court sprint drills that encompass multiple-direction-changes and simulated stroke making (ghosting) by elite-standard squash players reflects the recognition that training for the short-duration, explosive movements of match play must be undertaken in sport-specific movement patterns (Sharp, 1998). The specificity of this aspect of fitness has been demonstrated by Young *et al.* (1996) and Young *et al.* (2001). The earlier study reported a common variance of just 7% between performance on a straight 20-m sprint and a 20-m sprint with three 90° changes-of-direction in trained Australian rules footballers. The later study investigated changes in performance on 30-m sprint tests with 0 – 7 direction changes after no training (control), a six-week period of straight sprint training (speed group) or change-of-direction sprint training (change-of-direction speed group). Training was matched for total distance covered, total volume and intensity. Speed training resulted in improvements in straight sprint speed and speed on the test with two 160 ° direction changes ($P < 0.05$), but produced no changes in performance on the other five tests where changes-of-direction became more frequent ($P > 0.05$). Conversely, the change-of-direction speed training resulted in improvements in all change-of-direction speed tests ($P < 0.05$) but no improvement in straight sprint performance ($P > 0.05$). The authors concluded that straight sprinting speed and change-of-direction speed were separate qualities and each with specific training adaptations that had limited transfer to the other.

The specific nature of test responses and of training adaptations necessitates the development of sport-specific procedures. The specific movement patterns of squash provide a unique challenge to physiologists attempting to assess squash-specific fitness and suggest that tests should encompass the ability repeatedly to change direction at speed.

2.6.1 Game-simulation protocols

While there have been attempts to produce controlled tests to replicate squash-specific physiological demands (Todd *et al.*, 1998; Sherman *et al.*, 2004; Kingsley *et al.*, 2006), these tests were designed to simulate match play rather than assess squash-specific fitness components. The study of Kingsley *et al.* (2006) describes a squash-specific incremental test procedure that *could* be used to assess squash-specific fitness. However, the study focused on the use of the procedure in the development of a squash simulation protocol and does not address the validity of the incremental test for assessment of squash-specific fitness.

2.6.2 Incremental tests

Although several groups are working in this area, only two previous studies designed to assess the validity of on-court squash-specific protocols for assessment purposes have been published (Steininger and Wodick, 1987; Girard *et al.*, 2005). The procedure of Steininger and Wodick (1987) was devised to mimic physiological demands and techniques specific to squash movement, but in clearly defined increments to allow the assessment of squash-specific endurance fitness.

With thirteen nationally ranked players as participants, six lamps were suspended to hang just below the height of the 'out' line on the side walls of a squash court (three on each side). The first pair was positioned near to the front corners of the court (numbers one and two), the second pair (lamps three and four) level with mid-court, and the third pair (five and six), were located mid-way between lamps three and four and the rear wall. Squash balls were suspended on string under the pairs of lamps, at knee-height for one and two, eye-height for lamps three and four, and at hip-height for lamps five and six.

The lamps were connected to a sequencing device off-court which altered the frequency of light flashes. When a lamp lit, the player moved from the T position to strike the ball below the lamp in a technically appropriate manner, and returned to the T before the next lamp was lit. The first intensity level began with 12 light pulses per minute, equivalent to 36 dashes over the three-minute stage. Intensity was increased by six pulses (or moves) per three-minute level (two moves per minute) until volitional exhaustion was reached.

In the original protocol, 45-second rest intervals between stages were used to collect blood samples for lactate determination and for measurement of final-stage heart rate by 3-lead ECG. Table 7 summarises the results of the study.

Table 7. Physiological responses to the squash test for individual players (adapted from Steininger and Wodick, 1987)

Test person	Max. heart rate (beats·min^{-1})	Heart rate 5 min after step end (beats·min^{-1})	Max. blood lactate (mmol·l^{-1})	Max performance		Performance at the anaerobic threshold (light pulses per min)
				Last stage	Time on last stage (min)	
A	176	107	8.6	6	0.5	54.0
B	190	110	9.7	5	2.25	56.1
C	185	115	5.5	5	1.25	50.1
D	182	110	6.1	5	1.0	55.5
E	195	119	10.1	4	3.0	33.6
F	184	117	8.5	5	1.0	44.4
G	175	116	11.4	5	0.5	45.3
H	180	120	8.4	5	1.5	45.3
I	190	122	9.0	5	1.5	45.3
J	190	121	8.3	5	0.75	49.2
K	178	120	4.8	4	2.75	48.9
L	195	122	6.1	4	2.0	34.5
M	190	124	7.8	3	3.0	32.1
Mean	185	117	8.0			45.7
SD	7	5	1.8			7.7

Ranked performance data from the test correlated with ranked playing fitness coefficients estimated from competitive results and a coach's subjective estimates of match fitness ($r = 0.90$, $P < 0.05$). There was a modest correlation ($r = 0.50$, $P < 0.05$) between ranked playing fitness coefficients and ranked performance on a laboratory incremental treadmill test (Steininger and Wodick, 1987). This finding highlighted the ability of the test to assess physiological capacities in squash specific movements.

Steininger and Wodick (1987) used a fixed blood lactate of 4 mmol·l^{-1} to determine anaerobic threshold and reported that most players (who were national standard) had surpassed this value by intensity level 2 of the test. Chin *et al.* (1995) used the test with the Hong Kong men's national squad and showed similarly high lactate responses early in the test. This suggests that either the initial intensity is too high, that the step increase in intensity is too great, or both. It brings into question the value of the test for assessing players of a lower standard and fitness such as elite junior players, as it is likely that the test will be too difficult to gain any useful data.

While movement patterns created by the test clearly replicated those of squash play, account for the stochastic (random) characteristic of squash movement in match play was not made. The predictable sequence of movements used means the player must only travel *through* the T area *en-route* to the next court position. In contrast, match play is characterised by uncertainty about movement direction (Vučković *et al.*, 2004). The muscular demands of random movement are likely to be much greater and different from movement that is predictable. The ability of muscle to accommodate to unanticipated changes in direction and speed is a crucial performance characteristic in squash (Behm, 1992) but is likely to go undetected by a test in which movement sequences are predictable.

The squash-specific test described by Girard *et al.* (2005) overcomes the limitations of Steininger and Wodick's test by including uncertainty of movement direction. It does so by means of specialised software on a computer placed at the front centre of the court. A visual stimulus directs players to a particular location on court. However, it should be acknowledged that squash players also make use of auditory stimuli during match play such as the sound of the ball from the wall and an opponent's racket to judge movement direction and speed. In Girard *et al's.* (2005) study, seven male players ranked in the world top fifty completed incremental treadmill and squash-specific tests wearing a portable gas analyser for assessment of $\dot{V}O_2$. The squash-specific incremental test comprised stages of increasing intensity of exercise that involved two bouts of nine shuttle runs from the central 'T' position to one of six numbered targets located around the court (two front, two mid-court and two rear court). The nine displacements comprised two to the front-court targets, three to the mid-court targets and four to the back-court targets performed randomly. On reaching a target, players were instructed to mimic a forceful shot to the front wall before returning to the T position in time for the next displacement. The intensity of movement was increased by decreasing the time to complete the nine displacements and the test ended when the participants reached volitional exhaustion or failed to reach the specified target in time. Speed and direction of movement were controlled by visual stimuli on the screen of a computer placed at the front of the court.

Maximal oxygen uptake, ventilatory threshold and respiratory compensation point were calculated from breath-by-breath measurements of expired air. Heart rate and relative exercise intensity (% $\dot{V}O_{2max}$) at ventilatory threshold and respiratory compensation point were similar between the incremental treadmill and squash-specific tests but $\dot{V}O_{2max}$ was higher in the squash-specific test ($P < 0.01$). Furthermore, player rank correlated with performance time in the squash-specific test but not in the treadmill test ($r = - 0.96$, $P < 0.01$). The findings demonstrate the validity of the squash-specific test for the assessment of endurance performance and $\dot{V}O_{2max}$ in elite-standard players. However, the requirements for specialist software, computers and gas analysers should be accounted for when considering the practical aspects of test administration.

2.6.3 Areas for development

Previous tests developed to assess specific fitness in squash, while addressing some of the criteria for sport-specific procedures (Winter *et al.*, 2007), have focussed on maximum and sub-maximum cardio-pulmonary responses and have involved movement patterns that, although specific to squash, are performed at intensities to assess aerobic capabilities. However, match analysis has revealed that players cover a mean distance of only 12 m during rallies lasting 16-21 s and recent physiological analysis has reported mean post-match blood lactate concentrations of 8 $\text{mmol}\cdot\text{l}^{-1}$ indicating marked contributions from glycolysis (Vučković *et al.*, 2004; Girard *et al.*, 2007).

Despite the multiple-sprint nature of squash and the documented importance of qualities such as explosive strength and speed and the rapid accelerations, decelerations and direction changes that characterise squash movement, there appear to be no published squash-specific tests of multiple-sprint capabilities or change-of-direction speed. This is surprising as the specificity of change-of-direction speed has been demonstrated (Young *et al.*, 1996; Young *et al.*, 2001) and a sport-specific test of multiple-sprint capability has been shown to discriminate ability in a field-based multiple-sprint sport (Boddington *et al.*, 2004). Furthermore, the complexity of existing squash-specific tests is likely to limit their widespread use for training prescription and tracking of training-induced adaptations.

Future research should focus on the development of squash-specific fitness tests that:

1. Are simple to administer
2. Can assess fitness factors of importance to squash performance
3. Are reproducible
4. Are sensitive enough to detect training-induced adaptations
5. Can discriminate ability within and between standards of play

The development of procedures that satisfy these criteria would allow detailed description of physiological factors that relate to squash performance.

2.7 General aims

The aim of the thesis is therefore to develop and validate squash-specific procedures to identify indicators of performance and multiple-sprint capability in sub-elite and elite-standard squash players.

2.7.1 Objectives

The objective of the thesis is to identify physiological factors related to squash performance and multiple-sprint capability and so lead to the design of more effective training methods and more sensitive assessment of training effects. It is intended that the development of sport-specific procedures will improve the practices of players and coaches.

2.7.2 Research questions

1. Which measures of fitness are most related to sub-elite and elite-squash performance?
2. What are key indicators of squash-specific-multiple-sprint capability in sub-elite and elite players?

3 GENERAL METHODS

This chapter will provide details of the methods adopted for the determination of outcome measures used in this thesis. Specific details of how validity and reproducibility of new squash-specific procedures were addressed are discussed in detail in specific chapters that follow. Similar metrics for reproducibility were used on all other outcome measures and their reproducibility is reported here.

3.1 Pre-test preparation and habituation

All participants were instructed to report for testing well-rested, well-hydrated, well-nourished and to have refrained from eating at least two hours prior to testing. Participants were also instructed to abstain from drinking alcohol and avoid stimulants such as caffeine for at least eight hours prior to testing.

Habituation for all tests comprised two practice trials of the test procedure in question performed on separate days. Each visit involved completion of an abridged version of the full test while wearing any equipment that was required for actual test sessions. Participants were requested to wear the same footwear and similar clothing for habituation and all subsequent testing sessions.

3.2 Testing methods

This section will describe the methods used to administer the tests and secure outcome measures adopted in the studies that follow including procedures for zero adjustment, calibration and post-test verification of equipment. Where reproducibility is reported, it was assessed between two measurement occasions separated by seven days with tests conducted at the same time of day in similar environmental conditions.

3.2.1 Body Mass

Body mass was assessed to the nearest 0.05 kg before the start of test sessions using balance-beam scales (SECA, Vogel and Halke, Hamburg, Germany). Before each measurement, the scales were set to zero and adjusted via the turn screw until perfectly balanced. Linearity was then checked using known masses of 50 and 100 kg. Participants were required to remove footwear then stand as still as possible on the scales while the sliding weights were adjusted to bring the scales into balance.

Typical Error of Measurement (TEM) and the 90% confidence interval thereof (90% CI) and Limits of Agreement (LOA) were calculated to assess reproducibility. Both metrics showed small test-retest variation (TEM 0.56 kg, 0.7%, 90% CI 0.4 – 1.0 kg; LOA -0.53 ± 1.47 kg).

3.2.2 Stature

Prior to the test session, stretch stature was measured using a Holtain stadiometer (Holtain Ltd., Crymych, Dyfed, Wales) and according to the guidelines laid down by the International Society for the Advancement of Kinanthropometry (Marfell-Jones *et al.*, 2006). Before each measurement, accuracy of the stadiometer was checked using a one-meter ruler and was adjusted if required. With footwear removed, participants were instructed to stand with heels, buttocks and shoulder blades in contact with the back board of the stadiometer with heel together. The position of the participants head was then adjusted so that it lay in the Frankfort plane (orbit and tragus horizontally aligned) when viewed from the side. Participants were asked to inspire and hold their breath while the headboard was lowered (compressing the hair) to contact the head. The same reproducibility metrics were applied as with body mass and test-retest error was low (TEM < 0.01 m 0.3%, 90% CI 0.00 – 0.01 m; LOA 0.00 ± 0.01 m).

3.2.3 Gas analysis

Breath-by-breath oxygen uptake ($\dot{V}O_2$) was recorded using a portable telemetric system (Metamax 3B, CORTEX Biophysik, Leipzig, Germany) that was calibrated according to manufacturer's guidelines prior to each test. The manufacturer's recommendation for gas concentration was for a two-point calibration using room air (with assumed oxygen and carbon dioxide concentrations of 20.93% and 0.03 % respectively) and a span gas with known oxygen and carbon dioxide concentrations (15% and 5% respectively) and nitrogen balance (Cranlea and Company, Bournville, Birmingham, England). A similar two-point calibration was applied for the triple-V volume transducer using zero flow and a known flow rate delivered by a 3-L syringe where expired and inspired flow were determined by filling and emptying of the syringe in time with a visual stimulus from the gas analyser software (Metasoft v3, CORTEX Biophysik, Leipzig, Germany). Before starting the gas calibration, barometric pressure was entered into the software read from an electronic barometer (Oregon Scientific, Oregon, USA). Following each test, the accuracy of gas concentration was verified by running a sample of span gas through the analyser. Expired and inspired volume measurements were also verified using the 3-L syringe.

Following calibration, the analyser was placed into a lightweight shoulder harness that was secured to the participant using Velcro straps. The participant was then fitted with an appropriately sized nose and mouth mask to ensure the best seal possible while maximising comfort. The triple-V volume transducer and gas sample line were inserted into the front of the mask and the mask was firmly secured to the participant's face using a head net with elasticated, adjustable straps. A one-minute period of baseline data collection took place with the participant standing still after the warm-up and before any exercise test began.

Reproducibility of steady-state $\dot{V}O_2$ at a fixed sub-maximal exercise intensity (below lactate threshold) and of $\dot{V}O_{2max}$ on a squash-specific incremental test were assessed in eight trained squash players of county standard with seven days between tests. The results of this analysis are reported in Chapter five.

3.2.4 Heart rate measurement

Heart rate was recorded via telemetry from a chest belt transmitter directly into the gas analyser software and a wrist watch worn by the participant (Polar S625X, Polar Electro OY, Finland).

3.2.5 Analysis of blood lactate concentration

Blood lactate concentration was assessed by an electrochemical method in triplicate using 25 µl samples (YSI 1500, Yellow Springs Instruments, Yellow Springs, Ohio, USA). Samples of capillary blood were obtained from a finger prick using a sterile lancet and an automatic lancet delivery device (Safe-T-pro, Accu-Chek, Boehringer Manneheim Corporation, Maryland, USA). Blood was collected into heparinised glass capillary tubes and drawn for ejection into the analyser using an automatic pipette. Prior to testing, the analyser was calibrated with a lactate standard of known concentration (5 $mmol{\cdot}L^{-1}$) and linearity was checked with standards of 15 and 30 $mmol{\cdot}L^{-1}$. When analysis was complete, accuracy of the instrument was verified using the 5 $mmol{\cdot}L^{-1}$ standard. Blood lactate concentration was taken as the mean of the three samples at each measurement occasion.

3.2.6 Incremental treadmill test

Participants underwent a standardised five-minute warm-up on a motorised treadmill (Pulsar, H/P/ Cosmos Sports and Medical GMBH, Nussdorf-Traunstein, Germany) at

10 km·h^{-1} and 0 % grade prior to the incremental test. Prior to testing, treadmill belt speed was confirmed at 10, 12, 14 and 16 km·h^{-1} by recording the number of belt revolutions in one-minute and multiplying this by the belt length. Treadmill zero gradient was confirmed using a spirit level.

The treadmill test comprised an initial speed of 13 km·h^{-1} at 0 % grade followed by an increase in speed of 1 km·h^{-1} every minute up to 16 km·h^{-1}. Thereafter, speed remained constant but treadmill grade was increased by 1 % every minute until volitional exhaustion. The test was designed to cater for the range of habitual running speeds of distance runners recruited for the study detailed in Chapter four, while allowing both runners and squash players to reach volitional fatigue without the inability to run at higher speeds becoming a factor leading to premature ending of the test (Jones, 2007).

Breath-by-breath $\dot{V}O_2$ and heart rate were determined continuously using the methods described in sections 3.2.3 and 3.2.4. Participants ended the test by either lifting their feet astride the moving treadmill belt or depressing the emergency stop button. Standardised verbal encouragement was provided during the test and the condition of the participant was monitored throughout and after the test. At the end of the test, the gas analyser, face mask and heart rate chest belt transmitter were immediately removed and the participant remained on the treadmill to complete a five minute cool down at a self-selected walking speed. Figure shows a participant undertaking the incremental treadmill test.

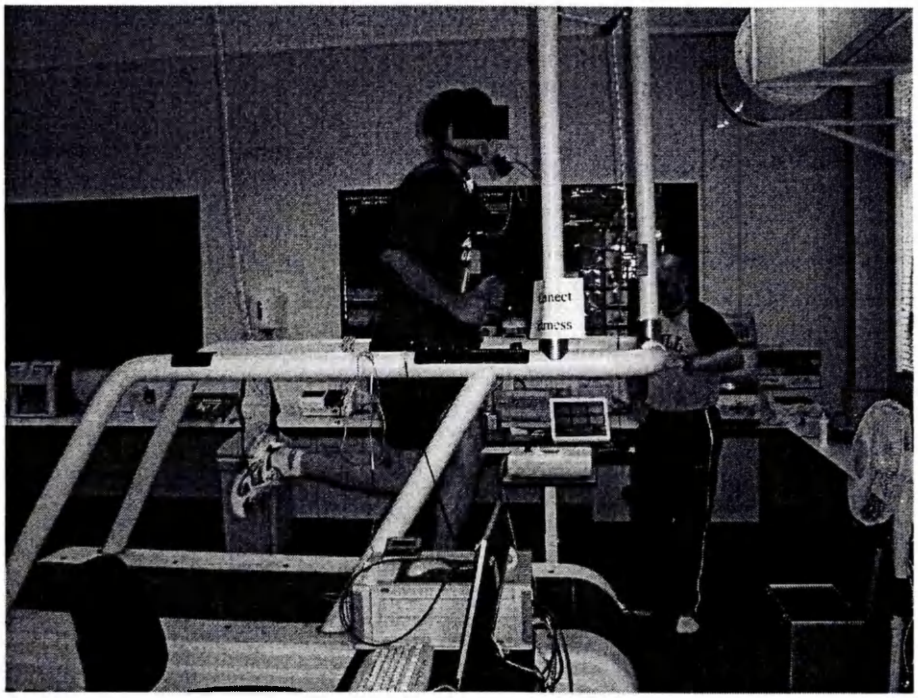


Figure 3. A participant completing the incremental treadmill test (displayed with permission but face blanked to retain anonymity).

3.2.7 Squash-specific incremental test

The squash-specific incremental test involved squash-specific movement patterns, to and from four marked positions (two front corners, and two back corners) on a squash court floor (Figure 4). Movements began from a central 'T' position performed in one-minute stages and were performed randomly with the order and frequency controlled by an audio signal of a number corresponding to one of the four marked and numbered targets. While individual movements were administered randomly, proportions of movements to particular court areas minute-by-minute reflected those seen in match play as identified from match analysis (74% back corner movements, 26% front corner movements) (Hughes and Robertson, 1998). Movement distances and mean movement speeds involved were encompassed in the ranges reported in previously published match analysis studies (Hughes and Robertson, 1998; Vučković *et al.*, 2004).

Upon hearing a signal, the participant was required to move to that court position from the T position, place one foot on the marked target, "ghost" *i.e.* mimic a forceful shot down the nearest side wall of the court and return to the T position in time for the next audio signal. Participants were instructed to keep pace with the audio signals so that they were arriving back at the T just as the next audio signal was given and not before, or after the signal. This was to ensure that the mean movement speed for the stage corresponded to that dictated by the audio signal. No specific or technical instructions about stroke technique or movement were provided, but care was taken to ensure that all participants adhered to the requirement to place one foot on the target and mimic a forceful shot on each displacement. Stage one of the test comprised fourteen movements per minute with the intensity of exercise increasing by one extra movement per minute in each subsequent stage with twenty possible test levels.

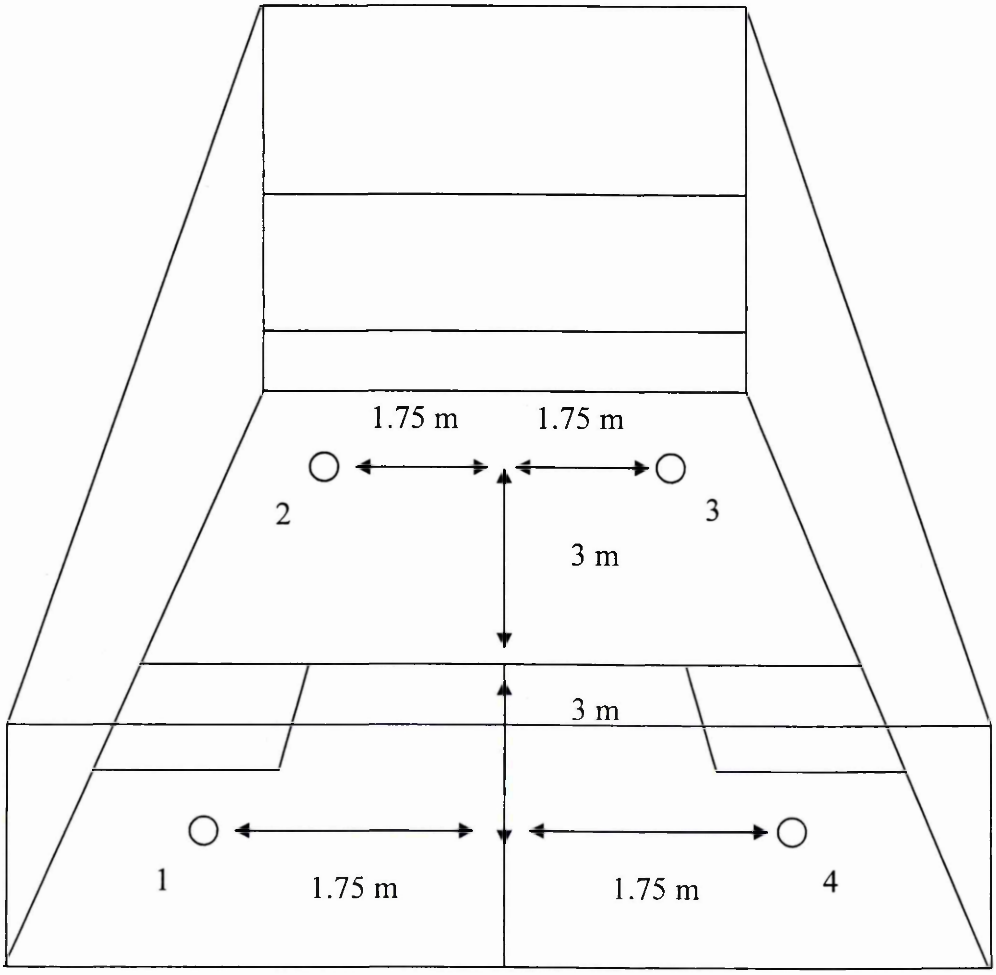


Figure 4. Set-up and dimensions of the squash-specific incremental test. Numbered court positions are indicated (1-4). Arrows indicate distances for the location of the numbered court positions relative to court markings not the route to the court positions.

The validity of the squash-specific incremental test and the reproducibility of performance and physiological responses from the test are reported in Chapters four and five respectively. Figure 5 shows a participant undertaking the test.

Figure 5. A participant completing the squash-specific incremental test (with permission).

3.2.8 Field-based tests of change-of-direction speed.

Following a standardised warm-up, each test session comprised three trials of either a non-sport specific test (Illinois Agility Run) or a squash-specific test of change-of-direction speed with the best performance time recorded to the nearest one hundredth of a second using a hand-held electronic stop clock (FastTime 1, Click Sports, Cambridge, UK). The standardised warm-up required participants to perform five minutes of jogging, followed by four runs through the test being performed at approximately 50, 60, 70 and 80 % of perceived maximum effort to warm-up the specific muscle groups required for the movements involved. Each run through was separated by 60-s recovery. A four-minute period of static stretching of the quadriceps, hamstrings, gastrocnemius and soleus muscle groups was carried out following the sub-maximal runs and prior to the three experimental trial runs. This was the preferred standard practice of the squash players recruited and was therefore used for all participants to standardise pre-test conditions. Participants were instructed to perform each of the three experimental trial runs on both tests 'all-out' following a '3-2-1' countdown. Two-minute recovery periods were allowed between each trial run to minimise the effects of fatigue on subsequent attempts.

3.2.8.1 Squash-specific change-of-direction speed test.

A participant under test and the dimensions, layout and movement path through the squash-specific test are shown in Figures 6 and 7 respectively. From the start line, participants were required to move between and around the large cones (denoted by crosses on Figure 7) to reach out and touch the smaller cones (denoted by circles) with either hand depending on their preference. No instructions were given as to the most effective movement technique. Participants were simply encouraged to complete the course as fast as possible. The movement patterns and distances were designed using match analysis data and through consultation with an England Squash advanced coach (Eubank and Messenger, 2000; Vučković *et al.*, 2004).

3.2.8.2 Illinois Agility Run

The dimensions, layout and movement path through the Illinois Agility Run are shown in Figure 8. Participants began from a standing start, and following a '3-2-1' countdown ran the course with maximum effort without knocking over any cones. Participants were encouraged to complete the course as fast as possible.

In both tests, timing commenced when the hips of the participant broke an imaginary line at hip height and ceased when the participant's hips broke the imaginary line for a second time at the end of the looped test courses. The Illinois Agility Run was performed in a non-slip sports hall and the squash-specific test was carried out on a marked-out squash court. Validity of the squash-specific test and reproducibility of both tests are reported in Chapter six.

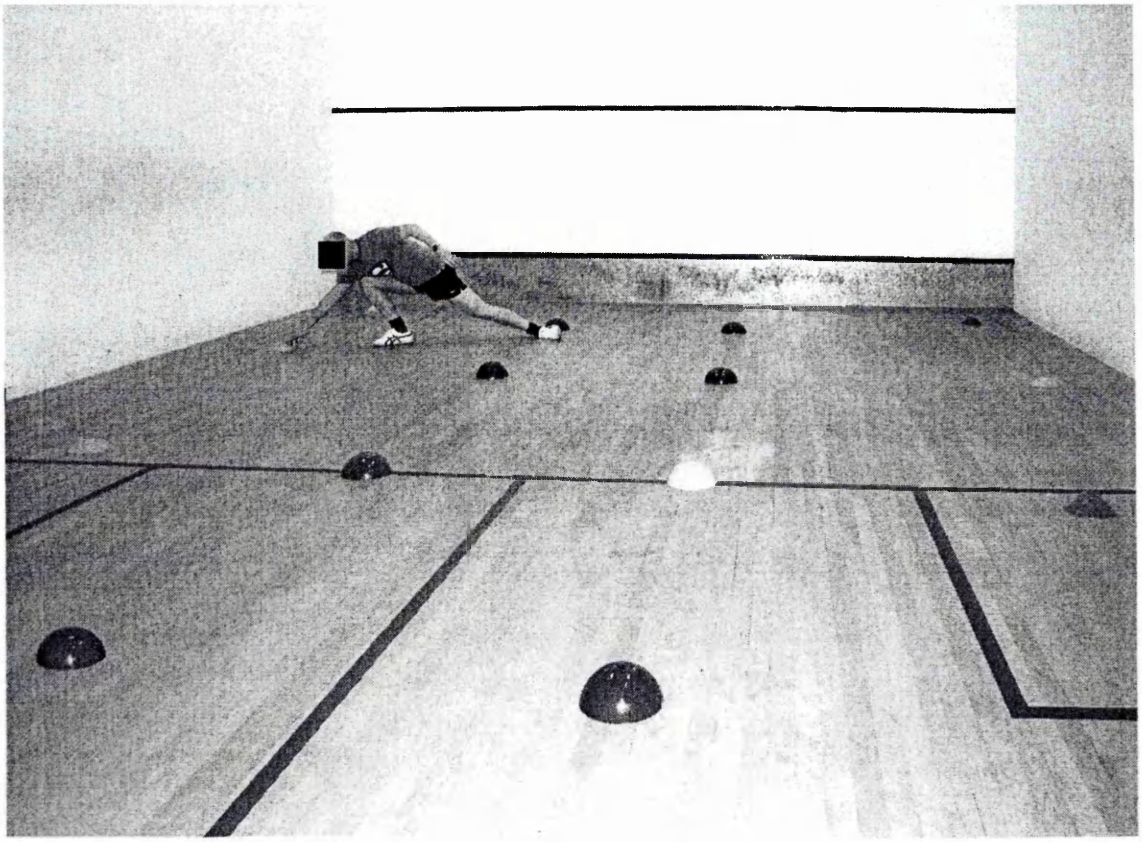


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Figure 6. The author completing the squash-specific change-of-direction-speed test.

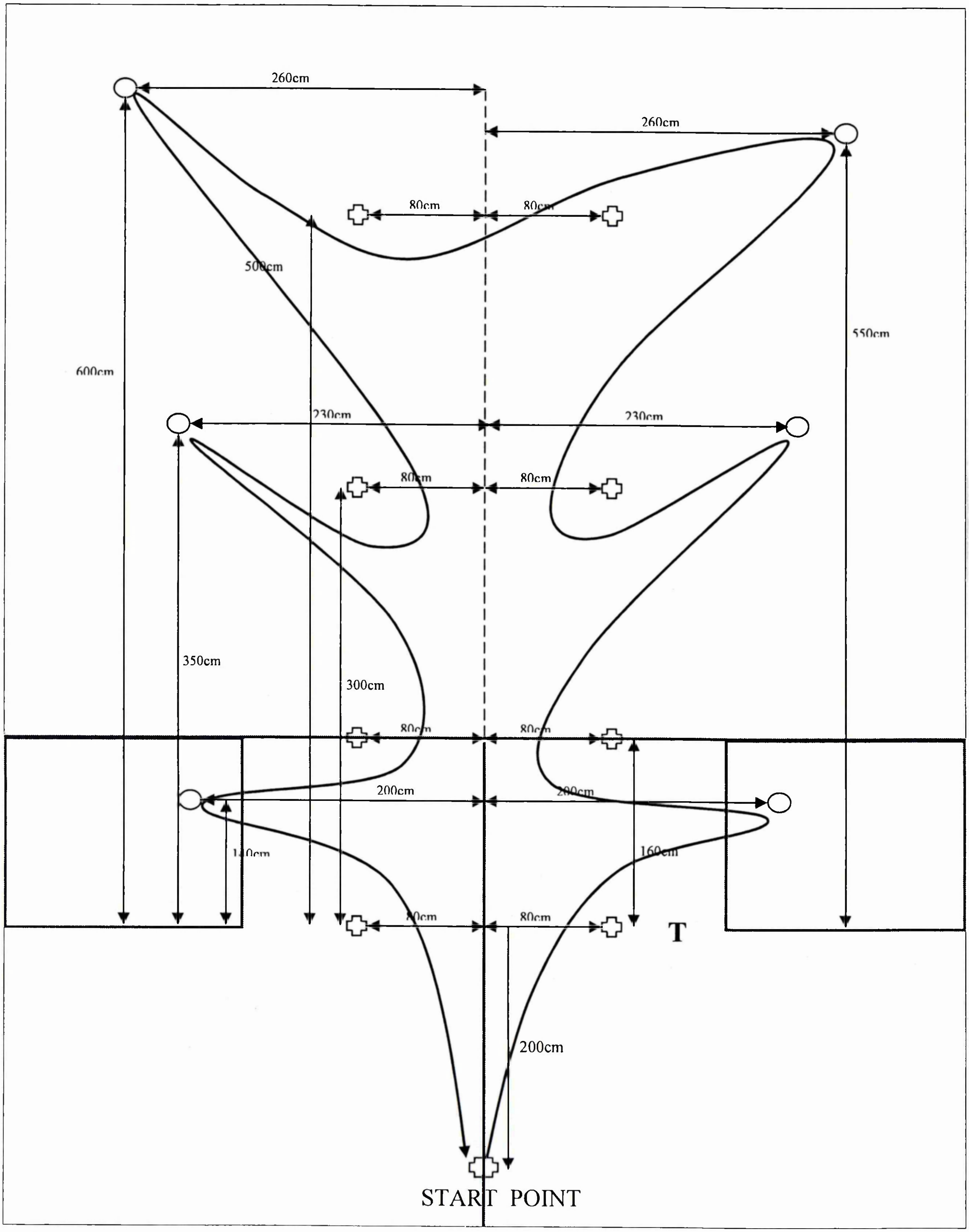

Figure 7. Dimensions and route for the squash-specific test of change-of-direction-speed. T = position of the timer adjacent to the cones where timing started and finished.

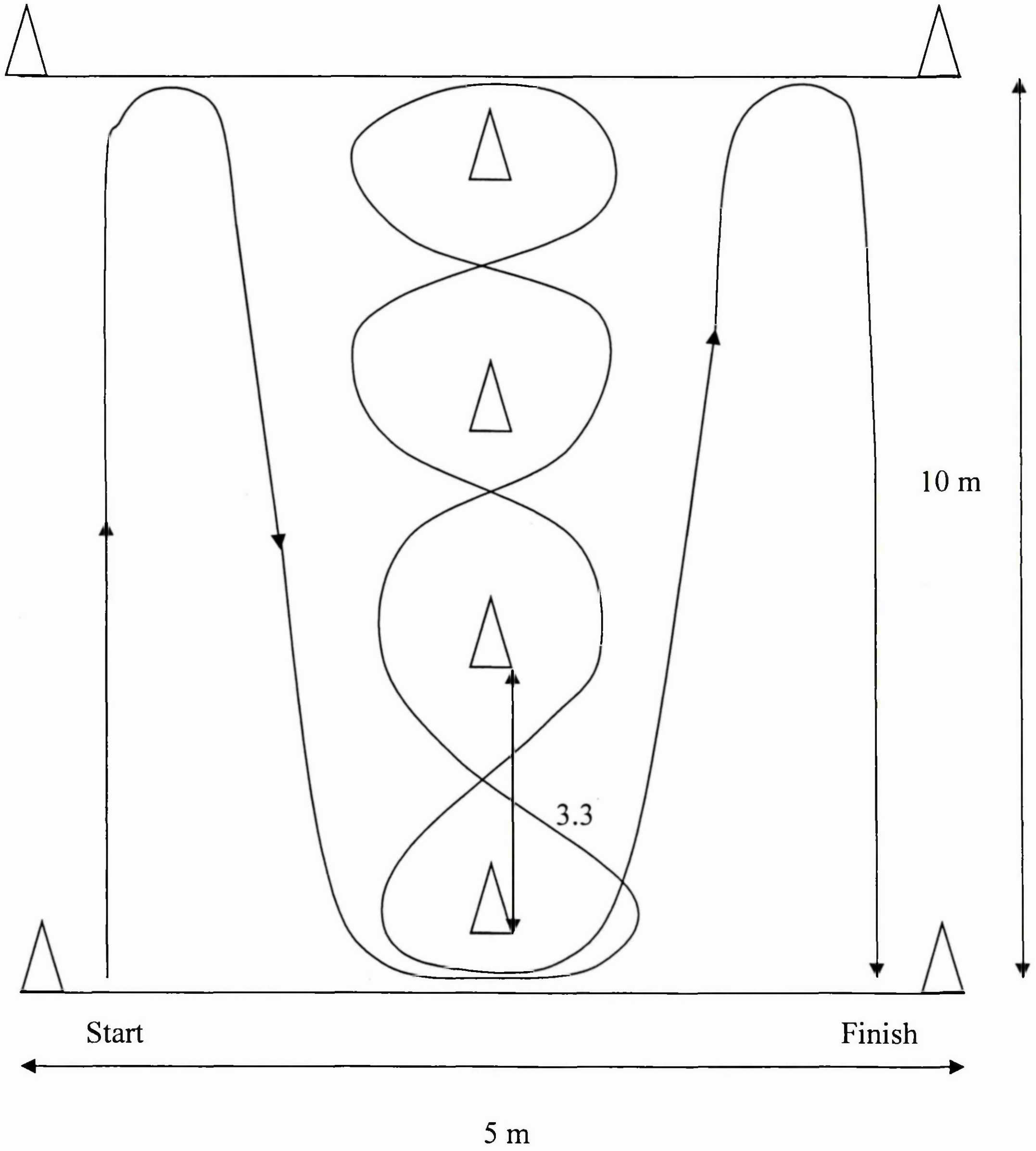

Figure 8. Illinois Agility Run dimensions and completion route. Timer is positioned adjacent to the cones at the start – finish line.

3.2.9 Field-based tests of multiple-sprint ability.

Participants performed Baker's 8 × 40-m sprints (Baker *et al.*, 1993) and a squash-specific multiple-sprint test on separate days (separated by at least 48 hours). Habituation was as described in section 3.1. A standardised warm-up was completed as described in section 3.2.8. Participants were instructed to perform each sprint effort on both tests 'all-out' and to avoid adopting any pacing strategy.

3.2.9.1 Baker's 8 × 40 m Sprint test

The dimensions, layout and route of completion are shown on Figure 9. Participants began from a standing start and following a '5-4-3-2-1' countdown ran the course with maximum effort changing direction at the two end cones. Participants were encouraged to complete the course as fast as possible and performance time for each sprint effort was recorded. Participants were allowed twenty seconds recovery between sprints. Sprint and recovery time were recorded using electronic stop clocks (FastTime 1, Click Sports, Cambridge, UK) in the manner described in section 3.2.8.2. Performance was recorded as the sum of the eight individual sprint times.

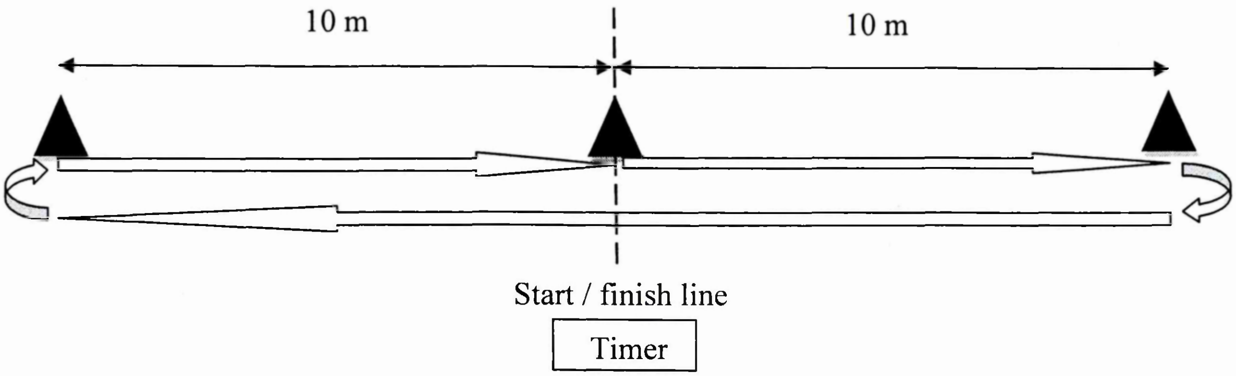

Figure 9. Layout, dimensions and route of completion for Baker's 8 × 40 m sprint test.

3.2.9.2 Squash-Specific Multiple-sprint Test

The dimensions, layout and movement path through the squash-specific test are shown in Figure 10. It should be noted that one complete repetition comprised two laps of the test course with the participants changing direction for the second lap at the start cone shown on Figure 10. A participant completing the course (the layout being the same as the change-of-direction-speed test) was shown previously in Figure 6. Although participants started each sprint effort at the start / change-of-direction cone, timing of each sprint did not commence until participants passed between the first set of cones (marked start / finish on Figure 2) hence they had a running start. From the start line, participants were required to move between and around the large cones (denoted by crosses on Figure 10) and to reach out and touch the smaller cones (denoted by circles) with either hand depending on their preference. No instructions were given as to the most effective movement technique. Participants were simply encouraged to complete the course as fast as possible. The test comprised ten sprint efforts, each separated by twenty seconds recovery. Multiple-sprint ability was recorded as the sum of the ten sprints. Performance time for the fastest repetition was also recorded. Although similar to the change-of-direction speed test, the duration of a repetition comprising two laps of the course is closer to the mean duration of a squash rally in modern match play (Girard *et al.*, 2007). The movement patterns and distances between directional changes were derived from match analysis data (Eubank and Messenger, 2000; Vučković *et al.*, 2004) and through consultation with an England Squash advanced coach. The recovery duration between sprint efforts was initially chosen to approximate the rest periods between rallies reported in elite standard match play (mean 8-12 seconds) (Hughes, 1998; Vučković *et al.*, 2004; Girard *et al.*, 2007), but during pilot testing participants indicated that performing ten 'all-out' sprint efforts with such short recovery was too difficult. As such the recovery between sprints was extended to twenty seconds approximating the recovery durations of other non-specific multiple-sprint protocols (Baker *et al.*, 1993; Bangsbo, 1994; Boddington *et al.*, 2004).

The validity of the squash-specific multiple-sprint test and the reproducibility of performance in both tests are examined in Chapter seven. Baker's test was completed in a non-slip sports hall and the squash-specific test was completed on a marked-out squash court.

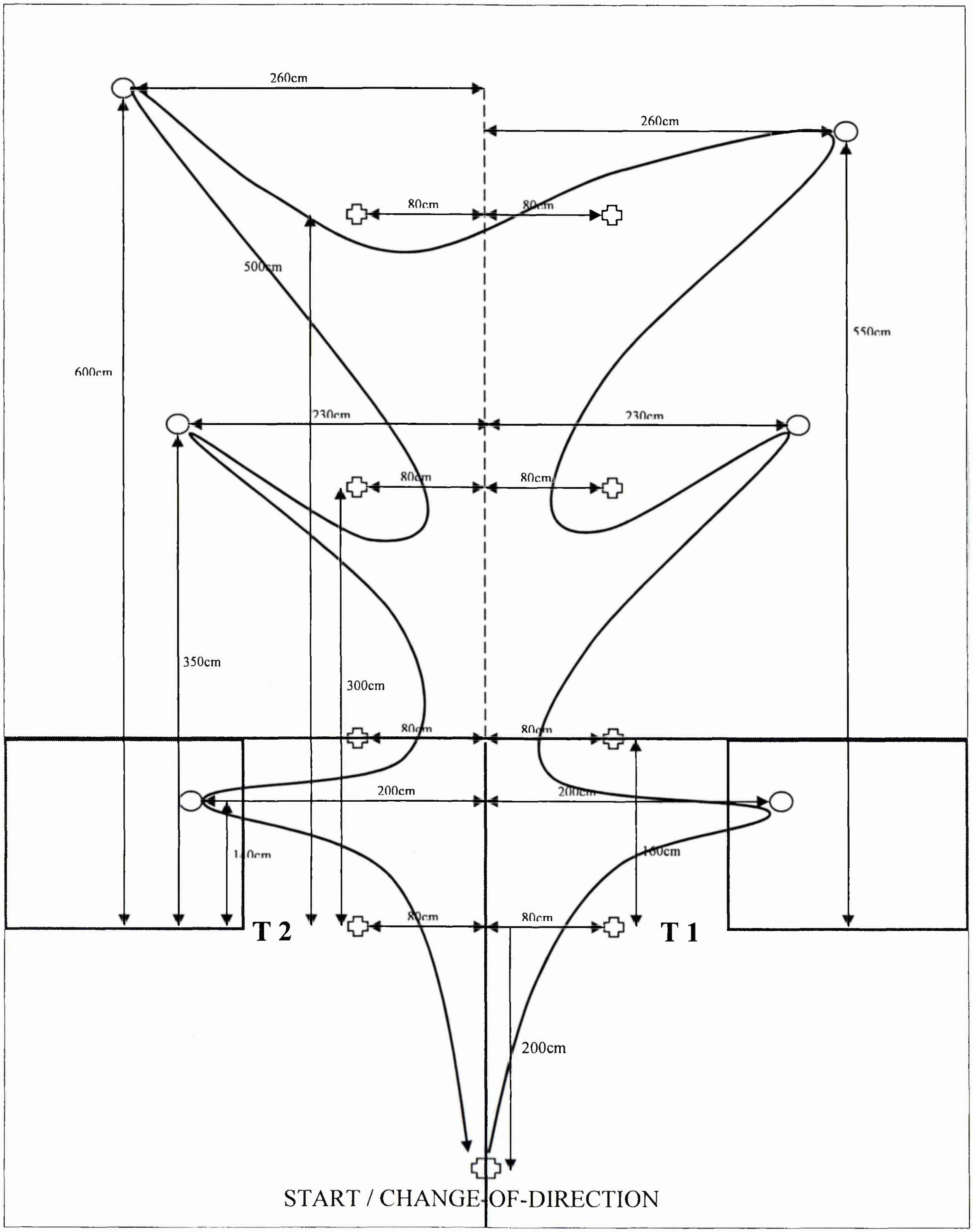

Figure 10. Squash-specific multiple-sprint test dimensions and route of completion. One repetition is two laps of the course. T1 and T2 indicate the positions of the timers with the start / finish line for timing between the pair of adjacent cones.

3.2.10 Drop jump, reactive strength index (RSI) and counter-movement jump.

Reactive strength index is a ratio of jump height to ground contact time during a drop jump test. The RSI is considered to be a measure of explosive ability of the leg extensors in fast stretch-shortening cycle actions under high stretch loads (Young, 1995).

Following individual warm-up that comprised five minutes jogging followed by dynamic stretching of the lower limb musculature, participants completed three drop jumps from a 0.3-m high box onto a force platform with a sampling frequency of 1000 Hz (Fitech, Melbourne, Australia). The force plate was zeroed prior to each test. The RSI was calculated as jump height ÷ contact time (with jump height being calculated from flight time). It should be acknowledged that the calculation of jump height from flight time is valid only if the participant's take-off and landing position are identical. It has been assumed that this was the case. Participants were instructed to step off the box, land with both feet simultaneously and rebound from the force plate for maximum height while minimising ground contact time. Arms were akimbo throughout the jump. The highest RSI from three attempts was recorded. Highest mean power output from the three drop jump trials was also recorded. Participants also completed three counter-movement jumps on the same equipment. From a standing start with hands placed on the hips, participants were instructed to bend at the hips, knees and ankles to a comfortable depth before propelling the body upwards for maximum jump height. Highest mean power output from the three attempts was recorded. Power in each jump (power = work ÷ time) was calculated from the highest force immediately prior to take-off, with distance estimated from flight time and assumed to represent the distance travelled by the body's centre of mass. Time in the equation was half of flight time. The use of power as a measure in impulsive, explosive activities like jumping has been questioned (Winter, 2005). In this particular instance, it should be noted that the mechanical principles involved in the calculation are at best weak and at worst inapplicable.

These tests were conducted at the National Squash Centre, Manchester under the supervision of an England Institute of Sport strength and conditioning coach working with the elite English squash players. Because of time constraints and availability of the England elite squash players, it was not possible to assess reproducibility of performance on this test, nor was it possible to perform habituation trials. However, all participants had prior experience of the jump test procedures and RSI assessment and had undertaken previous test on the same equipment, though these tests were generally on an annual basis.

3.2.11 Multi-stage fitness test

This test was conducted in a non-slip sport hall at the National Squash Centre, Manchester. Participants completed twenty-metre shuttle runs in a continuous fashion in time with an audio signal. Exercise intensity was increased by shortening the duration between audio signals at regular intervals. Participants were required to keep pace with the audio signal for as long as possible until volitional fatigue. Test level and shuttle within the test level were used to estimate $\dot{V}O_{2max}$ using a regression equation. Details of the test procedure and derivation of the regression equation are detailed in Leger and Lambert (1982). As with assessment of RSI, time constraints and player availability prevented habituation or assessment of reproducibility. Moreover, this test was performed on the same day as and following on from assessment of RSI, squash-specific change-of-direction speed and multiple-sprint ability.

3.2.12 Racket accuracy test

Participants were required to hit ten under-arm forehand volleys from a self-feed aimed to hit a target on the front wall of the squash court. Players had to stand on the T position, 5.49 m from the target that was placed at the height of the cut line. The target consisted of three concentric circles with diameters of 0.58 m, 0.4 m and 0.2 m drawn on a sheet of white A1 paper. Hits to the centre circle scored fifty points, with hits to the second and third circles out scoring twenty five and ten points respectively. Hits outside the outer circle but still on the A1 sheet scored five points, but no points were scored for shots missing the paper. The shots were taken at the participants self-selected pace and force. No technical instructions were given and no practice shots were allowed. Points were recorded after each shot by examining the mark left on the paper by the black rubber squash ball and test performance was taken as the sum of points scored for the ten attempts. Reproducibility of test performance was not examined but was probably weak.

3.3 Summary

This chapter has described the methods for administering all outcome measures used in this thesis. Where reproducibility and validity for the measures described are not reported here, precise details can be found in specific chapters that follow.

4 VALIDITY OF A SQUASH-SPECIFIC TEST OF ENDURANCE FITNESS

In common with multiple-sprint activities such as soccer, basketball and other racket sports, the specific movement patterns and demands of squash provide a unique challenge to physiologists in their attempts to produce valid and reliable assessments of physiological factors relevant to squash performance, such as aerobic power. The challenge is to combine the control of laboratory procedures with the ecological validity of tests carried out in specific movement patterns of the sport. Müller (2000) stated that improvements in elite sport performance arise mainly from an increase in the quality of training and that this is best improved through the development of sport-specific tests. Valid and reliable squash-specific-yet controlled-tests are likely to provide more useful data for the design of training programmes and tracking of sport-specific training adaptations that might otherwise go undetected by conventional non-specific procedures.

The validity of field-based tests can be determined by: a) comparison of a new test with a 'gold standard' procedure (criterion validity); b) the ability of a test to discriminate between groups of performers from sports with different characteristics or between abilities within a group of performers (construct validity); and c) a test's ability to assess components of fitness known to be important for performance (logical validity) (N.C.F., 1995). Endurance capability is such a component for squash players and a contributory factor to this is maximal oxygen uptake (Girard *et al.*, 2007; Brown *et al.*, 1998; Chin *et al.*, 1995).

The importance of sport-specific testing of $\dot{V}O_{2max}$ has been previously demonstrated. St Clair Gibson *et al.* (1998) reported that maximal oxygen uptake estimated from a field-based 20-m shuttle test correlated more highly with laboratory-determined $\dot{V}O_{2max}$

in runners (r = 0.71) than in squash players (r = 0.61). This indicates sport-specific differences in the prediction of $\dot{V}O_{2max}$. The test specificity of $\dot{V}O_{2max}$ in squash players has also been demonstrated elsewhere. Two studies compared responses of elite squash players in squash-specific incremental tests and laboratory-based treadmill incremental tests and showed that higher $\dot{V}O_{2max}$ was achieved by squash players on the squash-specific tests (Steininger and Wodick, 1987; Girard *et al.*, 2005). Furthermore, both studies also reported strong correlations between player rank and maximum performance on the squash-specific tests, thus demonstrating both the construct and logical validity of the sport-specific protocols.

While there have been attempts to produce controlled tests to replicate squash-specific physiological demands, (Todd *et al.*, 1998; Sherman *et al.*, 2004; Kingsley *et al.*, 2006) these tests were designed to simulate match play rather than assess squash-specific fitness components. Although several groups are working in this area, only two previous papers designed to assess the validity of on-court squash protocols for assessment purposes have been published, the findings of which are summarised above. However, the complexity of these procedures probably limits their widespread use for assessment and tracking of training-induced changes in fitness.

In summary, maximal aerobic power is a key aspect of fitness in squash and is known to be specific to sporting background (continuous activity performers vs intermittent activity performers) and to test procedures (St Clair Gibson *et al.*, 1998; Steininger and Wodick, 1987; Girard *et al.*, 2005). A valid assessment of squash-specific aerobic power should therefore discriminate between performers of sports with continuous and mostly linear movements and squash players whose activity profile is intermittent and whose movement is stochastic in nature (St Clair Gibson *et al.*, 1998). Furthermore, maximum values of squash players from a squash-specific test are likely to differ from those measured using non-specific tests of aerobic power (Girard *et al.*, 2005). Accordingly, the purpose of this study was twofold: first, to examine the validity of a squash-specific incremental test that comprised randomised movements and auditory stimuli, by determining the endurance capability and $\dot{V}O_{2max}$ of trained squash players (intermittent activity profile) and distance runners (continuous activity profile) using a squash-specific incremental test; and second, to compare the $\dot{V}O_{2max}$ values with those determined on an incremental treadmill protocol.

4.1 Methods

4.1.1 Participants

With institutional ethics approval, eight trained squash players age (mean ± SD) 30.0 ± 11.2 years, stature 1.80 ± 0.04 m, body mass 81.3 ± 10.2 kg and eight trained distance runners age (mean ± SD) 29.6 ± 9.4 years, stature 1.77 ± 0.05 m, body mass 69.4 ± 6.7 kg who had previously undergone two visits to habituate to the procedures, participated. Habituation procedures and standard pre-test preparation instructions are described in Chapter three. Squash players were all regular and current competitors in the premier or first division of regional leagues, with at least five years' playing experience at this standard. Distance runners were good club-or county-standard athletes training and competing with a similar frequency to the squash players (three to five times per week).

4.1.2 Experimental design

In a randomised order participants performed incremental treadmill (TT) and squash-specific (ST) tests to volitional exhaustion separated by at least 48 hours. Squash players also performed a second trial of the ST seven days after the first to assess the reproducibility of $\dot{V}O_{2max}$, HR_{max} and time-to-exhaustion. The results of this reproducibility analysis are reported in Chapter five. Tests were conducted under similar environmental conditions (temperature 18.9 ± 3.4 °C, relative humidity 49 ± 8 %, barometric pressure 1016 ± 11 mBar) at the same time of day and in the same footwear and clothing. Details of test procedures are described in section 3.2.6. For the squash-specific test, continuous one-minute exercise stages were used with the intensity of movement being increased by one movement per minute for each new stage.

4.1.3 Physiological and performance measures

During both tests, breath-by-breath oxygen uptake ($\dot{V}O_2$) and heart rate (HR) were continuously recorded using a portable telemetric system. Detailed description of the procedures, calibration and verification are given in sections 3.2.3 and 3.2.4. In both tests, 30-s means were calculated for cardiopulmonary variables and the highest values for $\dot{V}O_2$ and HR over 30 s, during the final stages, were regarded as $\dot{V}O_{2max}$ and HR_{max}. Time to exhaustion on each test was recorded using an electronic stopclock (FastTime 1, Click Sports, Cambridge, UK). A post-test finger prick blood sample was taken five-minutes after completion of each test for subsequent determination of lactate concentration (procedures are detailed in Chapter three). With due acknowledgement to recent criticisms, (Midgley *et al.*, 2007) attainment of a plateau in $\dot{V}O_2$ ($\leq$ 2.1 ml·kg^{-1}·min^{-1} rise with an increase in exercise intensity), RER > 1.1, post-test blood lactate concentration > 8 mmol·L^{-1}, HR within 10 beats·min^{-1} of age-predicted maximum and participant subjective reporting of maximal effort were used as criteria to judge whether or not test performances were truly maximal. If a participant failed to satisfy three or more of these criteria the test result was deemed to be a peak rather than a maximum value.

4.1.4 Ranking of squash players

Two England Squash qualified coaches (part three - advanced level), located in the area where the study was performed, independently assigned a rank to each squash player using personal knowledge of the players and recent performances in local regional league matches. Where independent ratings differed, a resolution was obtained through discussion between the two coaches.

4.1.5 Statistical analysis

Data were analysed using SPSS® v 12 (SPSS Inc., Chicago, IL) statistical software package. Mean and standard deviation were calculated for each measure. Following verification of underlying assumptions such as normality of distributions (using Shapiro-Wilk's procedure) and homogeneity of variance (using Levene's procedure), independent t-tests compared the squash players and runners in $\dot{V}O_{2\,max}$, HR_{max} and time to exhaustion, both on the ST and TT. Paired-sample t-tests were used to compare $\dot{V}O_{2\,max}$ and HR_{max} scores between the TT and ST. Paired sample t-tests were also used to compare end-test RER, change in $\dot{V}O_2$ in response to the final intensity increase and post-test blood lactate concentration between the TT and ST. Cohen's d effect size was calculated for significant differences and interpreted against effect size categories of ≤ 0.2 = small effect, ≈ 0.5 = moderate effect and ≥ 0.8 large effect (Cohen, 1969). Spearman's rho examined the relationship between maximum scores on the ST and subjective ranking of the squash players' ability. Pearson's correlation examined relationships between $\dot{V}O_{2max}$ scores on the ST and TT in squash players and runners. Statistical significance for all tests was accepted at $P \leq 0.05$.

4.2 Results

4.2.1 Achievement of criteria for maximal oxygen uptake.

All squash players satisfied three or more of the criteria for attainment of $\dot{V}O_{2max}$ in both the TT and ST. TT and ST (mean ± SD) RER (1.31 ± 0.1 and 1.23 ± 0.8, $P = 0.16$), post-test blood lactate concentration (9.8 ± 2.4 and 9.0 ± 1.3 mmol·L^{-1}, $P = 0.25$) and final $\dot{V}O_2$ increase (0.71 ± 0.7 and 1.02 ± 0.8 ml·kg^{-1}·min^{-1}, $P = 0.43$) for squash players did not differ between the tests. Similarly, all runners also satisfied three or more of the criteria for attainment of $\dot{V}O_{2max}$ both in the TT and ST. The TT and ST (mean ± SD) RER (1.29 ± 0.2 and 1.24 ± 0.1, $P = 0.45$), post-test blood lactate concentration (9.4 ± 2.2 and 9.3 ± 1.2 mmol·L^{-1}, $P = 0.95$) and final $\dot{V}O_2$ increase (1.0 ± 0.8 and 1.28 ± 1.2 ml·kg^{-1}·min^{-1}, $P = 0.38$) for runners did not differ between the tests.

4.2.2 Comparisons between groups on the ST.

Squash players had greater time to exhaustion on the ST than the runners (mean ± SD 775 ± 103 v 607 ± 81 s, $t_{14} = 3.638$, $P < 0.01$, effect size = 1.83). There was no difference in $\dot{V}O_{2\ max}$ or HR_{max} between the squash players and runners on the ST ($\dot{V}O_{2max}$ 52.2 ± 7.1 v 56.6 ± 4.8 ml·kg^{-1}·min^{-1}, $P = 0.17$; HR_{max} 190 ± 7 v 182 ± 11 beats·min^{-1}, $P = 0.12$ respectively).

4.2.3 Comparisons between groups on the TT.

Runners had greater time to exhaustion (mean ± SD 521 ± 135 v 343 ± 115 s, $t_{14} = -2.84$, $P = 0.01$, effect size = 1.42) and also achieved higher $\dot{V}O_{2\ max}$ than the squash players on the TT (58.6 ± 7.5 v 49.6 ± 7.3 ml·kg^{-1}·min^{-1}, $t_{14} = -2.43$, $P = 0.03$, effect size = 1.22). There were no differences in HR_{max} between the runners and squash players on the TT (183 ± 10 v 191 ± 13 beats·min^{-1}, $P = 0.17$ respectively).

4.2.4 Within-group comparisons between the ST and the TT.

Squash players achieved higher $\dot{V}O_{2\,max}$ on the ST than on the TT (mean ± SD 52.2 ± 7.1 v 49.6 ± 7.3 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$, $t_7 = 3.105$, $P = 0.02$, effect size = 0.4). There were no between-test differences in HR_{max} in the squash players (190 ± 7 v 191 ± 13 $beats{\cdot}min^{-1}$, $P = 0.71$). There were no differences in HR_{max} and $\dot{V}O_{2\,max}$ in the runners between the ST and TT (182 ± 11 v 183 ± 10 $beats{\cdot}min^{-1}$, $P = 0.90$ and 56.6 ± 4.8 v 58.6 ± 7.5 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$, $P = 0.45$ respectively).

Between- and within-group differences in physiological responses and performance capability are shown in Figures 11 and 12, respectively. Figure 13 shows the mean oxygen uptake and heart-rate responses of the squash players to the ST including the linear regression equations for oxygen uptake and heart rate against exercise time (and thus exercise intensity) on the test.

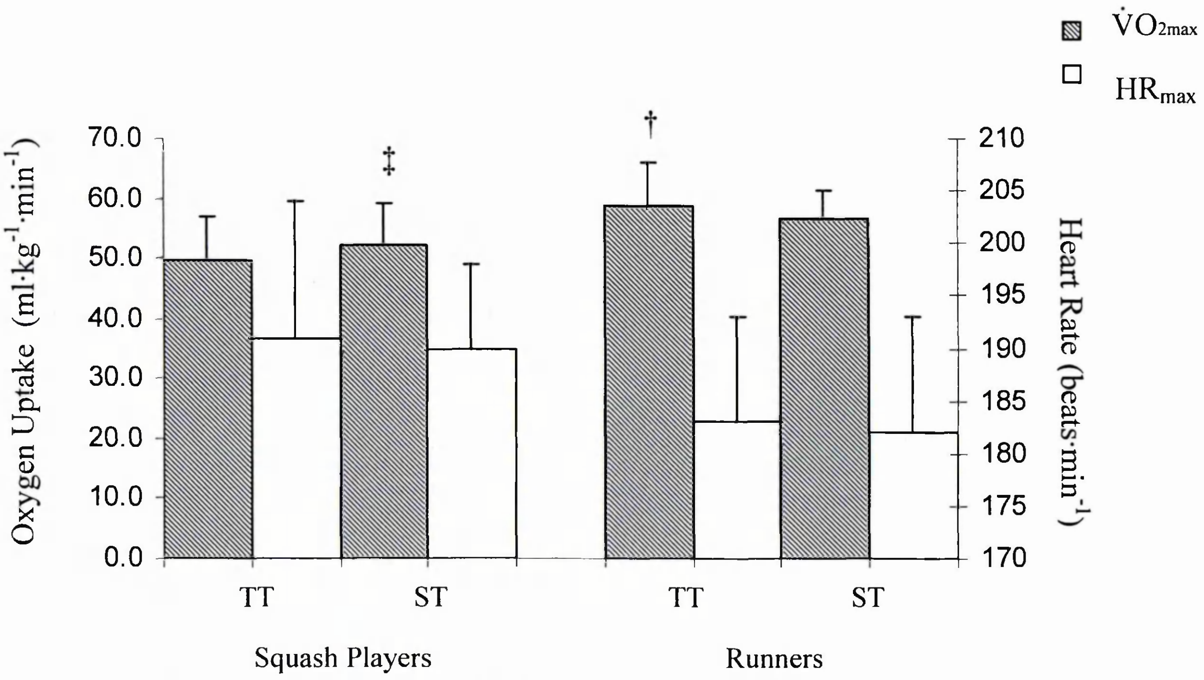

Figure 11. Physiological variables in squash players (n = 8) and distance runners (n = 8) corresponding to the greatest intensity of exercise for incremental treadmill (TT) and squash-specific tests (ST). Values are mean + SD. † = difference ($P = 0.03$) between runners and squash players, ‡ = difference ($P = 0.02$) between scores on the TT and ST.

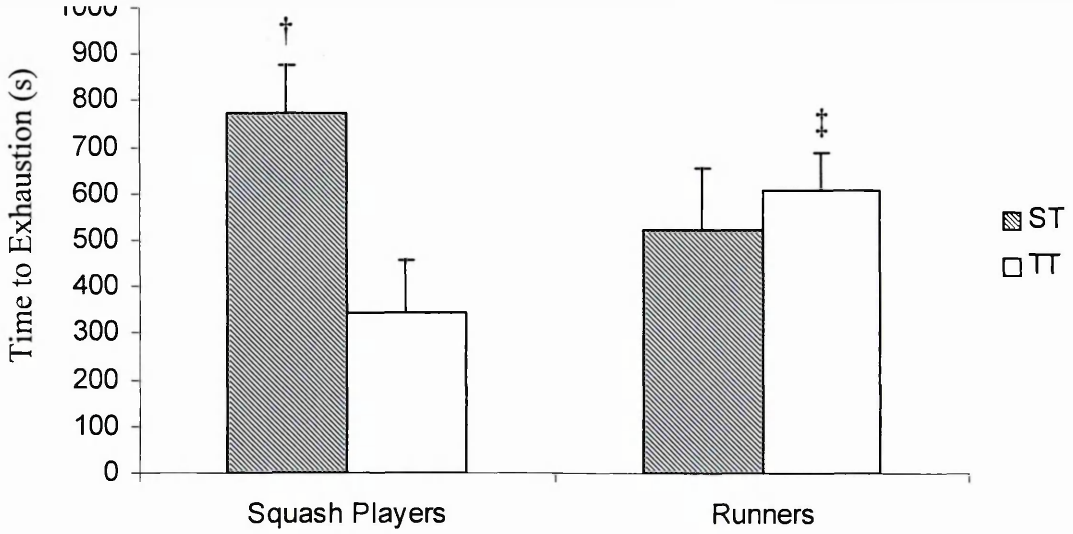

Figure 12. Time to exhaustion recorded for the incremental treadmill (TT) and the squash-specific (ST) incremental tests in squash players (n = 8) and distance runners (n = 8). Values are mean + SD. † = difference between squash players and runners ($P < 0.01$) in time to exhaustion on the ST; ‡ = difference between squash players and runners ($P = 0.01$) in time to exhaustion on the TT.

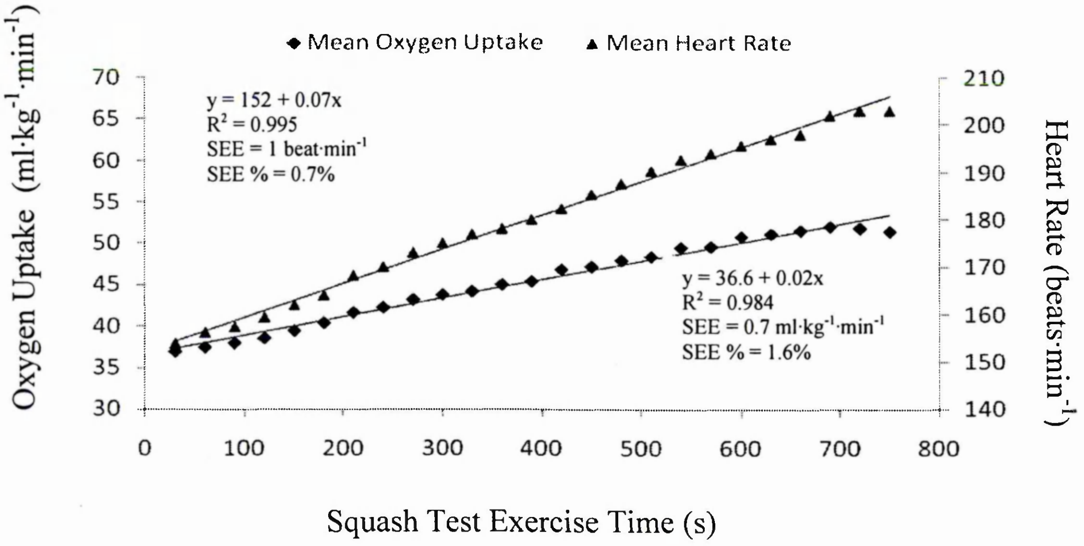

Figure 13. Mean oxygen uptake and heart rate responses of eight trained squash players on the squash-specific incremental test (ST). Linear regression equations for mean heart rate and oxygen uptake are shown at the upper left and lower right of the figure respectively.

4.2.5 Correlation of ST performance with player rank in squash players.

Spearman's rho indicated moderate but non-significant negative correlations between time to exhaustion ($\rho = -0.60$, $P = 0.12$) and $\dot{V}O_{2max}$ ($\rho = -0.70$, $P = 0.07$) on the ST and player rank for the squash players.

4.2.6 Correlation of ST and TT maximal oxygen uptake in squash players and runners.

Pearson's correlation showed relationships between $\dot{V}O_{2max}$ scores from the ST and TT both in squash players ($r = 0.94$, $P < 0.01$) and runners ($r = 0.88$, $P < 0.01$).

4.3 Discussion

The results indicate that the squash players outperformed the trained distance runners on the squash-specific incremental test despite there being no difference in aerobic power between the groups on the squash-specific test. The extent to which participants met the criteria for a true maximal effort did not differ between the ST and TT for squash players and runners, with all participants meeting three or more of the criteria in both tests. As such, differences in time to exhaustion between squash players and runners could not be explained by runners not exercising maximally. Moreover, the attainment of the criteria for a maximum effort in the ST suggests that it possesses logical validity, given the aerobic demands of high-standard squash (Girard *et al.*, 2007; Brown *et al.*, 1998; Chin *et al.*, 1995). The similarity in achievement of $\dot{V}O_{2max}$ criteria in the ST and TT is in contrast to the findings of St Clair Gibson *et al.* (1999). They showed that the extent to which $\dot{V}O_{2max}$ criteria were satisfied differed between a progressive-incline treadmill test and a progressive-speed treadmill test indicating that achievement of $\dot{V}O_{2max}$ criteria can be test specific.

The endurance performance advantage of the squash players on the ST is probably the result of specific adaptations to the movement patterns involved, and together with the similarity of aerobic power suggests superior movement economy of the squash players in their habitual exercise mode. The poorer time to exhaustion of the runners on the ST could also be a reflection of their lack of skill in the techniques of squash movement, racket swing and the blending of these two skills characteristic of high-standard squash players. However, differences in racket and movement technique and the combination of the two are likely to contribute to test performance in squash players too, so the inclusion of technical aspects in the ST procedures is integral to the specificity of the test. The strong correlations between player rank and maximum performance on the squash-specific incremental tests of Steininger and Wodick (1987), and of Girard *et al.* (2005) and the moderate though non-significant correlations found in this study suggest that this is the case. However, the low number of participants and homogeneity in the sample of squash players in this study could explain the reduced and non-significant relationships (Sale, 1990). Moreover, endurance capability (with $\dot{V}O_{2max}$ as a contributory factor to this) is only one component of the game (Lees, 2003) and perhaps a less important component for sub-elite participants such as those used in the present study. The suggestion that adaptations to specific movement patterns are the cause of the findings of this study was supported by the performance of the runners versus the squash players on the treadmill incremental test. The superior performance capability of the runners in their habitual exercise mode mirrored that of the squash players on the squash-specific test.

Another key finding of this study was that the squash players attained higher $\dot{V}O_{2max}$ on the squash-specific test than on the treadmill test. These findings agree with those of Girard *et al.*(2005). In the present study, the higher $\dot{V}O_{2max}$ of the squash players on the

ST than on the TT despite no differences in HR_{max} could be attributable to a larger active muscle mass in the ST, commensurate with the upper body actions of swinging a racket and the high demands placed on the lower leg musculature.

The greater time to exhaustion of squash players than runners with similar test-specific $\dot{V}O_{2max}$ demonstrates the construct validity of the squash test for the assessment of squash-specific endurance capabilities (N.C.F., 1995). The higher $\dot{V}O_{2max}$ scores of the squash players on the sport-specific test, with all participants meeting the criteria for attainment of $\dot{V}O_{2max}$, suggests that the ST also possesses logical validity, (N.C.F., 1995) given the importance of this fitness component at higher standards of play (Girard *et al.*, 2007; Brown *et al.*, 1998; Chin *et al.*, 1995; Steininger and Wodick, 1987). Moreover, the strong correlations between $\dot{V}O_{2max}$ scores on the ST and the TT is evidence that the ST demonstrates criterion validity (i.e. it relates well to another recognised method of $\dot{V}O_{2max}$ assessment) (N.C.F., 1995).

4.3.1 Test specificity and assessment

Laboratory-based exercise tests are challenged by the need to reflect the specific muscular, metabolic and technical demands of a particular sport. In common with other racket sports, success in squash depends on technical, tactical and motor skills (Lees, 2003). However, because of the nature of the game at the highest standard, endurance fitness is an essential attribute (Brown *et al.*, 1998; Chin *et al.*, 1995; Steininger and Wodick, 1987). Non-specific exercise tests such as treadmill running, do not account for the movement patterns and muscle actions involved in squash, for example the frequent changes in direction and speed and the high eccentric, isometric and concentric loads required to accomplish these. This study and others (Girard *et al.*, 2005) have demonstrated the test specificity of maximum oxygen uptake in squash players who achieved lower values in treadmill running compared with squash-specific testing. Treadmill testing, therefore, is less discriminating for the assessment of $\dot{V}O_{2max}$ in squash players.

Endurance-performance capability is another important variable that could indicate positive training adaptations in the absence of changes in maximal oxygen uptake. The superior times to exhaustion of trained squash players over runners of similar test-specific (ST) $\dot{V}O_{2max}$ shown in this study is further evidence for the ability of the squash test to detect sport-specific capabilities.

4.3.2 Applications to squash-specific testing

Sport-specific training is recognised as essential for improvement and success in any sport (Müller *et al.*, 2000). A large part of a squash player's training takes place on court, and the efficacy of on-court training as preparation for match play has been demonstrated (Todd *et al.*, 1998). However, appropriate training intensities based on prior physiological assessment are integral to the success of training (Müller *et al.*, 2000). It is a recent recommendation common in other endurance-based sports, such as running, to train at heart rates and at speeds that correspond to directly determined $\dot{V}O_{2max}$ to bring about improvements in this physiological variable (Midgley *et al.*, 2006). Both the test described in this study and the incremental test described by Girard *et al.* (2005) are capable of providing training speeds for on-court movement training equivalent to an individual player's $\dot{V}O_{2max}$. Accordingly, they can be used to improve $\dot{V}O_{2max}$ in movements specific to the demands of match-play.

The ST could also be used to track training-induced adaptations in $\dot{V}O_{2max}$ and endurance capability. Furthermore, given the important role of $\dot{V}O_{2max}$ in the prediction of successful transition from junior to senior elite ranks, the ST could be used to identify performers whose $\dot{V}O_{2max}$ is sufficiently high in their age group and meeting the physiological demands of senior match play (Brown *et al.*, 1998).

Although not performed in this study, by the nature of its linear increase in the intensity of exercise (as shown in Figure 13), the ST described might also be useful for identification of sub-maximal metabolic thresholds using blood lactate analysis or ventilatory markers of metabolic acidosis. This practice was reported by Girard *et al.* (2005) and allowed the prescription of sub-maximal on-court training that corresponded to match-play intensities that have been recently reported. For example, on-court training speeds that correspond to blood lactate concentrations of 8 $mmol \cdot L^{-1}$ could be used to recreate the intensity of match play (Girard *et al.*, 2007). Further research is required to explore this possibility with the test described here.

4.4 Conclusion

The squash-specific incremental test described resulted in higher $\dot{V}O_{2max}$ values in squash players than a non-specific treadmill incremental test. In addition, squash players demonstrated superior time to exhaustion over runners of similar $\dot{V}O_{2max}$ on the squash-specific test. Furthermore, ST $\dot{V}O_{2max}$ scores correlated strongly with those achieved on a standard lab-based treadmill incremental test. The results suggest that the squash test is a more valid means to assess maximum oxygen uptake and endurance capability of squash players than a treadmill test.

5 REPRODUCIBILITY OF PHYSIOLOGICAL AND PERFORMANCE MEASURES FROM A SQUASH-SPECIFIC TEST OF ENDURANCE FITNESS

The specific movement patterns of squash provide a unique challenge to physiologists attempting to assess elements of fitness relevant to squash performance. The previous chapter demonstrated that aerobic power (measured as $\dot{V}O_{2max}$) was protocol specific in squash players and higher in a test using squash-specific movements. Improvements in elite sport performance arise mainly from increased training quality which it would be beneficial to assess with sport-specific tests (Müller *et al.*, 2000). This necessitates the development of valid and reproducible sport-specific procedures that can assess players' strengths and weaknesses and monitor training adaptations that might be missed by less sensitive non-specific procedures.

As described in the literature review, the physiological responses to match play in squash and the $\dot{V}O_{2max}$ values of 62 – 64 $ml \cdot kg^{-1} \cdot min^{-1}$ in elite male players (Chin *et al.*, 1995; Girard *et al.*, 2005) confirm the importance of high aerobic power at the highest standards of play. Despite the importance of $\dot{V}O_{2max}$ and endurance capability, only two previous papers describing on-court squash protocols developed for assessment purposes have been published (Steininger and Wodick, 1987; Girard *et al.*, 2005). The validity and limitations of these procedures has been detailed in Chapter two and the validity of a new, simpler procedure was examined in the previous chapter. However, the evaluation of reproducibility for these squash-specific protocols is lacking and requires further investigation.

Previous attempts to develop valid and controlled tests of squash-specific fitness are challenged by the stochastic nature of match play and the need for reproducibility of scores. Any valid sport-specific test devised for assessment purposes must also be reproducible if it is to be of value in tracking improvements in fitness and performance with training (Alricsson *et al.*, 2001; Atkinson and Nevill, 1998; Hopkins, 2000a). Accordingly, the purpose of this study was to assess reproducibility of measures from a squash-specific incremental test that comprised randomised movements and was designed to assess endurance fitness.

5.1 Methods

5.1.1 Participants

With institutional ethics approval, eight trained squash players (age mean ± SD) 29.6 ± 9.4 years, stature 1.77 ± 0.05 m, body mass 69.4 ± 6.7 kg who were fully habituated to the procedures participated. The players were regular and current competitors in the premier or first division of their regional leagues, with at least five years playing experience at this standard. Habituation procedures and pre-test preparation instructions are described in Chapter three.

5.1.2 Experimental design

Participants performed an incremental squash test (ST) to volitional exhaustion on two occasions, seven days apart to assess reproducibility of performance and physiological measures. Tests were conducted under similar environmental conditions (temperature 18.9 ± 3.4 °C, relative humidity 49 ± 8 %, barometric pressure 1016 ± 11 mBar) at the same time of day and in the same footwear and clothing.

5.1.3 Overview of the incremental squash-specific test

The ST involved squash-specific movement patterns to and from four marked positions (two front corners, and two back corners) on a squash court floor beginning from a central 'T' position (see Figure 4, p63). A detailed description of the test procedure is given in Chapter three and validity of the test is reported in Chapter four.

5.1.4 Assessment protocol

Testing was separated into two phases. Phase one was used to determine lactate threshold and movement economy. Participants completed between six and ten four-minute stages with one-minute rest intervals between stages for collection of capillary blood from a finger tip. The movement speed was held constant for the duration of each stage but was increased by one movement from the T to a corner and back per minute for each subsequent stage. Breath-by-breath oxygen uptake ($\dot{V}O_2$) and heart rate (HR) were continuously determined and recorded using a portable telemetric system (Metamax 3B, CORTEX Biophysik, Leipzig, Germany).

Lactate threshold was identified from visual inspection of lactate values plotted against test stage and was taken as the test stage prior to the first sudden rise in blood lactate concentration. Once participants reached a blood lactate concentration of $\geq$ 4 mmol·L^{-1}, phase one ceased and participants were allowed a 10-to 15-minute rest period before beginning phase two of testing. Calibration and verification procedures for the gas and lactate analysers and for the collection and analysis of capillary blood samples were as described in Chapter three.

Following the determination of lactate threshold, phase-one $\dot{V}O_2$ data were used to determine movement economy that was taken as the 60-s mean of $\dot{V}O_2$ in the final minute of the fourth stage (below lactate threshold for all participants).

Following recovery from phase one, participants completed incremental one-minute stages on the squash-specific test in a continuous manner commencing at stage one (10 movements per minute), with speed increased by one movement per minute every minute until volitional exhaustion for the determination of maximal oxygen uptake and performance time. Breath-by-breath oxygen uptake ($\dot{V}O_2$) and heart rate (HR) were continuously determined as previously described. This phase of testing ended when the participant voluntarily stopped exercising or was stopped by the experimenter if after two warnings they were unable to place a foot on the correct court mark in time with the audio signals.

The $\dot{V}O_{2max}$ was calculated using 30-s retrograde, stationary time mean with $\dot{V}O_{2max}$ taken as the highest 30-s mean during the final stages of each test. The HR_{max} was taken as the highest 30-s mean during the final stages of each test. Attainment of a plateau in $\dot{V}O_2$ (≤ 2.1 ml·kg^{-1}·min^{-1} rise with an increase in exercise intensity), RER > 1.1, post test blood lactate concentration > 8 mmol·L^{-1}, HR within 10 beats·min^{-1} of age-predicted maximum and participant subjective reporting of maximal effort were used as criteria to judge whether or not test performances were truly maximal (Midgley *et al.*, 2007). If a participant failed to satisfy three or more of these criteria the test result was deemed to be a peak rather that a maximum value. Performance time to exhaustion was recorded to the nearest second using an electronic stopclock (FastTime 1, Click Sports, Cambridge, UK).

5.1.5 Statistical analysis

Precisely which metric of reproducibility to use is the subject of enthusiastic debate because each has its detractors and supporters (Atkinson and Nevill, 1998; Hopkins, 2000a). As such, the following methods were used: Typical Error of Measurement

(TEM) (Hopkins, 2000a), Limits of Agreement (LOA) (Bland and Altman, 1986), Least Products Regression (LPR) (Ludbrook, 1997) and paired-sample t-tests. SPSS® v 12 (SPSS Inc., Chicago, IL) statistical software package was used to generate descriptive statistics and undertake the analysis for LPR. The TEM (and the 90% confidence intervals thereof) and LOA were calculated using the Microsoft Excel spreadsheet of Hopkins (Hopkins, 2000b) and together with LPR, were used to assess the reproducibility of scores. Paired sample t-tests were used to assess systematic bias between test and re-test scores. Prior to LOA analysis, the assumption of homoscedasticity was confirmed using Pearson's correlation coefficient to examine relationships between the individual mean of scores on each trial and the absolute individual difference between scores on consecutive trials for each variable.

5.2 Results

Movement speed at lactate threshold varied between players in a range from stage 4 (13 moves per minute) to stage 8 (17 moves per minute). However, each player achieved the same movement speeds at lactate threshold across both test sessions so movement speed at the lactate threshold was not subjected to reproducibility analysis. The descriptive statistics and reproducibility of other physiological and performance measures are shown below in Tables 8 and 9.

Table 8. Performance time, $\dot{V}O_{2max}$, HR_{max} and economy from two trials of the ST performed seven days apart (values are mean ± SD).

	Time (s)	$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	HR_{max} (beats·min^{-1})	Economy at test stage 4 (ml·kg^{-1}·min^{-1})
Test 1	692	50.8	189	32.6
(n = 8)	±148	±6.5	±10	±5.2
Test 2	715	51.2	187	28.7
(n = 8)	±168	±6.9	±10	±3.5

Table 9. Reproducibility of performance time, $\dot{V}O_{2max}$, HR_{max} and economy on the ST (n = 8).

	Time (s)	$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	HR_{max} (b·min^{-1})	Economy (ml·kg^{-1}·min^{-1})
Limits of Agreement	14 ± 62	0.2 ± 5.1	-2 ± 6	-3.9 ± 4.3
Typical Error	27 (4%)	2.4 (4.7%)	2 (1.3%)	1.55 (4.1%)
Least Products Regression:				
slope	1.1	1.1	0.99	0.7
intercept	-71	- 2.9	- 0.5	6.8

The data show a small increase in mean $\dot{V}O_{2max}$ (1.2 ml·kg^{-1}·min^{-1}) and mean performance time (23 s) between the first and second test in conjunction with a slight reduction in mean HR_{max} (2 beats·min^{-1}). There was also an improvement in economy with a reduced mean oxygen cost of movement at stage four of the ST (3.9 ml·kg^{-1}·min^{-1}).

The LOA values for performance time and $\dot{V}O_{2max}$ support the trends in the descriptive data showing a small positive systematic bias between test 1 and test 2 though paired t-tests showed these were not significant ($t_7 = - 1.69$, $P = 0.1$; $t_7 = - 0.27$, $P = 0.8$ for performance time and $\dot{V}O_{2max}$ respectively). Similarly, the trend was supported for HR_{max} and economy with small negative systematic biases between test 1 and test 2. Paired t-tests showed that there was no systematic bias for HR_{max} ($t_7 = 2$, $P = 0.1$), but there was for economy ($t_7 = 4.5$, $P < 0.01$). The random error component on all variables was low. Relative TEM (%) showed similar test-retest variation for performance time (4%), $\dot{V}O_{2max}$ (4.7%), HR_{max} (1.3%) and economy (4.1%). The 90% confidence intervals of the TEM scores were narrow for all variables (performance time 19 – 49 s; $\dot{V}O_{2max}$ 1.7 – 4.3 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$; HR_{max} 2 – 4 $beats{\cdot}min^{-1}$; economy 1.1 – 2.8 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$). The use of LPR showed variation in the assessment of reproducibility compared with other measures. For example using TEM, performance time had low test-retest variation (4 %). However, the LPR values for slope (1.14) and intercept (-71) were some way from the values of 1 and 0 that reflect perfect reproducibility. Bland-Altman and LPR plots for all measures are shown in Figures 14 and 15 respectively.

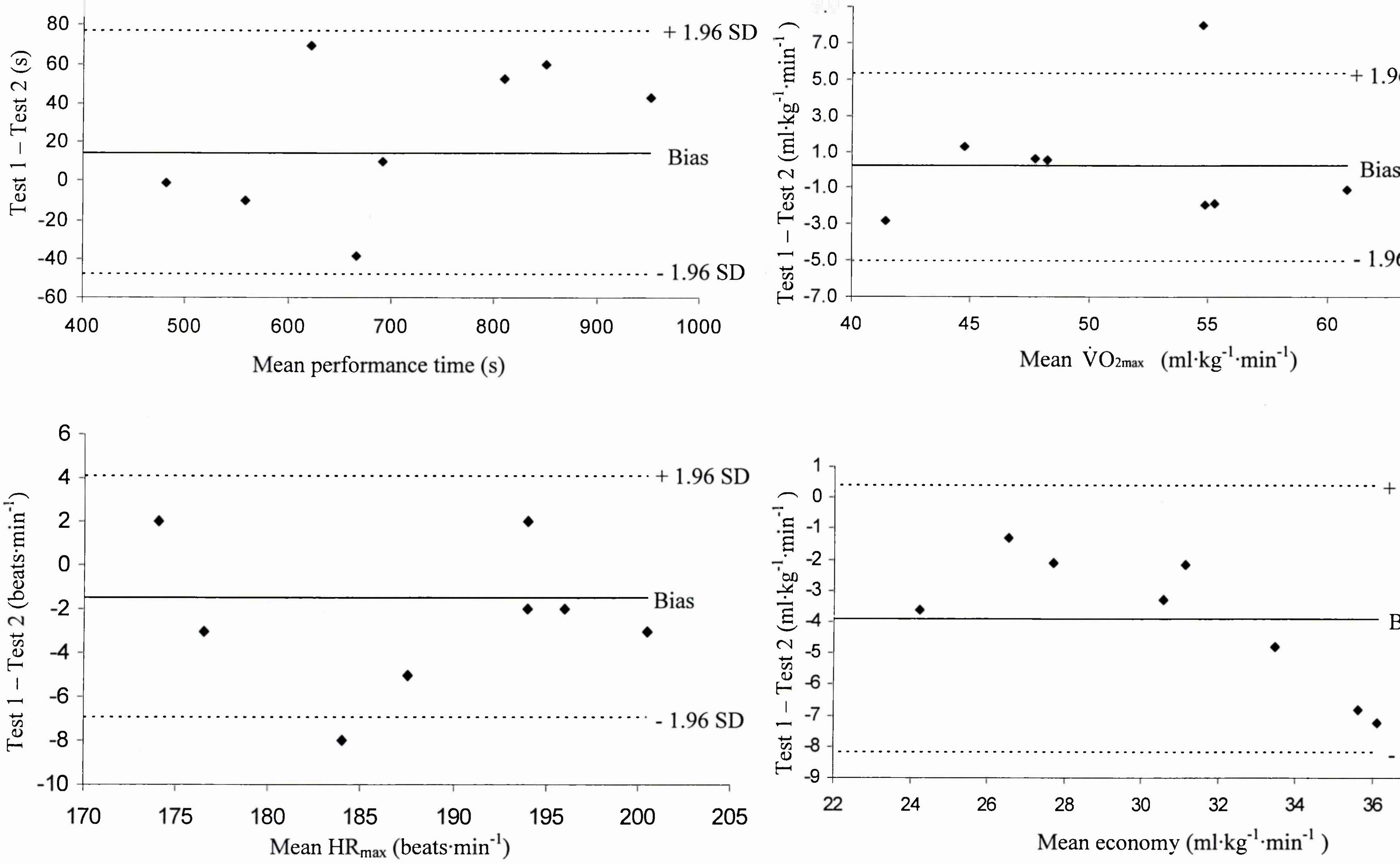

Figure 14. Bland-Altman plots for a) performance time; b) $\dot{V}O_{2max}$; c) HR_{max} and d) movement economy, measured in two trials of the ST performed seven days apart.

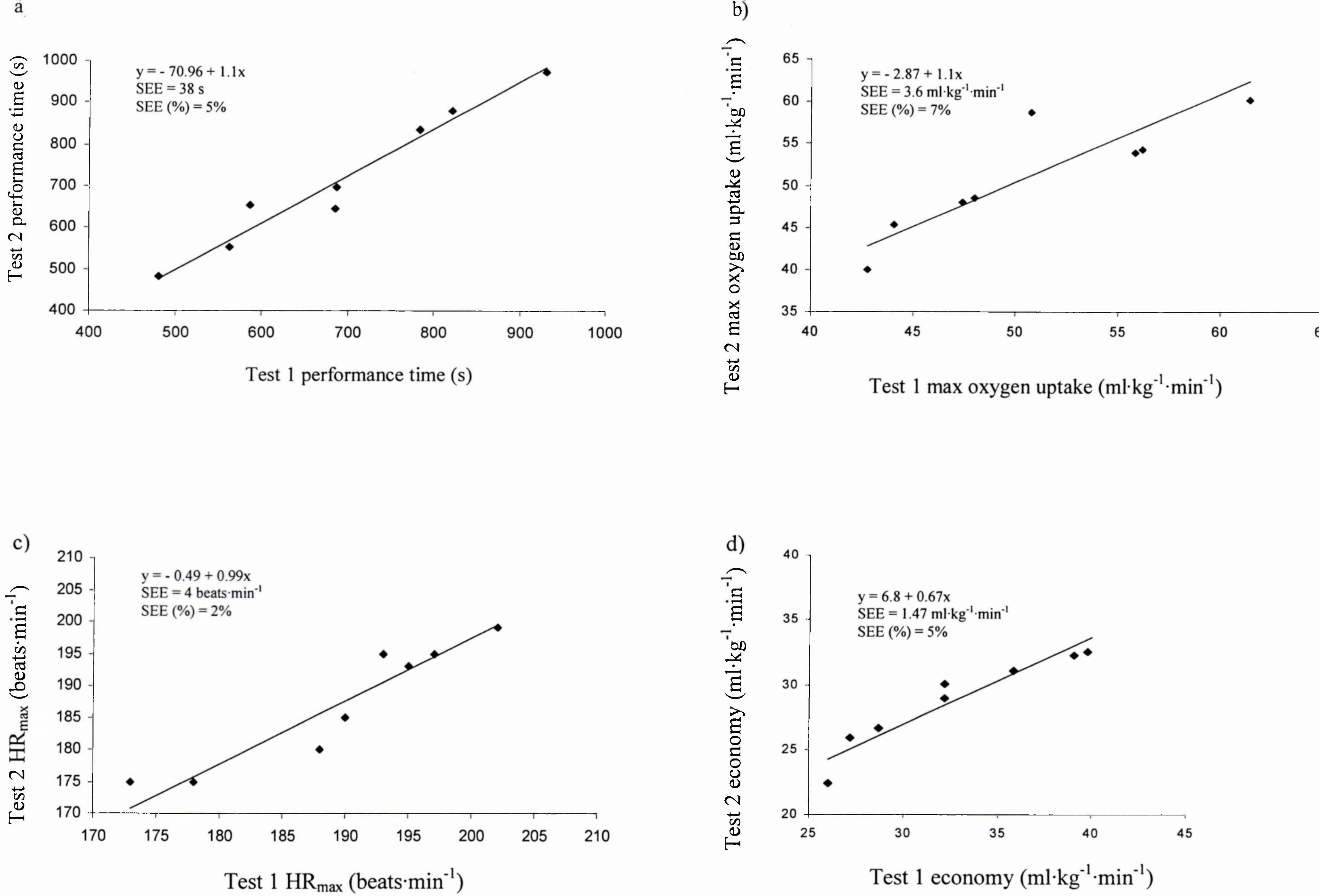

Figure 15. LPR plots for a) performance time; b) $\dot{V}O_{2max}$; c) HR_{max}; d) movement economy measured in two trials of the ST performed 7 days ap

5.3 Discussion

This study examined the reproducibility of physiological and performance measures in an incremental squash test devised to mimic squash movement patterns whilst replicating the stochastic nature of movement in match play.

The results show good though varying degrees of reproducibility in performance time, HR_{max}, $\dot{V}O_{2max}$ and economy depending on which metric of reproducibility is favoured. The relative TEM (%) for performance time (4 %) was higher than that reported for the Girard *et al* (2005) protocol (0.9%) and HR_{max} TEM (1.3 %) was lower in comparison (1.8 %). The TEM of $\dot{V}O_{2max}$ in this study (4.7 %) was within the range reported in other studies using treadmill running as the exercise mode (3 % (Bagger *et al.*, 2003); 5.6 % (Katch *et al.*, 1982). The results suggest that both endurance performance and physiological measures from the ST are reproducible, though there are no comparative values published for squash-specific economy.

5.3.1 Systematic bias between tests

The positive (though non-significant) bias evident in the LOA values for performance time and $\dot{V}O_{2max}$ suggests improved test two performance especially when viewed in conjunction with the negative (non-significant) bias for HR_{max} and the negative (significant) bias for economy. This suggests that a learning effect occurred despite two habituation visits. However, the magnitude of these differences should be considered in the light of normal biological variation and the size of the absolute TEM scores for these variables. An examination of these values indicates that the small positive and negative biases in the LOA analyses are well within previously discussed test-retest variability for these measures (Bagger *et al.*, 2003; Katch *et al.*, 1982).

5.3.2 Which reproducibility measure should be favoured?

Methods for assessing reproducibility are a current area of debate with some authors favouring LOA analysis, whilst others recommend test-retest coefficient of variation (TEM) and still others preferring LPR (Atkinson and Nevill, 1998; Hopkins, 2000a; Ludbrook, 1997). Typical error of measurement represents approximately 68 % of the error actually present in the repeated measurement of an individual in the sample, whereas LOA represents 95 % of the likely variation in scores between repeated tests of a population (Atkinson and Nevill, 1998). Ludbrook (1997) argues for the use of LPR analysis as it minimises the sum of the products both of horizontal and vertical distances of x and y values from the regression line.

However, Atkinson and Nevill (1998) point out that reproducibility analysis does not generally possess a predictor and response variable (an assumption of regression analysis) and that the assumption of a homogenous sample is not always met. The arguments that each of the authors presents for the use of their preferred analysis method all have merits, but it is beyond the scope of this thesis to discuss the statistical benefits of one method over another, or their application to particular study designs. However a common factor in all the methods discussed and used in the present study is that the interpretation of reproducibility requires the researcher to judge (based on proposed use of the test) whether or not the test-retest error is small enough for the test to be of practical use (Atkinson and Nevill, 1998). To make this judgement, the researcher must possess knowledge of the smallest worthwhile change in a performance or physiological variable, then assess whether the test is sensitive enough to detect such a change (Hopkins, 2000a).

It is suggested that TEM analysis best suits this purpose. This is because of the simplicity of interpretation (absolute and % error) and the accompanying confidence intervals, the upper value of which can be used (if the typical error and size of the CI is small) as an estimate of the lower limit for a *meaningful change* in a variable with repeat testing (Hopkins, 2000a). Moreover, the anticipated value for TEM is independent of sample size and does not suffer from the bias that can occur when LOA are calculated with small degrees of freedom (i.e. small sample sizes and few repeat tests) (Hopkins, 2000a).

5.3.3 Physiological profiling using the incremental squash test

Laboratory-based exercise tests are challenged by the need to reflect the specific muscular, metabolic and technical demands of a particular sport. Success in squash depends on technical, tactical and motor skills (Lees, 2003). However because of the nature of the game at the highest standard aerobic fitness is an essential attribute (Girard *et al.*, 2007; Brown *et al.*, 1998). The results of the study detailed in Chapter four and those of previous studies have demonstrated the specificity of aerobic fitness in squash players and the efficacy of specific training as preparation for match play (Girard *et al.*, 2005; Todd *et al.*, 1998).

However, measurement error in fitness tests must be quantified to allow accurate assessment of meaningful change in scores with repeat testing. This has been poorly considered in previous studies. The ST described here allows collection of all the data necessary to provide a full aerobic physiological profile of a player ($\dot{V}O_{2max}$, lactate threshold, economy, movement speed at $\dot{V}O_{2max}$) from which training intensities in squash-specific movement patterns can be derived. Furthermore, the reproducibility reported provides support for the use of the ST as an assessment tool. The confidence intervals reported could also be used to assess whether a training intervention has resulted in a meaningful change in endurance performance or physiological responses on the ST. However, this should be examined over greater test-retest durations to confirm the usefulness of the test for the tracking of training adaptations in fitness and performance. Test-retest variability should also be established for other samples of squash players such as juniors, females and sub-elite groups.

The importance of aerobic fitness and the value of sport-specific assessment of this attribute for squash are well documented. As such, squash-specific aerobic profiling using a test sensitive enough to track training-induced changes is likely to be a useful addition to the fitness assessment of squash players. It is suggested that the ST described here could provide these benefits.

5.4 Conclusions

The results suggest that the squash-specific incremental test produces reproducible measures for the assessment of squash-specific fitness and performance capabilities. Further testing is required to establish measurement error over greater test-retest durations and thus confirm the value of the test for tracking adaptations over extended training periods.

6 VALIDITY OF A SQUASH-SPECIFIC TEST OF CHANGE-OF-DIRECTION-SPEED

The importance and specificity of aerobic fitness in squash has been discussed and demonstrated in Chapters two and four respectively. The findings of Chapters four and five demonstrate that this aspect of squash fitness can be assessed using a valid and reproducible squash-specific procedure. However, in common with other racket sports, multiple-sprint ability and the ability to change direction at speed are also important determinants of performance in squash (Lees, 2003; Sharp, 1998; Behm, 1992). Squash movements are characterised by rapid accelerations and decelerations over short distances and involve frequent turning, lunging, and side-stepping (Eubank and Messenger, 2000; Vučković *et al.*, 2004). A recent match analysis study reported that more than 40% of squash movements occurred within 1 m of the court's T position and most movements were not in a straight line (Vučković *et al.*, 2004).

The use of on-court sprint drills encompassing multiple-direction changes (ghosting) by elite-standard squash players reflects the recognition that speed training must be undertaken in sport-specific movement patterns (Sharp, 1998). This is supported by findings that straight-line sprint training does not improve sprint performance involving changes of direction (Young *et al.*, 2001). The specific movement patterns of squash provide a unique challenge to physiologists attempting to assess squash-specific explosive capabilities and suggest that tests should encompass the ability to change direction at speed. Müller (2000) stated that improvements in elite sport performance arise mainly from an increase in the quality of training and that this is best improved through the development of sport-specific training and testing. Valid and reliable squash-specific, yet controlled, tests are likely to provide more useful data for the design of training programmes and tracking of sport-specific training adaptations that might otherwise go undetected by conventional non-specific procedures.

Field-based, sport-specific tests should satisfy criteria for validity, reproducibility and sensitivity (N.C.F., 1995; Winter *et al.*, 2007). Previous tests developed to assess specific fitness in squash, while addressing these criteria, have focussed on maximum and sub-maximum cardio-pulmonary responses and have involved movement patterns that, although specific to squash, are performed at intensities to assess aerobic capabilities (Steininger and Wodick, 1987; Girard *et al.*, 2005). This is surprising as match analysis has revealed that players cover a mean distance of only 12 m during rallies lasting 16-21 s (Vučković *et al.*, 2004) and recent physiological analysis has reported mean post-match blood lactate concentrations of 8 $mmol \cdot L^{-1}$ indicating marked contributions from glycolysis (Girard *et al.*, 2007).

Despite the documented importance of qualities such as explosive strength and speed (Behm, 1992; Sharp, 1998) and the rapid accelerations, decelerations and direction changes that characterise squash movement (Eubank and Messenger, 2000; Vučković *et al.*, 2004), there appear to be no published squash-specific tests of sprint capabilities or change-of-direction speed. Accordingly, the purpose of this study was to examine the validity of a squash-specific sprint-based test designed to assess such change-of-direction speed.

6.1 Methods

6.1.1 Participants

With institutional ethics approval 10 trained male squash players (mean ± SD age 23 ± 4 years; stature 1.8 ± 0.05 m; body mass 79.7 ± 5.3 kg), and 10 non-squash players (trained association-football and rugby-union players) (age 24 ± 3 years; stature 1.8 ± 0.08 m; body mass 85.9 ± 11.8 kg) who were fully habituated to the procedures participated. The squash players were English county-standard, had a competitive playing frequency of at least three times per week and had been competing at county standard for at least three years. The non-squash players were matched to the squash players for playing standard and frequency of participation in their respective sports. All participants were given standard instructions for pre-test preparation that are detailed in Chapter three.

6.1.2 Experimental design

Participants performed two test sessions on a squash-specific change-of-direction-speed test (SCODS) separated by twenty four hours and two test sessions on the Illinois Agility Run (IAR), also twenty four hours apart. The IAR was chosen for comparison as it is a popular non-specific field-based test of change-of-direction speed that has been used previously in the validation of other similar tests (Sale, 1990). Following a standardised warm-up, each test session comprised three trials of the test in question with the best performance time recorded to the nearest one hundredth of a second using a hand-held electronic stop clock (FastTime 1, Click Sports, Cambridge, UK). Details of the warm-up and timing procedures for both tests are provided in section 3.2.8. Tests were performed in a randomised order at the same time of day and in the same footwear and clothing and under similar environmental conditions (temperature 21 ± 2.4 °C, relative humidity 50 ± 8 %, barometric pressure 1002 ± 11 mBar). The IAR was performed in a non-slip sports hall because of the test dimensions and the SCODS was carried out on a marked-out squash court to increase the validity of the movement patterns. The sprung wooden flooring was the same at both test locations.

6.1.3 Experimental procedures

The dimensions, layout and movement path through the SCODS and the IAR are shown in Figures 7 and 8, detailed procedure for both tests are described in sections 3.2.8.1 and 3.2.8.2 in the general methods chapter.

6.1.4 Ranking of squash players

Two England Squash qualified coaches (part three - advanced level), located in the area where the study was performed, independently assigned a rank to each squash player using personal knowledge of the players and recent performances in local regional league matches. Where independent ratings differed, a resolution was obtained through discussion between the two coaches.

6.1.5 Statistical analysis

Data were analysed using SPSS® v 12 (SPSS Inc., Chicago, IL) statistical software package. Mean and standard deviation were calculated for performance time on the SCODS and IAR. Following verification of underlying assumptions such as normality and homogeneity of variance, independent t-tests were used to compare the best performance times on both the SCODS and IAR between the squash players and the non-squash players. Spearman's rho examined the relationship between best scores on the SCODS and IAR and subjective ranking of the squash players' ability. Pearson's correlation examined relationships between best scores on the SCODS and IAR in squash players. Statistical significance was accepted at $P \leq 0.05$. Typical Error of Measurement (TEM) and the 90% confidence interval thereof (90% CI), Limits of Agreement (LOA) and Least Products Regression (LPR) were calculated and used to assess reproducibility of performance time on both the SCODS and the IAR (Hopkins, 2000b; Bland and Altman, 1986; Ludbrook, 1997).

6.2 Results

6.2.1 Differences in performance on the IAR and SCODS tests between squash and non-squash players.

The results are illustrated in Table 10. There were no differences in performance time between squash and non-squash players on the IAR (*P* = 0.86). However, squash players were faster than non-squash players on the SCODS (t_{18} = -7.38, *P* = 0.001, effect size = 3.33).

Table 10. Performance times from two trials of the SCODS and the IAR tests performed on separate days (values are mean ± SD).

	Squash-specific Change-of-Direction-Speed test			Illinois Agility Run test		
	Test 1 (s)	Test 2 (s)	Best score (s)	Test 1 (s)	Test 2 (s)	Best score (s)
Squash (n = 10)	10.99 ± 0.44	10.97 ± 0.44	10.90 ± 0.44	14.94 ± 0.75	14.79 ± 0.54	14.75 ± 0.66
Non-squash (n = 10)	12.37 ± 0.47	12.49 ± 0.38	12.20 ± 0.34	14.99 ± 0.45	14.90 ± 0.49	14.79 ± 0.41

6.2.2 Reproducibility of performance scores on the IAR and SCODS tests.

Performance times of squash players and non-squash players combined on the IAR were reproducible (TEM 0.27 s, 1.8 %, 90 % CI 0.21 – 0.37 s; LOA -0.12 s ± 0.74; LPR slope 1, intercept -2.8), as were times on the SCODS (TEM 0.18 s, 1.5 %, 90 % CI 0.14 – 0.24 s; LOA 0.05 s ± 0.49; LPR slope 0.95, intercept 0.5). For squash players alone, test-retest variability of performance on both tests was reduced (SCODS TEM 0.13 s, 1.2 %, 90 % CI 0.09 – 0.21 s; IAR TEM 0.21 s, 1.7 %, 90 % CI 0.15 – 0.34 s). Bland-Altman and LPR plots for performance time on the SCODS for all participants are shown in Figure 13a and b.

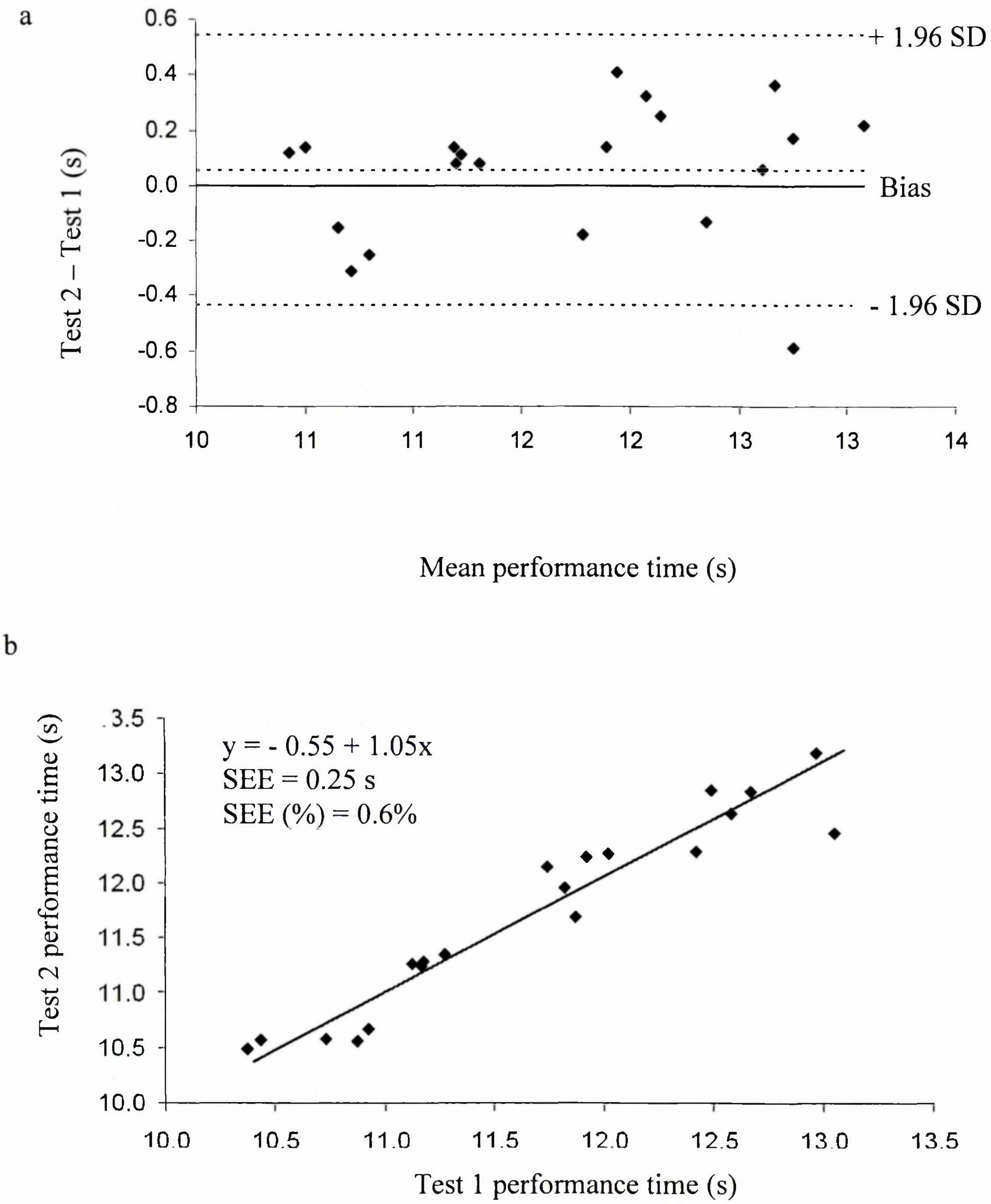

Figure 16. Bland – Altman (a) and LPR plot (b) for performance time measured in two trials of the SCODS test performed 24 hours apart.

6.2.3 Correlation of SCODS and IAR performance with player rank in squash players.

Spearman's rho indicated a positive correlation between performance time on the SCODS and player rank for the squash players ($\rho = 0.77$, $P < 0.01$). There was no correlation between performance time of squash players on the IAR and rank ($\rho = 0.43$, $P = 0.21$).

6.2.4 Correlation of performance on the IAR and SCODS tests.

Pearson's correlation showed no relationship between performance time on the IAR and SCODS tests in the squash players (r = 0.32, $P = 0.37$).

6.3 Discussion

The purpose of the study was to examine the validity and reproducibility of a squash-specific test of change-of-direction speed. Despite similar non-sport specific change-of-direction speed measured on the IAR, squash players outperformed non-squash players on a change of direction speed test that used squash-specific movements. Moreover, the positive correlation between squash player rank and performance on the SCODS showed that the test discriminated ability in a group of squash players. The ability of the squash-specific test to discriminate both between groups with similar non sport-specific change-of-direction speed and in squash players suggests that it possesses construct validity (N.C.F., 1995).

The difference in SCODS performance between groups suggests that squash training and the associated skill in squash-specific movements conferred a performance advantage on a test involving repeated changes of direction at speed over short distances as is required in squash (Vučković *et al.*, 2004). Young *et al.* (2001) previously demonstrated improvements in the performance of change-of-direction-speed tests with specific training and also showed no improvements in such performance with non-specific training that consisted of straight-line sprinting. Results from the IAR showed that the squash players and non-squash players possessed similar capabilities in this test that involved four straight sprints of 10 m and weaving around four cones. The SCODS in contrast possesses no straight sprints, but instead comprises several lateral movements of short distances requiring rapid and forceful changes of direction. Squash movements are characterised by rapid accelerations and decelerations over short distances and involve turning, lunging, and side-stepping (Eubank and Messenger, 2000; Vučković *et al.*, 2004). Squash players spend much time training in these movement patterns to improve court coverage and movement speed (Sharp, 1998; Sherman *et al.*, 2004; Todd *et al.*, 1998). The superior performance of the squash players in their habitual movement patterns shown in this study provides evidence for the specific nature of change-of-direction-speed and also for the logical validity of the SCODS test. The lack of correlation between performance of the squash players on the IAR and SCODS tests is further evidence for the specificity of change-of-direction speed.

6.3.1 Applications to squash-specific testing.

Sport-specific testing is important for accurate prescription of training, talent identification and tracking of training-induced adaptations (Müller *et al.*, 2000). Multiple-sprint capability and the ability to change direction at speed are important determinants of performance in squash (Lees, 2003; Sharp, 1998; Behm, 1992). As such, a valid and reliable squash-specific test that examines these capabilities is a useful addition to existing test batteries for squash players. The ability of the SCODS test to discriminate ability in a group of squash players confirms the construct validity of the test and suggests that it could be used for screening purposes. Moreover, the reproducibility reported provides further support for the use of the SCODS as an assessment tool for the tracking of squash players. The confidence intervals reported for the squash players could be used to assess the extent to which a training intervention has resulted in a meaningful alteration in change-of-direction speed, with the upper confidence interval representing the lower boundary for a meaningful change. However, future studies should examine reproducibility over greater test-retest durations to confirm the usefulness of the test to track training-induced adaptations in fitness and performance. Test-retest variability should also be established for other samples of squash players such as juniors, females and elite groups.

6.3.2 Conclusions

The results suggest that the squash-specific change-of-direction-speed test is a better measure of sport-specific capability than an equivalent non-specific field test and that it is a valid and reliable field based assessment that could be used for fitness testing and athlete tracking. However, further studies should be carried out using squash players of different age, sex and ability and across greater test-retest durations to confirm these findings.

7 VALIDITY OF A SQUASH-SPECIFIC TEST OF MULTIPLE-SPRINT ABILITY

The temporal and movement pattern data summarised in the literature review (section 2.5.2) confirm that squash is a high-intensity, multiple-sprint activity. Multiple-sprint ability is acknowledged as an important component of squash fitness along with endurance and the ability to change direction at speed (Lees, 2003; Sharp, 1998; Vučković *et al.*, 2004). The studies described in Chapters four, five and six have examined the validity and reproducibility of squash-specific tests designed to assess aerobic fitness and change-of-direction speed and have also demonstrated the specificity of these factors. Physiological profiling requires that all aspects of fitness important for performance are assessed to build a complete picture of player strengths and weaknesses. Therefore it is important to develop valid and reproducible sport-specific procedure capable of assessing squash-specific multiple-sprint ability.

Various field-based tests of multiple-sprint ability have been developed (Tumilty *et al.*, 1988; Dawson *et al.*, 1991; Baker *et al.*, 1993; Fitzsimons *et al.*, 1993; Wadley and Le Rossignol, 1998) including procedures specific to soccer (Bangsbo, 1994), basketball (Castagna *et al.*, 2007) and hockey (Boddington *et al.*, 2004). However, with the exception of the 5-m MST of Boddington *et al.* (2004), the validity of these multiple-sprint ability tests has been poorly considered. Furthermore, the specificity of change-of-direction speed (Young *et al.*, 2001), an important element in a test of multiple-sprint ability, questions the application of these procedures to sports other than those for which they were designed.

Despite the multiple-sprint nature of squash (Vučković *et al.*, 2004) there are no published squash-specific tests of multiple-sprint ability. Accordingly, the purpose of this study was to examine the validity and reproducibility of a test designed to assess multiple-sprint ability using patterns of movement specific to squash.

7.1 Methods

7.1.1 Participants

With institutional ethics approval eight trained male squash players (age mean ± SD 25 ± 5 years; stature 1.77 ± 0.04 m; body mass 72.8 ± 7.8 kg, $\dot{V}O_{2max}$ 56.8 ± 5.5 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$) and eight non-squash players (trained footballers) (age 22 ± 3 years; stature 1.79 ± 0.09 m; body mass 82 ± 12 kg, $\dot{V}O_{2max}$ 51.4 ± 5.1 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$) who were habituated to the procedures participated. Habituation and pre-test preparation were as detailed in Chapter three. Squash players were regular and current competitors in the premier or first division of the regional leagues, with at least five years' playing experience at this standard. The footballers were all members of Northumbria University's first team and had a similar weekly playing and training frequency to that of the squash players.

7.1.2 Experimental design

Participants performed Baker's 8 × 40-m sprints (Baker *et al.*, 1993) and a squash-specific multiple-sprint test on separate days (separated by at least 48 hours). Six squash players and six footballers repeated the tests seven days later to assess reproducibility of measures using Typical Error and associated 90% confidence intervals. Baker's 8 × 40-m sprints was chosen for comparison because it is a popular non-specific field-based test of multiple-sprint ability and has been shown to possess criterion validity (Baker *et al.*, 1993).

Following a standardised warm-up (see section 3.2.8), each test session comprised a single trial of the test in question with the performance time of each sprint recorded to the nearest one hundredth of a second using a hand-held electronic stop clock (FastTime 1, Click Sports, Cambridge, UK). The timer was positioned at the middle cone (the start / finish line) on Baker's test and directly beside the first pair of cones on the squash-specific test (shown in Figure 9 and Figure 10 respectively). Tests sessions were performed in a counterbalanced manner at the same time of day, in the same footwear and clothing and under similar environmental conditions (temperature 19 ± 2.8 °C, relative humidity 45 ± 7 %, barometric pressure 998 ± 13 mBar). Baker's test was performed in a non-slip sports hall because it requires a 20-m course and the squash-specific test was conducted on a marked-out squash court to add to the validity of the movement patterns. The sprung wooden flooring was the same in both venues.

7.1.3 Experimental procedures

Baker's and the squash-specific multiple-sprint test were carried out as detailed in chapter 3. Participants were fitted with a telemetric heart rate monitor and chest strap (Polar S625X, Polar OY, Finland) that recorded maximum heart rate attained during each test. Post-test blood lactate concentration was measured by an electrochemical method from a sample of capillary blood obtained from a finger prick. Sampling technique and calibration and verification of the blood lactate analyser are as described in Chapter three.

7.1.4 Ranking of squash players

Two England Squash qualified coaches (part three - advanced level), located in the area where the study was performed, independently assigned a rank to each squash player using personal knowledge of the players and recent performances in local regional league matches. Where independent ratings differed, a resolution was obtained through discussion between the two coaches.

7.1.5 Statistical analysis

Data were analysed using SPSS® v 15 (SPSS Inc., Chicago, IL) statistical software package. Mean and standard deviation were calculated for performance time, maximum heart rate and post-test blood lactate scores on the squash-specific and Baker's tests. Following verification of underlying assumptions such as normality and homogeneity of variance, independent t-tests were used to compare total performance times both on the squash-specific and Baker's test between the squash players and the non-squash players. Paired-samples t-test were used to compare maximum heart rate and post-test blood lactate scores between the squash-specific and Baker's test in squash and non-squash players. Pearson's correlation examined the relationship between performance on the squash-specific and Baker's test in both groups. Spearman's rho examined relationships between rank and performance on both tests in the squash players. Statistical significance was accepted at $P \leq 0.05$. Typical Error of measurement (TEM) and the 90% confidence interval thereof (90% CI) assessed reproducibility of performance time on both tests.

7.2 Results

7.2.1 Differences in performance on Baker's and the squash-specific test between squash and non-squash players.

The results are illustrated in Figure 17. Performance time on Baker's test did not differ between squash (72.9 ± 3.9 s) and non-squash (72.9 ± 2.8 s) players ($t_{14} = 0.04$, $P = 0.97$, effect size = 0). However, squash players (232 ± 32 s) outperformed non-squash players (264 ± 14 s) on the squash-specific test ($t_{14} = 2.56$, $P = 0.02$, effect size = 1.4).

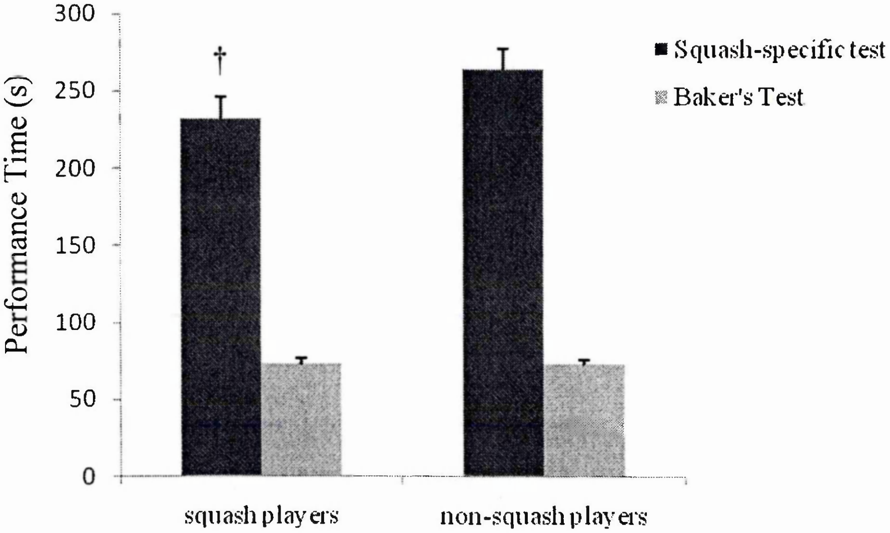

Figure 17. Differences in performance time on a squash-specific multiple-sprint test and Baker's 8 × 40 m sprint test in trained squash players (n = 8) and trained footballers (n = 8). Values are mean + SD. † = difference in performance time on the squash-specific test between squash and non-squash players (*P* = 0.02).

7.2.2 Differences in physiological responses to Baker's and the squash-specific test in squash and non-squash players.

The results are illustrated in Figure 18. Squash players had higher maximum heart rates on the squash-specific (mean ± SD 180 ± 8 beats·min^{-1}) than the Baker's (172 ± 8 beats·min^{-1}) test ($t_7 = 3.33$, $P = 0.01$, effect size = 1.0). Post-test blood lactate concentration was also higher after the squash-specific test (5.5 ± 1.9 mmol·L^{-1}) than Baker's (4.1 ± 1.2 mmol·L^{-1}) test in the squash players ($t_7 = 3.11$, $P = 0.01$, effect size = 0.9). Maximum heart rate did not differ between the squash-specific and Baker's test

(187 ± 13 and mean 190 ± 17 beats·min^{-1} respectively) in non-squash players (t_7 = - 0.50, $P = 0.63$, effect size = 0.2). Blood lactate concentration after the squash-specific test (7.1 ± 1.4 mmol·L^{-1}) also did not differ from that after Baker's test (7.3 ± 2.9 mmol·L^{-1}) in non-squash players (t_7 = - 0.17, $P = 0.87$, effect size 0.09).

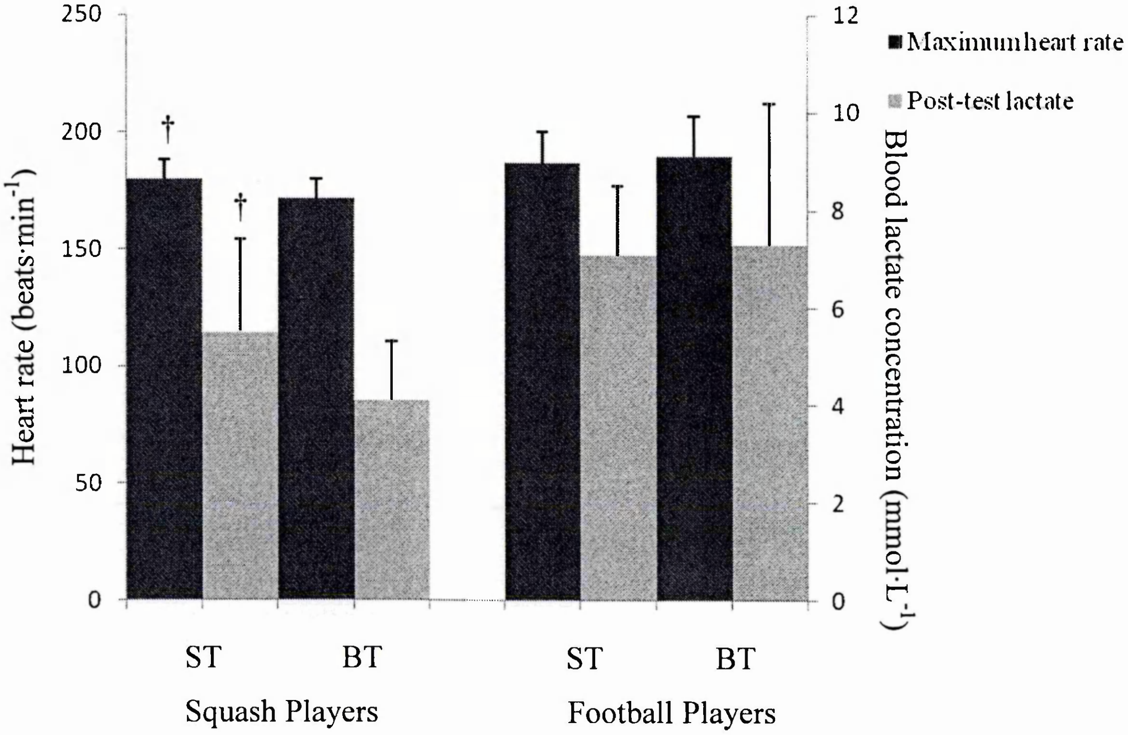

Figure 18. Differences in physiological responses to a squash-specific multiple-sprint test (ST) and Baker's 8 × 40-m sprint test (BT) in trained squash players (n = 8) and trained footballers (n = 8). Values are mean + SD. † = difference ($P = 0.01$) between scores on the ST and BT in squash players.

7.2.3 Reproducibility of performance scores on Baker's and the squash-specific test.

Performances on the squash-specific (TEM 6 s, 2.2%, 90% CI 4 – 13 s; TEM 6 s, 2.3%, 90% CI 4 – 12 s) and Baker's test (TEM 1 s, 1.6%, 90% CI 1 – 2 s; TEM 1 s, 1.7% 90% CI 1 – 3 s) were reproducible in squash players and footballers respectively.

7.2.4 Correlation of Baker's and squash-specific test performance with player rank in squash players.

Spearman's rho indicated a moderate positive correlation between performance time on the squash-specific test and player rank for the squash players (Spearman's $\rho = 0.79$, $P = 0.02$). There was no correlation between performance time of squash players on Baker's test and rank (Spearman's $\rho = 0.55$, $P = 0.16$).

7.2.5 Correlation of performance on Baker's and the squash-specific test.

Performance on the Baker's and squash-specific tests were related in squash players (Pearson's $r = 0.98$, $P < 0.01$) but not in non-squash players ($r = - 0.08$, $P = 0.87$).

7.3 Discussion

The purpose of this study was to examine the validity and reproducibility of a squash-specific test designed to assess multiple-sprint ability. Despite similar non-sport specific multiple-sprint ability assessed on Baker's test, squash players outperformed non-squash players on a test of multiple-sprint ability that used squash-specific movements. Moreover, the positive correlation between squash player rank and performance on the squash-specific test showed that the test discriminated ability in a group of squash players. The absence of correlation between squash-player rank and performance on Baker's test suggests it was an insensitive measure for squash players. The ability of the squash-specific test to discriminate both between groups with similar non sport-specific multiple-sprint ability and in squash players suggests that it possesses construct validity (N.C.F., 1995).

Performance on the squash-specific and Baker's tests was related in squash players suggesting that both assessed multiple-sprint ability though the squash-specific test was more sensitive to sport-specific ability. However, test performances were not related in the non-squash players suggesting that they were unable to demonstrate their multiple-sprint ability on a test involving squash-specific movements. The correlation between test performances suggests that the squash-specific test possesses criterion validity when used with squash players. In addition, the physiological response to the squash-specific test was different to that in Baker's test in squash players, with higher maximum heart rates and post-test blood lactates in the squash-specific test. It is notable that the physiological responses of the non-squash players did not differ between the two tests. That the squash-specific test elicited different responses than Baker's test in squash players only is further evidence of the specific nature of the test. Moreover, the heart rate and blood lactate scores recorded from the squash players in the squash-specific test approximate those reported from actual match play (Girard *et al.*, 2007).

The difference in performance on the squash-specific test between groups suggests that squash training and the associated skill in squash-specific movements conferred a performance advantage on a test involving repeated short-duration sprints characterised by repeated changes-of-direction at speed over short distances and with short recoveries as is required in squash (Vučković *et al.*, 2004; Eubank and Messenger, 2000). The test-specific physiological response in squash players also suggests that squash play and training allowed squash players to exercise at higher intensities in multiple-sprint activity involving movement patterns to which they were accustomed.

Currently there are no comparable investigations of multiple-sprint ability in squash, however studies described in Chapters four and six have confirmed the specificity of endurance performance and change-of-direction speed in squash players and showed that a squash-specific test of change-of-direction speed discriminated ability in trained squash players when an equivalent non-specific field-based test could not. In addition, Boddington *et al.* (2004) reported that a hockey-specific test of multiple-sprint ability was able to discriminate playing standard in women hockey players. The superior performance and specific physiological responses of the squash players in their habitual movement patterns shown in this study provides evidence for the specific nature of multiple-sprint ability and also for the logical validity of the squash-specific test.

7.3.1 Application.

Sport-specific testing is important for the optimisation of training prescriptions and tracking of training-induced adaptations (Winter *et al.*, 2007; Müller *et al.*, 2000). Multiple-sprint capability and the ability to change direction at speed are important determinants of performance in squash (Lees, 2003; Sharp, 1998; Behm, 1992). As such, a valid and reliable squash-specific test that examines these capabilities is a useful addition to existing test batteries for squash players. The ability of the squash-specific multiple-sprint test to discriminate ability in a group of squash players confirms the construct validity of the test. Moreover, the reproducibility of scores suggests that the squash-specific test could be used as an assessment tool for the tracking of squash players' fitness. However, reproducibility should be examined over greater test-retest durations to confirm this suggestion. In addition, test-retest variability should also be established for other samples of squash players such as elite and junior groups.

7.4 Conclusion

The squash-specific test discriminated both between groups with similar non sport-specific multiple-sprint ability and in squash players. In conjunction with the relationship between test performances and the specific physiological responses of squash players on the squash test, the results suggest that the squash-specific test is a valid and reproducible field-based assessment of multiple-sprint ability in squash players that could be used for optimising training and athlete tracking. However, in addition to exploring test-retest variability over longer durations, further studies should examine different ages, sex and standards of play to confirm these findings.

8 CORRELATES OF MULTIPLE-SPRINT ABILITY AND PERFORMANCE IN SUB-ELITE SQUASH PLAYERS

Squash is a multiple-sprint sport, where success depends on physical, technical, tactical and motor skills (Lees, 2003). As described previously, match play imposes diverse physiological demands on cardio-pulmonary endurance, muscle endurance, explosive strength, speed and flexibility (Sharp, 1998). The assessment of player capabilities in these physiological factors is a challenge because of the unique and varied movement patterns of the game. However, test specificity is important to ensure validity and sensitivity of procedures and to better enable coaches and scientists to build accurate profiles of player strengths and weaknesses and for subsequent assessment of the success of interventions (Müller *et al.*, 2000; Winter *et al.*, 2007).

Match analysis studies have modelled tactical approaches common to elite-standard players that can discriminate between standards of play (Hughes and Robertson, 1998). Moreover, it has been reported that a player's tactical profile can be used to predict success in future matches within a tournament (McGarry and Franks, 1995). Differences in movement patterns and the tactical use of the T area have also been found to discriminate winning and losing players (Hughes and Franks, 1994; Vučković *et al.*, 2004). Less in known about the physiological and skill factors that discriminate squash ability. This might be, in part be attributable to the lack of specific test procedures to assess players of different standards on factors important for performance. The need for sport-specific procedures has been acknowledged and two studies have validated squash-specific tests of endurance capability where test performance correlated with player rank (Steininger and Wodick, 1987; Girard *et al.*, 2005). However, both test procedures are complex and require specialist equipment and computer software. The validity and reproducibility of a simpler procedure has been reported in Chapters four and five. Chapters six and seven also report the validity and reproducibility of squash-specific tests of change-of-direction speed and multiple-sprint capability, both important fitness factors for squash performance (Eubank and Messenger, 2000; Vučković *et al.*, 2004).

It has been acknowledged that success in squash is determined by a multitude of factors including various aspects of fitness, technique and tactics (Sharp, 1998; Lees, 2003). Sport-specific procedures are now available that can quantify player capabilities in these characteristics. However, it is unclear which of these factors best relate to performance or which fitness components relate to squash-specific multiple-sprint ability. Accordingly, the purpose of this study was twofold: 1) to examine relationships between player rank and performance on a battery of squash-specific tests of racket accuracy and fitness and 2) to investigate fitness components associated with squash-specific multiple-sprint capability.

8.1 Method

8.1.1 Participants

With institutional ethics approval eighteen male squash players (mean ± SD age 32 ± 12 years; stature 1.79 ± 0.05 m; body mass 77 ± 10 kg) who were fully habituated to procedures (see Chapter three) participated. Participants were all regular competitors in the Northumberland regional squash leagues. Playing standard ranged from premier to third division with all participants having at least two years' experience at their present level. Pre-test preparation was as previously described in Chapter three.

8.1.2 Experimental Design and procedures

Following a standardised warm-up, participants completed squash-specific tests of shot accuracy, $\dot{V}O_{2max}$ (from a squash-specific incremental test using squash movements and breath-by-breath determination of $\dot{V}O_2$), endurance capability (performance time on the squash-specific incremental test), change-of-direction speed and multiple-sprint ability. Tests sessions were performed in a randomised manner at the same time of day, in the same footwear and clothing and under similar environmental conditions. Detailed descriptions of these procedures are given in Chapter three.

8.1.3 Ranking of players

Two England Squash qualified coaches independently ranked the squash players using knowledge of the players and recent performances in local leagues.

8.1.4 Statistical analysis

Data were analysed using SPSS® v 15 (SPSS Inc., Chicago, IL) statistical software package. Following verification of underlying assumptions such as normality and homogeneity of variance, relationships between test scores, player rank and multiple-sprint ability were examined using Spearman's rho and Pearson's correlations respectively. Statistical significance was accepted at $P \leq 0.05$.

8.2 Results

8.2.1 Correlations between test scores and player rank.

Player rank was negatively correlated with endurance capability (time to fatigue) on the squash-specific incremental test ($\rho = -0.71$, $P = 0.007$) and positively related with squash-specific multiple-sprint capability ($\rho = 0.82$, $P = 0.001$). Squash-specific change-of-direction speed ($\rho = 0.54$, $P = 0.06$), $\dot{V}O_{2max}$ ($\rho = -0.41$, $P = 0.17$) and shot accuracy ($\rho = -0.48$, $P = 0.09$) did not correlate with rank.

8.2.2 Correlations between fitness tests and multiple-sprint ability.

Squash-specific $\dot{V}O_{2max}$ ($r = -0.57$, $P = 0.04$), endurance capability ($r = -0.63$, $P = 0.02$) and change-of-direction speed ($r = 0.84$, $p < 0.01$) correlated with squash-specific multiple-sprint ability.

8.3 Discussion

The purpose of the study was to examine relationships between player rank and performance on a battery of squash-specific tests of racket accuracy and fitness and to investigate fitness components associated with squash-specific multiple-sprint capability.

Squash-specific endurance and multiple-sprint capability were related to player rank. There were moderate but non-significant correlations between rank, $\dot{V}O_{2max}$, change-of-direction speed and shot accuracy. The relationship between squash-specific endurance capability and player rank supports the findings of Steininger and Wodick (1987) who reported a strong correlation ($r = 0.9$, $P < 0.05$) between player rank and ranked performance on a squash-specific incremental test in national standard players. It is also in agreement with Girard *et al.* (2005) who showed player rank to be correlated with performance time on their incremental, squash-specific test ($r = -0.96$, $P < 0.01$) in players ranked in the world top fifty. The strength of the correlations in the previous studies in comparison to the findings of this study might reflect the greater importance of endurance capability for performance at national and international standard.

The association between player rank and multiple-sprint ability is not a surprising one as repeated sprinting is characteristic of match play and underpins the ability to reach the ball and therefore make use of the technical and tactical skills at the player's disposal (Vučković *et al.*, 2004). Although there are no previous studies of this relationship in squash, multiple-sprint ability has been shown to discriminate performance standard in hockey, a sport that shares the multiple-sprint characteristics of squash (Boddington *et al.*, 2004).

The lack of relationship between $\dot{V}O_{2max}$ and rank suggests that it is not the rate of energy supply that is of importance as much as how that energy is converted to movement about the court, highlighting the possible role of economy in squash movement. Similarly, the lack of correlation between change-of-direction speed and player rank suggests that change-of-direction speed is not as important to performance as the ability to repeat changes-of-direction at speed after short recoveries. Change-of-direction speed was, however, associated with multiple-sprint ability and is probably an important component of such ability. The correlation of $\dot{V}O_{2max}$ and endurance capacity with multiple-sprint ability supports what is known about the energetics of multiple-sprint exercise, in particular the contribution of aerobic metabolism to resynthesis of phosphocreatine and replenishment of glycolytic substrates during recoveries between sprints (Glaister, 2005).

Lees (2003) acknowledges that success in squash is a combination of technical, tactical and fitness factors. As such it is reasonable to expect a correlation between a test of racket skill and player rank. In this study, the relationship between a test of ball-striking accuracy and rank was weak (*P* = 0.09). This might be because of the validity and or reproducibility of the racket accuracy test. Neither of these issues were addressed in this study.

In summary, player rank (a proxy for performance ability) was related to endurance in an incremental test using squash-specific movements and to multiple-sprint ability also assessed in a test using squash-specific movements in sub-elite squash players up to county standard. The results suggest that the squash-specific incremental and multiple-sprint ability tests could be used as indicators of playing ability. Further research is required to explore this ability of these tests to discriminate ability in elite players, female players and juniors.

8.4 Conclusion

Squash-specific endurance and multiple-sprint capability were related to player rank. There were no correlations between rank, $\dot{V}O_{2max}$, change-of-direction speed and shot accuracy. Multiple-sprint ability was associated with change-of-direction speed, $\dot{V}O_{2max}$ and endurance capacity. The results suggest that both endurance capability and multiple-sprint ability are important for success in squash. Future studies should address these relationships in players of elite standard and in female and junior players.

9 INDICATORS OF MULTIPLE-SPRINT ABILITY AND PERFORMANCE IN ELITE SQUASH PLAYERS

The previous chapter examined the elements of fitness that discriminated ability in sub-elite squash players. Success in squash at elite standard requires high levels of technical, tactical and motor skills (Lees, 2003) and challenges a number of aspects of fitness (Sharp, 1998). The challenge for scientists and coaches aiming to improve performance is to identify those factors that determine performance which might well be different at elite rather than sub-elite standard.

Previous studies have profiled the endurance fitness of elite-standard players using squash-specific procedures and found endurance capability to discriminate playing ability (Steininger and Wodick, 1987; Girard *et al.*, 2005). However, recent changes to the dimensions of the court and the scoring system for professional competitions have altered the physiological demands of match play with data showing increased contributions from glycolysis (Girard *et al.*, 2007). As such, aspects of fitness other than endurance capability might be of greater importance to performance in elite match play under the new rules. The rule changes described have not been applied to sub-elite competition and it is notable that the findings of the previous chapter support those of Steininger and Wodick (1987) and Girard *et al* (2005) showing that endurance capability discriminated playing ability. The study described in Chapter nine also profiled the high-intensity exercise capabilities of sub-elite players using squash-specific procedures and found that multiple-sprint ability discriminated playing ability in addition to endurance capability. Currently however, there are no published investigations profiling the high-intensity exercise capabilities of elite squash players using sport-specific procedures.

In summary, it is acknowledged that elite squash performance is a combination of tactical, technical and fitness factors (Lees, 2003; Sharp, 1998). Tactical determinants of success and the importance of endurance fitness have been explored. However, in the light of altered game demands resulting from rule changes and in the absence of specific tests of high-intensity exercise capabilities, it is not known what elements of fitness discriminate performance in elite squash players, or which factors are related to multiple-sprint capability. Accordingly, the purpose of this study was threefold and to investigate: 1) differences in performance on a battery of fitness tests between elite squash players on different tiers of a national performance program; 2) relationships between test scores and player rank in elite squash players; and 3) fitness factors that relate to squash-specific multiple-sprint ability in elite squash players. It is hypothesised that fitness scores will increase with performance programme tier, that measures of high-intensity exercise capability will correlate most with player rank, reflecting the recent increase in the intensity of elite match play and that high-intensity exercise capability will correlate better with multiple-sprint ability than endurance fitness.

9.1 Methods

9.1.1 Participants

With institutional ethics approval, thirty one (twenty men, eleven women) squash players from the England Squash performance program participated. The performance programme comprises three tiers: 1) Senior squad players are established full-time professionals competing on the Professional Squash Association world tour and are in the highest funding bracket (n = 12, 5 women and 7 men, mean ± SD body mass was 62.5 ± 3.1 kg for women and 79.5 ± 6 kg for men); 2) Transition squad players are new full-time professionals on the world tour and receive reduced and variable funding (n = 7, 3 women and 4 men, mean ± SD body mass was 58.4 ± 1.7 kg for women and 69.9 ±

2.8 kg for men); 3) Talented Athlete Scholarship Scheme (TASS) players are full-time university students who play part-time on the Professional Squash Association tour and have been identified as having world class potential. They receive limited funding towards the costs of training, physiotherapy support and travel to competitions (n = 12, 3 females and 9 males, mean ± SD body mass 66.2 ± 9.1 kg for females and 69.5 ± 6.8 kg for males). Among the men, world rank ranged from 3 to 364 with six of the seven senior players falling in the top thirty. Women world ranks ranged from 6 to 241. All senior women players were ranked in the world top thirty at the time of testing.

9.1.2 Experimental design

Testing of transitional and TASS players took place on separate days at the National Squash Centre, Manchester as part of the England Squash annual summer training camps. Senior squad players were tested on one day at Lilleshall National Sports Centre because the National Squash Centre facilities were not available at the time of testing. Following individual warm-ups comprising jogging, side-stepping, controlled lunging and dynamic stretching, participants completed a battery of tests to assess high-intensity exercise capabilities and endurance fitness. Timing of tests was similar for all tiers. Because of time constraints (two hours were allocated for fitness testing on one day of two-day training camps), all tests were conducted in one test session and in a fixed order. An England Institute of Sport strength and conditioning coach working with the squash performance program assisted in the testing of the transition and TASS players and at the request of the national coaches, conducted all tests on the senior squads.

9.1.3 Experimental procedures

In one test session, participants completed counter-movement and drop jump tests, squash-specific tests of change-of-direction speed and multiple-sprint ability and a general field test of endurance fitness (multi-stage fitness test). Reactive strength index was calculated from the drop jump test. Short recovery intervals were allowed between each procedure and all participants walked and jogged through the course of the squash-specific tests to habituate themselves with the route of completion prior to data collection. Procedures for each test are described in Chapter three except that wireless electronic timing gates were used to record performance time in the squash-specific tests (Brower wireless sprint system, Brower Timing Systems, Utah, USA). Drop jump and counter-movement tests took place on a portable force platform, squash-specific tests were administered on a marked-out squash court and the endurance fitness test took place in a non-slip sports hall.

Because of a technical fault with electronic timing gates, hand-timing was used for four of the transition players on the squash-specific tests. In subsequent test sessions with other participants, discrepancies between hand-timing and timing gate recordings were noted and found to be negligible (Typical error 0.4 s, 0.9%).

9.1.4 Ranking of squash players

World rank at the time of testing was obtained from the Professional Squash Association website for all senior and transition players. As not all TASS players had a world rank, their national rank at the time of testing was obtained from the England Squash website. Where TASS players did have a world rank, it was also recorded.

9.1.5 Statistical analysis

Data were analysed using SPSS® v 15 (SPSS Inc., Chicago, IL) statistical software package. Following verification of underlying assumptions such as normality and homogeneity of variance (using the < threefold difference rule) (van Belle, 2002), two-way fully between-groups ANOVA's were used to compare senior, transition and TASS players by sex on all outcome measures. Where main effects occurred, post-hoc pairwise comparisons (Least Significantly Different) were used to identify differences. Pearson's correlation examined relationships between test scores and multiple-sprint ability and Spearman's rho correlated test scores with player rank in men and women separately. Statistical significance was accepted at $P \leq 0.05$.

9.2 Results

9.2.1 Counter-movement jump

There was no difference in counter-movement jump performance between the tiers of the performance programme ($F_2 = 2.68$, $P = 0.08$) and no interaction effect ($F_2 = 1.86$, $P = 0.18$). Men outperformed women on the counter-movement jump test ($F_1 = 51.76$, $P < 0.01$). Sex-based differences in counter-movement jump performance at each tier of performance are shown in Figure 19.

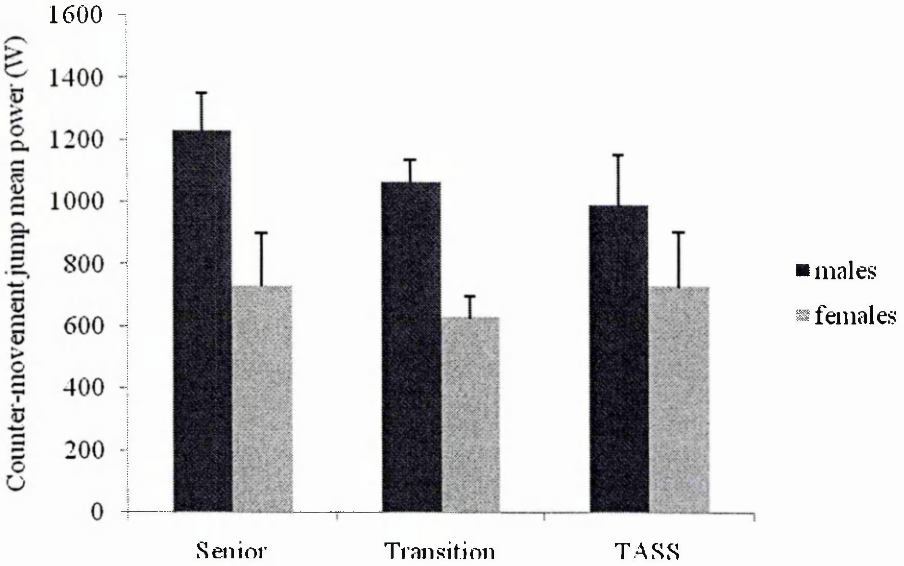

Figure 19. Mean power output from a counter-movement jump test in men (n = 20) and women (n = 11) squash players from three tiers of the England Squash performance programme. Bars are mean and SD.

9.2.2 Drop jump

Drop-jump performance differed between the senior, transition and TASS players ($F_2 = 5.35$, $P = 0.01$). Post-hoc tests showed that senior and transition players produced higher power than TASS players ($P < 0.01$, and $P = 0.03$ respectively). Men produced higher power in the drop jump than women ($F_1 = 21.72$, $P < 0.01$) in all performance tiers as indicated by the lack of interaction between sex and performance tier ($F_2 = 0.44$, $P = 0.65$). The results are shown in Figure 20.

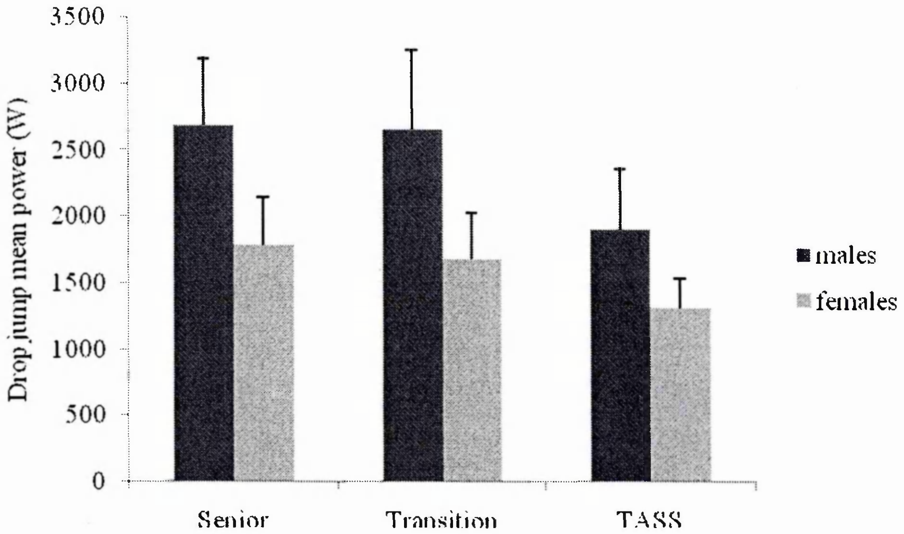

Figure 20. Mean power output from a drop jump test in men (n = 20) and women (n = 11) elite squash players on different levels of the England Squash performance programme. Bars are mean and SD.

9.2.3 Reactive strength index

Reactivity different across the performance tiers ($F_2 = 5.23$, $P = 0.01$) with senior and transition players having greater reactivity than TASS players ($P = 0.01$ and $P = 0.02$ respectively). Men had higher reactivity than women players ($F_1 = 5.82$, $P = 0.02$) and this was the case at all performance tiers ($F_2 = 0.02$, $P = 0.98$). Figure 21 illustrates these differences.

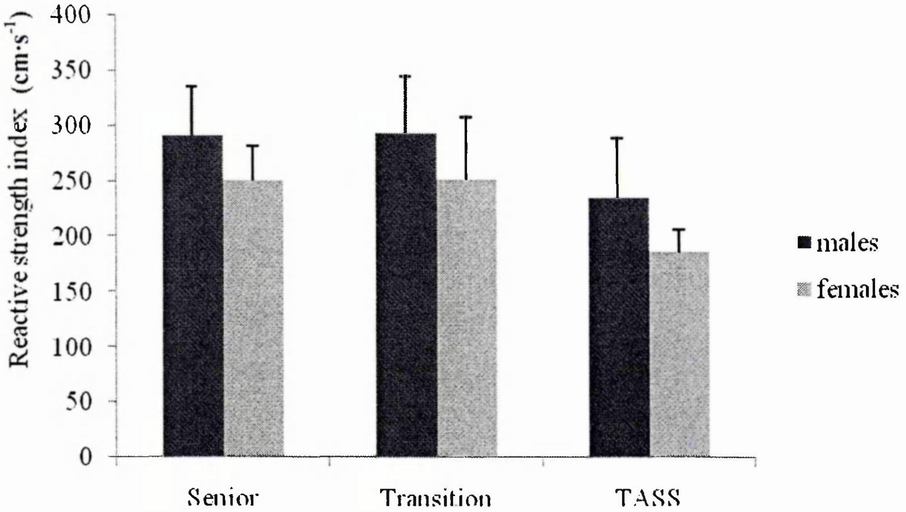

Figure 21. Differences in reactive strength index between men (n = 20) and women (n = 11) squash players from three tiers of the England Squash elite performance programme. Bars are mean and SD.

9.2.4 Squash-specific change-of-direction speed

There was a performance tier difference in change-of-direction speed ($F_2 = 7.34$, $P < 0.01$) with senior players being faster than TASS players ($P < 0.01$). Men were faster than women ($F_1 = 4.79$, $P = 0.04$) at all performance tiers ($F_2 = 1.71$, $P = 0.20$). The magnitude of differences are shown in Figure 22.

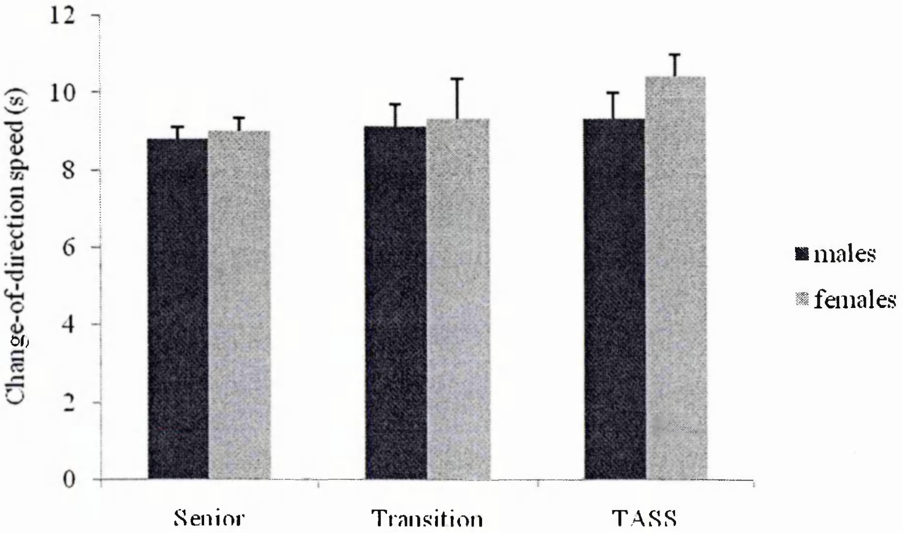

Figure 22. Change-of-direction speed on a squash-specific test in elite men and women squash player (n = 20 and 11 respectively) from the three tier England Squash performance programme. Bars are mean and SD.

9.2.5 Squash-specific multiple-sprint ability

Findings are illustrated in Figure 23. Multiple-sprint ability (sum of ten sprint efforts) differed between performance tiers ($F_2 = 9.60$, $P < 0.01$) with senior players outperforming both transition ($P < 0.01$) and TASS players ($P < 0.01$). Men had better multiple-sprint ability than women ($F_1 = 15.50$, $P < 0.01$) and this was the case at all tiers of the performance programme ($F_2 = 1.35$, $P = 0.28$).

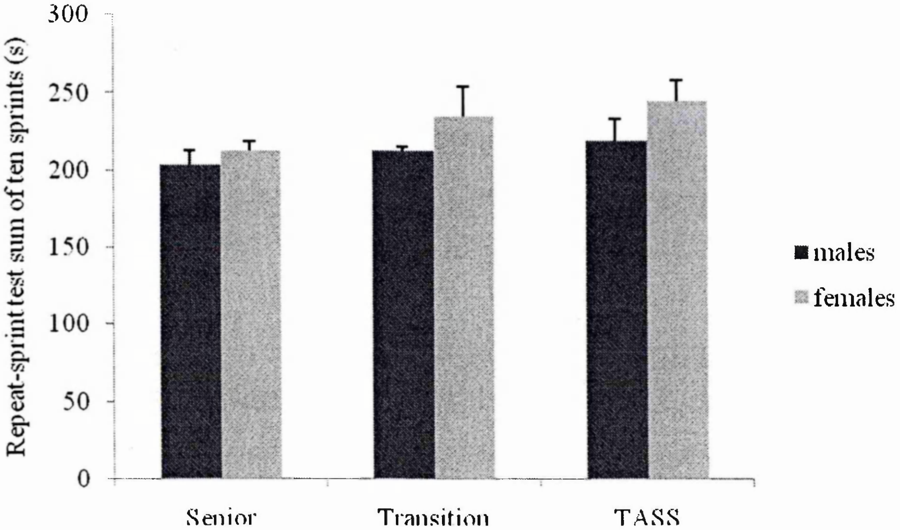

Figure 23. Sum of performance time from ten sprints on a squash-specific multiple-sprint test in men (n = 18) and women (n = 10) players from the three-tier England Squash elite performance programme. Bars are mean and SD.

9.2.6 Fastest repetition from the multiple-sprint test

Fastest repetition time differed between the performance tiers ($F_2 = 9.99$, $P < 0.01$) with senior players outperforming both transition ($P = 0.04$) and TASS players ($P = 0.01$). Men were faster than women ($F_1 = 14.87$, $P < 0.01$) at all performance tiers ($F_2 = 1.21$, $P = 0.31$). Differences are shown in Figure 24.

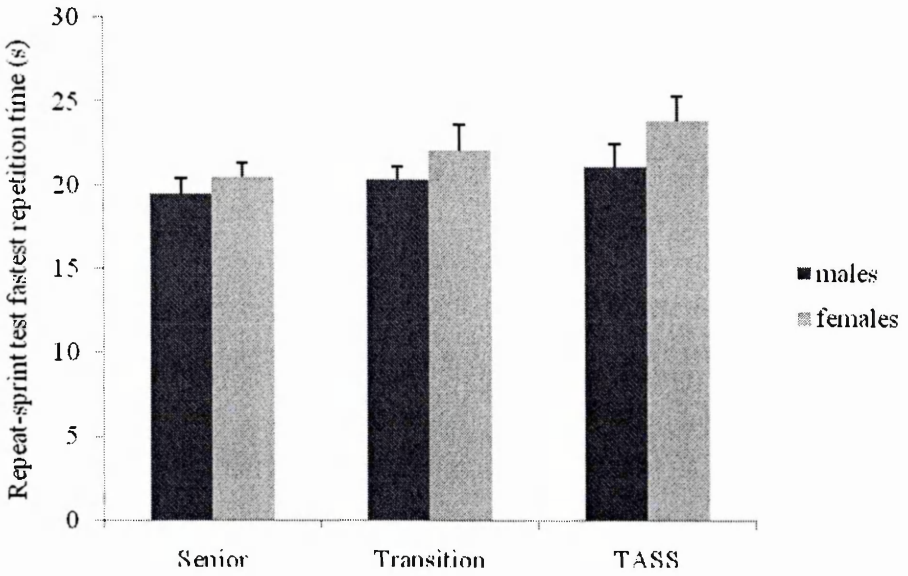

Figure 24. Performance time of the fastest repetition from a squash-specific multiple-sprint test in men (n = 18) and women (n = 10) elite squash players from three tiers of the England Squash performance programme. Bars are mean and SD.

9.2.7 Endurance fitness

Endurance fitness (estimated $\dot{V}O_{2max}$ from the Multi-stage Fitness test) did not differ between the performance tiers ($F_2 = 1.80$, $P = 0.19$). However, there was a sex-based difference with males achieving higher scores than females ($F_1 = 26.4$, $P < 0.01$). The findings are illustrated in Figure 25.

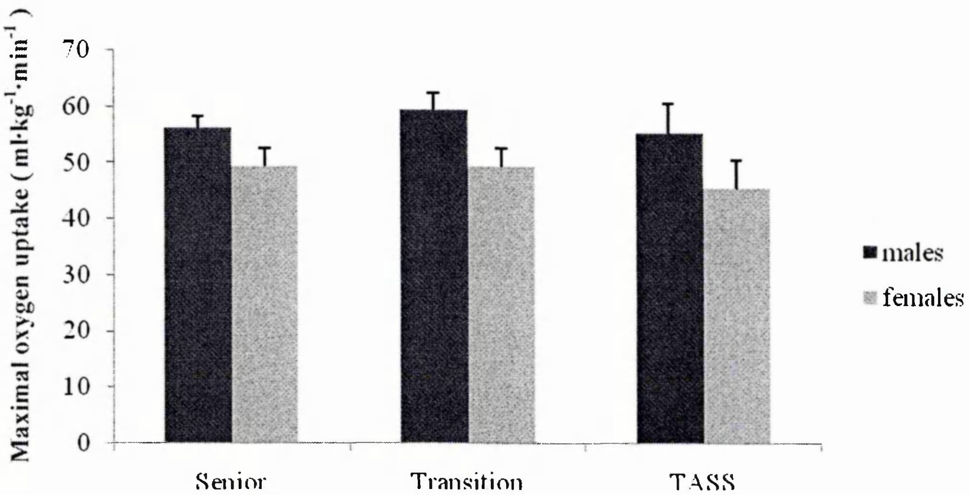

Figure 25. Estimated $\dot{V}O_{2max}$ in elite men (n = 15) and women (n = 11) squash players on the England Squash performance programme. Bars are mean and SD.

9.2.8 Correlations between test scores and player rank

In men, counter-movement jump power ($\rho = -0.78$, $P < 0.01$, n =14), change-of-direction speed ($\rho = 0.59$, $P = 0.02$, n = 14) multiple-sprint ability ($\rho = 0.78$, $P < 0.01$, n = 13) and fastest sprint from the squash-specific multiple-sprint test ($\rho = 0.86$, $P < 0.01$, n = 13) correlated with world rank. Drop jump power ($\rho = -0.48$, $P = 0.07$, n = 14), reactive strength index ($\rho = -0.32$, $P = 0.26$, n = 14) and estimated $\dot{V}O_{2max}$ ($\rho = 0.01$, $P = 0.97$, n = 10) did not correlate with world rank.

In women, only fastest repetition from the multiple-sprint test correlated with world rank ($\rho = 0.65$, $P = 0.04$, n = 10). Multiple-sprint ability was moderately correlated and close to significant ($\rho = 0.61$, $P = 0.06$, n = 10), but world rank relationships with counter-movement ($\rho = -0.04$, $P = 0.89$) and drop jump power ($\rho = -0.28$, $P = 0.39$), reactive strength index ($\rho = -0.25$, $P = 0.45$), change-of-direction speed ($\rho = 0.39$, $P = 0.23$) and estimated $\dot{V}O_{2max}$ ($\rho = -0.26$, $P = 0.43$) were weak (n = 11 for all variables).

9.2.9 Correlates of multiple-sprint ability

Correlations between performance on the battery of fitness tests for male and female players are shown in Tables 11 and 12 respectively.

Table 11. Pearson's correlations between multiple-sprint ability and other fitness scores in elite men squash players.

		1	2	3	4	5	6	7
1	Multiple-sprint ability	–	0.90 N = 13 $P < 0.01$	0.96 N = 13 $P < 0.01$	-0.71 N = 13 $P < 0.01$	-0.37 N = 13 $P = 0.21$	-0.74 N = 13 $P < 0.01$	-0.44 N = 9 $P = 0.24$
2	Change-of-direction speed		–	0.86 N = 13 $P < 0.01$	-0.61 N = 14 $P = 0.02$	-0.27 N = 14 $P = 0.35$	-0.62 N = 14 $P = 0.02$	0.17 N = 10 $P = 0.64$
3	Best sprint of multiple-sprint test			–	-0.66 N = 13 $P = 0.01$	-0.48 N = 13 $P = 0.10$	-0.68 N = 13 $P = 0.01$	-0.25 N = 9 $P = 0.52$
4	Reactive Strength Index				–	0.09 N = 14 $P = 0.75$	0.98 N = 14 $P < 0.01$	0.28 N = 10 $P = 0.44$
5	Counter-movement jump					–	0.17 N = 14 $P = 0.55$	-0.34 N = 10 $P = 0.33$
6	Drop jump						–	0.35 N = 10 $P = 0.32$
7	Maximal oxygen uptake							–

Table 12. Pearson's correlations between multiple-sprint ability and other fitness scores in elite women squash players.

		1	2	3	4	5	6	7
1	**Multiple-sprint ability**	–	0.84 N = 10 *P* < 0.01	0.96 N = 10 *P* < 0.01	-0.10 N = 10 *P* = 0.78	-0.07 N = 10 *P* = 0.84	-0.13 N = 10 *P* = 0.73	-0.53 N = 11 *P* = 0.12
2	Change-of-direction speed		–	0.81 N = 10 *P* < 0.01	-0.40 N = 11 *P* = 0.22	-0.08 N = 11 *P* = 0.82	-0.42 N = 11 *P* = 0.20	-0.59 N = 11 *P* = 0.052
3	**Best sprint of multiple-sprint test**			–	-0.14 N = 10 *P* = 0.70	< 0.01 N = 10 *P* = 0.99	-0.11 N = 10 *P* = 0.76	-0.60 N = 10 *P* = 0.07
4	Reactive Strength Index				–	-0.46 N = 11 *P* = 0.89	0.89 N = 11 *P* < 0.01	-0.13 N = 11 *P* = 0.70
5	**Counter-movement jump**					–	0.38 N = 11 *P* = 0.25	0.06 N = 11 *P* = 0.87
6	Drop jump						–	-0.06 N = 11 *P* = 0.85
7	**Maximal oxygen uptake**							–

Change-of-direction speed, fastest repetition time of the multiple-sprint test, reactive strength index and drop jump power output were related to multiple-sprint ability in men. In women, multiple-sprint ability correlated with change-of-direction speed and fastest repetition time of the multiple-sprint test.

9.3 Discussion

The purpose of this study was to: 1) examine differences in performance on a battery of fitness tests between elite squash players on different tiers of a national performance program; 2) examine relationships between test scores and player rank; and 3) identify the fitness factors that relate to squash-specific multiple-sprint ability.

9.3.1 Differences between senior, transition and TASS players.

There were differences in test scores across the performance program tiers, but not for all variables and not always in the pattern 'senior > transition > TASS'. Regardless of sex, senior players outperformed TASS players in all aspects of fitness except counter-movement jump power and $\dot{V}O_{2max}$ where no performance tiers differed. This was anticipated as TASS players are younger, less experienced and compete only on a part-time basis. Senior players outperformed the transition players on the test of multiple-sprint ability and had faster best repetition times from the same test. This suggests that the ability repeatedly to change-direction at speed in squash-specific movements discriminates between experienced and less experienced elite players. Given the high-intensity, intermittent nature of movements in match play (Eubank and Messenger, 2000; Vučković *et al.*, 2004), this is not surprising.

Transition players outperformed TASS players on measures of drop jump mean power and reactive strength index (calculated from drop jump height and ground contact time). Both procedures assess the ability to make fast and explosive counter-movements and are theoretically linked to the ability to perform fast stretch-shortening cycle actions (Young, 1995). The absence of differences between senior and transition players on these measures suggests that the ability to perform fast and explosive counter-movements is characteristic of more experienced elite players.

Counter-movement jump performance and $\dot{V}O_{2max}$ did not differ between the performance tiers. Young (1995) suggested that counter-movement jump tests assess the ability to perform slow stretch-shortening cycle actions (> 500 ms) and that this might not be important in sports where explosive counter-movements occur over shorter durations. The similarity of $\dot{V}O_{2max}$ across the performance program suggest that it is not an important discriminator within elite players, however given the demands of match play, it is likely a physiological factor that must be present at some threshold level to be able to compete at this standard in the professional game (Brown *et al.*, 1998).

There were sex-based differences on all tests with males outperforming female players at all levels of the performance program. With the exception of $\dot{V}O_{2max}$, there are no normative data for comparison. The mean $\dot{V}O_{2max}$ of the male players (56.2 ± 2.1; 59.4 ± 2.8; 55.2 ± 5.3 $ml \cdot kg^{-1} \cdot min^{-1}$ in elite senior, transition and TASS players respectively) approximated values reported in previous studies using direct measurements of $\dot{V}O_2$ during incremental treadmill testing (Steininger and Wodick, 1987; Gillam *et al.*, 1990; Girard *et al.*, 2005), but were lower than values reported in studies using the multi-stage fitness test (60.4 ± 4.1 $ml \cdot kg^{-1} \cdot min^{-1}$) and an on-court, squash-specific test (63.6 ± 3.0 $ml \cdot kg^{-1} \cdot min^{-1}$) in elite players (St Clair Gibson *et al.*, 1998; Girard *et al.*, 2005). Only one previous study reported mean $\dot{V}O_{2max}$ of elite female players (Gillam *et al.*, 1990) and it was higher (53.8 $ml \cdot kg^{-1} \cdot min^{-1}$) than recorded from any of the players in this study (49.2 ± 3.1; 49.3 ± 3.3; 45.5 ± 5.0 $ml \cdot kg^{-1} \cdot min^{-1}$ in senior, transition and TASS players respectively). However, comparisons with previous studies for both male and female players should be interpreted with caution as this test was the last in a battery conducted in a single session and was preceded by high-intensity exercise tests that could have resulted in fatigue. Moreover, differences in protocol have been shown to influence $\dot{V}O_{2max}$ results (St Clair Gibson *et al.*, 1998; Steininger and Wodick, 1987; Girard *et al.*, 2005).

9.3.2 Correlations between fitness tests and world rank

As men and women players compete on different professional circuits with separate ranking systems, relationships between test performance and ranks were examined for each sex separately. It was hypothesised that tests of high-intensity exercise capabilities would better discriminate ability in elite players than aerobic fitness. In men, world rank correlated with multiple-sprint ability, fastest sprint from the multiple-sprint test, change-of-direction speed and counter-movement jump power. There was no correlation between rank and $\dot{V}O_{2max}$ ($\rho = 0.01$, $P = 0.97$). In women, world rank correlated only with fastest sprint from the multiple-sprint test, though multiple-sprint ability was moderately correlated and close to significant ($P = 0.06$). As with men players, $\dot{V}O_{2max}$ did not correlate with rank. The poor correlation between aerobic fitness and player rank is in contrast to previous studies of elite players (Steininger and Wodick, 1987; Girard *et al.*, 2005) though it should be noted that both investigations used squash-specific protocols, and Girard *et al.* (2005) reported that player rank did not correlate with aerobic fitness assessed on a treadmill in the same group of players. These findings suggest that the use of sport-specific procedures is necessary to examine the importance of aerobic fitness for elite squash players. In summary, the correlation analysis suggests that high-intensity exercise capabilities (in particular the ability to sustain changes-of-direction at speed) are more important than endurance capability for success in elite squash although endurance is still a requirement.

9.3.3 Indicators of multiple-sprint ability.

Change-of-direction speed and fastest sprint from the multiple-sprint test correlated strongly with multiple-sprint ability in men and women players. A single repetition of the multiple-sprint test comprised two laps of the test course used to assess change-of-direction speed. Correlations between fastest repetition from the multiple-sprint test and multiple-sprint ability were higher than those with change-of-direction speed for both sexes. The mean duration of the fastest repetition for the multiple-sprint test (20.41 ± 1.26 s in men; 21.64 ± 1.72 s in women) approximated the mean duration of rallies from match play (≈ 19-21 s) reported in recent match analysis studies (Hughes and Robertson, 1998; Vučković *et al.*, 2004; Girard *et al.*, 2007). In contrast, the mean performance time on the squash-specific change-of-direction speed test was much shorter than mean rally durations from match play (9.12 ± 0.59 s in men, 9.49 ± 0.84 s in women). The similarity of performance time with mean rally duration might explain the stronger correlation with multiple-sprint ability and might also explain why this measure correlated well with player rank in men and women.

In men, multiple-sprint ability also correlated (moderately) with mean power from a drop jump, and with reactive strength index. Both measures are associated with the quick reversal of a lengthening muscle action into a shortening action and are likely related to the change-of-direction-speed aspect of multiple-sprint ability, indicated by the relationship between these variables (Table 14).

9.4 Conclusion

Squash-specific change-of-direction speed, measures from a squash-specific multiple-sprint test, drop jump power and reactive strength index discriminated full-time and part-time elite squash players. Multiple-sprint ability and fastest sprint from a squash-specific multiple-sprint test discriminated experienced and less experienced full-time elite players. In elite men, counter-movement jump power, change-of-direction speed, multiple-sprint ability and best repetition in the multiple-sprint test correlated with world rank, whereas only best repetition from the multiple-sprint test correlated with world rank in elite women. Endurance capability did not discriminate ability in elite men or women. Multiple-sprint ability was related to change-of-direction speed and best repeat-sprint-test repetition in men and women and also to drop jump power and reactive strength index in men. The results confirm that high-intensity, variable-direction exercise capabilities are important for success in elite squash.

10 GENERAL DISCUSSION

The aim of the thesis was to: 1) develop and validate squash-specific procedures to examine aspects of fitness in squash players and 2) apply these tests to examine indicators of performance and multiple-sprint ability in sub-elite and elite-standard squash players. The thesis was successful in achieving these aims.

10.1 Development and validation of squash-specific fitness tests

Section 2.4 in Chapter three discusses criteria that are used to judge the validity of field-based exercise tests. These criteria were applied in Chapters four to seven to assess the validity of squash-specific procedures.

The aim of study one (Chapter four) was to validate a squash-specific test of endurance capability and $\dot{V}O_{2max}$. Trained squash players achieved higher $\dot{V}O_{2max}$ scores on the squash-specific test than on a laboratory treadmill test whilst satisfying criteria for attainment of $\dot{V}O_{2max}$ to the same extent in both tests. Moreover, $\dot{V}O_{2max}$ scores were highly correlated between the lab specific and non-specific tests showing they assessed the same aspect of fitness. Because of the nature of the game, aerobic fitness (with $\dot{V}O_{2max}$ as a contributory factor) is an attribute for attainment of elite standard performance (Brown *et al.*, 1998; Chin *et al.*, 1995; Girard *et al.*, 2005; Girard *et al.*, 2007). As such the squash-specific test possesses logical validity. Furthermore, the test discriminated endurance performance between squash players and trained distance runners with similar test-specific $\dot{V}O_{2max}$ supporting the specificity of $\dot{V}O_{2max}$ (St Clair Gibson *et al.*, 1998; Girard *et al.*, 2005) and confirming the construct validity of the squash-specific test.

An essential quality of a valid test is reproducibility of measures. Study two (Chapter five) examined this quality in the squash-specific test of endurance fitness. Test-retest reproducibility of endurance performance, $\dot{V}O_{2max}$, maximum heart rate and steady state oxygen consumption were found to possess good reproducibility, though the magnitude of variation differed depending on the metric used.

Studies three and four (Chapters six and seven) assessed the validity and reproducibility of squash-specific tests of change-of-direction speed and multiple-sprint ability. Both studies showed the squash-specific tests discriminated performance within a group of trained county-standard squash players when equivalent non-specific tests could not. Moreover, the squash players outperformed trained footballers of equivalent competitive standard on the squash-specific but not the non-specific tests. The ability of the squash-specific procedures to discriminate performers of multiple-sprint sports demonstrates the specificity of movement patterns used in the squash-specific tests and highlights specific nature of change-of-direction speed and multiple-sprint ability (Young *et al.*, 1996; Young *et al.*, 2001). Both tests demonstrated low test-retest variability.

10.2 Indicators of performance and multiple-sprint ability in sub-elite and elite squash players.

Study five (Chapter eight) examined relationships between player rank and performance on the squash-specific fitness tests validated in studies one to four and also between these tests and repeat-sprint-test performance in male squash players competing in regional leagues from division three to premier. Multiple-sprint ability and endurance capability discriminated performance, with multiple-sprint ability being related to change-of-direction-speed, $\dot{V}O_{2max}$ and endurance capability. In world-ranked men and women (study six, Chapter nine), measures associated with the ability to perform and sustain rapid changes-of-direction were related to multiple-sprint ability, with the same measures and multiple-sprint ability discriminating performance. Aerobic fitness was not related to performance or to multiple-sprint ability in elite players. Senior elite players performed better than part-time, younger elites (TASS players) on all aspects of fitness except $\dot{V}O_{2max}$ and counter-movement jump power. Drop-jump power and reactive strength discriminated senior and transition level from TASS players, and indices from the multiple-sprint test discriminated senior, experienced players from transition and TASS players. The findings suggest that multiple-sprint ability is an essential attribute for squash players (in-keeping with the nature of match play). The difference in importance of aerobic fitness could be explained by the difference in variability of this factor within sub-elite and elite players. The aerobic demand of elite play is known to be high (Girard *et al.*, 2007), but if players possess similar and adequate capabilities, correlations will be poor (Sale, 1990). It should be noted however that aerobic capability of sub-elite players was assessed using the squash-specific procedure whereas a field-based shuttle run test was used with the elites. The sport-specific test might have discriminated elite players better as previous studies suggest (Girard *et al.*, 2005).

In summary, this thesis has developed and validated squash-specific tests of endurance and high-intensity exercise capabilities that have been used to determine the aspects of fitness important for multiple-sprint ability and performance in sub-elite and elite squash players.

11 SUMMARY AND CONCLUSIONS

11.1 Summary of findings

This thesis has found that:

1. A squash-specific test of aerobic fitness elicited higher $\dot{V}O_{2max}$ scores in squash players than an incremental treadmill test demonstrating the specificity of $\dot{V}O_{2max}$.
2. Endurance capability on a squash-specific test of aerobic fitness discriminated trained squash players and trained distance runners with similar test-specific $\dot{V}O_{2max}$.
3. Physiological and performance measures from a squash-specific test of aerobic fitness were reproducible in county-standard players.
4. Squash-specific tests of change-of-direction-speed and multiple-sprint ability discriminated between county-standard squash players and non-squash playing multiple-sprint sport performers (footballers) of equivalent standard, with similar non-sport-specific capabilities.
5. Squash-specific tests of change-of-direction-speed and multiple-sprint ability discriminated ability in county-standard squash players where equivalent non-specific tests did not.
6. In sub-elite squash players, multiple-sprint ability and endurance capability in squash-specific tests discriminated performance and squash-specific change-of-direction-speed, $\dot{V}O_{2max}$ and endurance capability correlated with multiple-sprint ability.
7. In elite squash players, squash-specific multiple-sprint ability indices, change-of-direction-speed and mean power during a counter-movement jump correlated with performance in men and fastest repetition time from a multiple-sprint test discriminated performance in women.

8. Best sprint time from a squash-specific multiple-sprint test and change-of-direction speed correlated with multiple-sprint ability in elite men and women, with drop jump power and reactive strength index also related in men.

11.2 Recommendations for future research

Future studies should:

1. Assess the validity of the squash-specific tests described with juniors and with larger groups of female players.
2. Examine the reproducibility of physiological and performance measures from the squash-specific tests over longer test-retest durations that approximate the period of training interventions.
3. Examine reproducibility of the squash-specific tests in elite, junior and female players.
4. Assess the sensitivity of the squash-specific procedures for the tracking of training-induced changes in physiological responses and performance.
5. Examine the correlates of multiple-sprint ability and performance in elite and sub-elite junior players.
6. Attempt to replicate the studies examining correlates of performance and fitness with larger numbers of elite and sub-elite players to confirm the findings.
7. Examine the relationship between performance, multiple-sprint ability and $\dot{V}O_{2max}$ measured with a squash-specific test in elite players.

11.3 Conclusions

The results of this thesis suggest that squash-specific tests discriminate ability within squash players and between squash and non-squash players better than non-specific tests. The specific nature of test performances in squash players suggests that procedures replicating the movements and physiological demands of match play are better for assessing player strengths and weaknesses than non-specific procedures. This thesis also suggests that both endurance and high-intensity exercise capabilities are important for performance in sub-elite players, while elite performance is discriminated by fitness factors related to the ability to sustain repeated changes-of-direction at speed. The importance of indices of multiple-sprint ability for elite and sub-elite players is in-keeping with the high-intensity, intermittent nature of match play.

It is hoped that the findings of this thesis will inform the practice of coaches and scientists working with squash players of all standards, not least that traditional non-specific methods of fitness assessment will be disregarded in favour of those shown to be of value in the studies reported here. It is regrettable that as our national success in squash has grown, and as the sport is aggressively lobbying for Olympic status, research interest has waned. If the output of this thesis stimulates even a small increase in interest in the assessment of fitness and determinants of performance in squash, it will have been a worthwhile venture. While this might be the case, it is appropriate to conclude with Wilkie's (1986) words of caution

"Our predecessors were not fools, and we should take satisfaction from adding a brick or two to an existing edifice, not in imagining that we built the whole thing ourselves"

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13 APPENDICES

13.1 Appendix one – Study one ethics documents and letter of approval.

CONFIDENTIAL

Sheffield Hallam University

School of Sport and Leisure Management

Research Ethics Committee

APPLICATION FOR APPROVAL OF RESEARCH

In designing research involving humans, principal investigators should be able to demonstrate a clear intention of benefit to society and the research should be based on sound principles. These criteria will be considered by the Ethics Committee before approving a project. ALL of the following details must be provided, either typewritten or word-processed preferably at least in 11 point.

Please either tick the appropriate box or provide the information required.

1. Date of Application	07.11.03

2. Anticipated Date of Completion	31.01.04

3. Title of Investigation	Validity of a squash specific movement test for measurement of physiological responses and time to fatigue.

4. Subject Area	Physiology of Exercise

5. Principal Investigator	Mick Wilkinson
Email address	
Telephone/mobile number	

6. Is this

6.1 a research project? ☐

		Unit Name	**Unit Number**
6.2 an undergraduate project?	☐		
6.3 a postgraduate project?	☒	PhD	

7. Director of Studies/ Supervisor/Tutor	Professor Edward M Winter

8. Purpose and benefit of investigation

Statement of the research problem with any necessary background information.
(No more than 1 side of A4)

Squash imposes diverse physiological demands including cardio-pulmonary endurance, muscle endurance, muscle strength, speed, and flexibility (Sharp, 1998). At elite standard, squash has been classed as a high-intensity intermittent activity with mean rally lengths of 16 s and roughly equal recovery times between rallies (Montpetit, 1990). Matches at the elite level can last up to 3 hr in which players are active for up to 67% of the time (Montpetit, 1990). This obviously places extreme demands on energy supply. Studies into heart rate responses have demonstrated that despite the intermittent nature of play, heart rate quickly reaches a steady state which is equivalent to 80-90% of predicted maximum (Blanksby et al., 1980; Docherty, 1982; Mercier et al., 1987; Brown and Winter, 1995). Measurement of oxygen uptake during competitive play has revealed mean values of approximately 60% of individual maxima (Montpetit et al., 1987). When viewed in conjunction with mean lactate levels of between 2-4 $mmol \cdot l^{-1}$ (Beauchamp and Montpetit, 1980; Noakes et al., 1982; Mercier et al., 1987) there is clear evidence that squash is a predominantly aerobic endurance based activity.

Specificity

It is well known that specific training results in physiological adaptations that are specific to the mode, type and intensity of the training stimulus. As such, the most accurate assessments of an athlete's physiological capacities will be gained from testing them as near as is practically possible in the mode of exercise in which they train. Previous studies have demonstrated that athletes trained in specific modes of exercise can produce higher $\dot{V}O_{2max}$ values when tested in this mode compared to tests performed in non-specific exercise modes (Stromme *et al.,* 1977; Hagberg *et al.,* 1978; Faulkener *et al.,* 1985).

The movement patterns involved in squash play are unique and varied. Specific training for squash involves imposing a physiological stress within the movement patterns encountered during match play. The efficacy of on-court movement training regimens has been examined and they have been found to be a good replication of game related physiological demands (Todd et al., 1995)

Research Problem

The efficacy of movement specific training for squash is beyond question, however, specificity is no less important in physiological measurement. This dictates the need for a valid and reproducible squash-specific test that can be used to assess squash-specific physiological capacities, and as a monitoring tool to detect improvements resulting from squash-specific training regimens.

Purpose of the study

The study aims to compare the physiological and performance capacities of trained squash players and trained distance runners in response to an incremental squash-specific movement test, and an incremental treadmill test. Superior performance on the squash-specific test by the trained squash players would provide evidence for the validity of the squash movement test as a means of assessing squash-specific physiological capacities.

9. Is this study

9.1 Collaborative? ☐ **If yes please include appropriate agreements in section 19**

9.2.1 Replication ☐ of

9.2.2 New ☒

10. Participants

10.1 Number	12
10.2 Rationale for this number: (eg calculations of sample size)	Sample size has been estimated from a power analysis using mean and SD values from pilot testing
10.3 Criteria for inclusion and exclusion:	The squash playing participants will be trained male squash players frequently competing in divisions 1 and 2 of Yorkshire's County leagues aged between 18-40 yrs. Selection criteria for inclusion in the studies will include similarity of age, a minimum of 5 years playing experience at the specified competitive levels, a frequency of participation of at least 3 sessions weekly, and satisfactory medical pre-screening results. Selection criteria for the male distance running participants will include similarity of age to the squash participants, at least 5 years experience of competitive distance running at county standard, a frequency of training of at least 3 sessions weekly, and a satisfactory medical pre-screening result.
10.4 Are these normally 'pre approved' within Ethics Guidelines	Yes ■ No ☐

11. Details of the design and protocol(s)

11.1 Provide details	All participants will complete an incremental test that is designed to assess maximum physiological capacity ($\dot{V}O_{2max}$), and performance time to exhaustion, using squash-specific movement patterns. This will be based on the procedure developed and used by Damon Leedale-Brown with the England squash program (personal communication). With modifications, the test will allow squash-specific movement patterns to be performed at controlled intensities whilst oxygen uptake is continuously measured using a Metamax 3B portable gas analyser. In addition, heart rate (via telemetry), and a post exercise blood lactate sample (from a finger prick) will be used as secondary criteria for verification of maximum effort in the test. The squash test movements are performed in a 'semi-random' manner, with the pattern of movement to each portion of a simulated court floor repeated nominally every minute. This element of randomness is essential to replicate specific squash demands. The test is performed in time with audio signals in the form of numbers which correspond to the four positions marked on the floor. On the audio signal, a participant must move to place one foot on the appropriate floor mark and return to a central marked position before the next audio signal. Exercise intensity is controlled by shortening the time between audio signals, thereby increasing average movement speed. Following a specific warm-up, the test will begin at the 3rd of 13 test levels with a increase in the exercise intensity (average movement speed) every minute. Participants will also complete a second incremental test to assess maximum physiological capacity ($\dot{V}O_{2max}$), and performance time to exhaustion on a motorised treadmill. Following a standardised warm-up, the participants will run at a constant speed with the treadmill gradient increasing by 1% every minute until volitional exhaustion. $\dot{V}O_2$ will be measured online and continuously during the test using the same 3B portable gas analyser used in the squash test. Termination heart rate and blood lactate will also be collected as described above. All participants will be habituated with the squash movement and treadmill test procedures, as well as the data collection methods to ensure valid data are collected. The maximal tests will be separated by at least 48 hours to ensure full recovery. Test time, footwear, and clothing will be standardised between tests. Test environment will be controlled as far as is possible.
11.2 Are these normally 'pre approved' within Ethics Guidelines	Yes ☐ No ☒

12. Indicative methods of analysis

Differences in $\dot{V}O_{2max}$ and performance time to exhaustion between the two participant groups in the two exercise tests will be examined using two factorial ANOVA with appropriate post hoc tests. Data will also be analysed using a MANOVA. Both methods will be employed due to uncertainty about the best method given the probable relationship between the dependent variables.

13. Intended duration and timing of project	Habituation sessions are planned for late December, with the exercise tests planned for early January 2004.

14. Location of project (If parts are external to SHU, provide evidence in support in section 19)	All testing will take place in the Physiology laboratory of Hull Universities Sport Science department.

15. Substances to be administered
State their potential hazards, if any, and the precautions to be taken

16. Degree of discomfort that participants might experience

There will be minimal discomfort associated with finger prick blood sampling. Participants will experience generalised discomfort associated with maximal exertion in the assessment of maximal oxygen uptake.

17. Your experience and that of those testing and your supervisor/other investigator in this type of investigation

The principal investigator has undergone BASES physiology supervised experience and is in the process of generating an accreditation portfolio for science support. This investigator also regularly takes and analyses bloods and assesses maximal oxygen uptake in a variety of protocols and exercise modes. The study supervisor is a BASES accredited exercise physiologist. The study assistant is a BSc qualified senior laboratory technician who has undergone 2 years of supervised experience in sport science support, is qualified first in aid and is also the department deputy health and safety officer. He is fully competent in the administration of maximal exercise stress tests, and is a trained venepuncturist.

17.1 Who will be present? Please indicate their skills.	Principal investigator and senior lab technician (see above for skills).

18. Signature	

19. Attachments

19.1 Risk Assessment(s)	▨
19.2 Participant Information Sheet	▨
19.3 Informed Consent Form	▨
19.4 Pre-Test Medical Questionnaire	▨
19.5 Collaboration evidence/support (see 9)	▨
19.6 Collaboration facilities (see 14)	▨

(Place a tick in the appropriate description)

Sheffield Hallam University

School of Sport and Leisure Management

Research Ethics Committee

Participant Information Sheet

Project Title	Validity of a squash specific movement test for measurement of physiological responses and performance time to fatigue.

Name of Participant	

Supervisor/Director of Studies	Professor Edward M Winter The Centre for Sport and Exercise Science Sheffield Hallam University Collegiate Hall SHEFFIELD S10 2BP

Principal Investigator	Mick Wilkinson

Purpose of Study and Brief Description of Procedures

Background to the study.
It is well known that different types of training result in different types of fitness that are specific to the type and intensity of the training performed. As such, the most accurate measurements of an athlete's fitness will be gained from testing them in the type of exercise in which they usually train.
The movement patterns involved in squash play are unique and varied. Training for squash involves imposing a physical stress using the movements encountered during match play. As squash players play and train within the unique movements of the game, any measurement of their fitness should be carried out using similar movements. Using such testing should allow any fitness gains from training and playing to be detected. This dictates the need for a squash-specific test that can be used to assess squash-specific fitness, and as a monitoring tool to detect improvements resulting from squash training.

Purpose of the study.
This study aims to compare the physical responses of trained squash players and trained distance runners to a squash-specific fitness test, and a standard treadmill running test (non squash-specific). Superior performance on the squash-specific test by the trained squash players would provide evidence for the usefulness of the squash movement test as a means of testing squash players.

Procedures.
You will be required to attend two practice sessions to experience the squash movement and treadmill running test procedures, and get used to wearing some testing equipment whilst exercising. You will then be required to attend two test sessions separated by at least 48 hours for measures of your fitness to be taken during and immediately after the squash movement test on one occasion, and the treadmill running test on the second occasion. Both tests are designed to assess your maximum physical fitness ($\dot{V}_{O_2max}$), and the time it takes before you have to stop on each test.

- On arrival, your weight and height will be measured, and you will be asked to complete a pre-test medical questionnaire to ensure you are healthy enough to carry out the testing.
- You will then be fitted with a small shoulder harness holding a portable analyser, a nose and mouth mask for collection of your expired breath during the tests, and a chest belt to record heart rate during the test.
- The squash fitness test consists of repeated movements to and from one of four numbered marks placed on the floor from a central basepoint. Any single movement to and from the base must be completed between the time of audio signals. The audio signals are numbers which correspond to the marks on the floor. The speed of movement required will increase every minute, and you must keep pace for as long as possible until you feel you cannot continue. The latter portion of the test will feel hard, however fatigue will disappear shortly after finishing.
- The treadmill test will take place on a motorised treadmill. Following a standard warm-up, you will be required to run at 13 km/h with the speed increasing every minute up to 16 km/h, then continuing to run at that speed with the treadmill slope increasing by 1% every minute until you feel you cannot continue. Again the latter test stages will feel particularly tough.
- Each test will last no more than 12-14 minutes.
- Immediately after you finish each test, a small blood sample will be collected from a finger prick by a qualified tester for measurement of chemical markers of maximum effort.
- You will be required to complete both tests at approximately the same time of day, and wearing the same footwear and type of clothing.

Your rights as a participant.
Your participation in this study is voluntary. You are free to refuse to start the testing or withdraw at any time in the proceedings without penalty or prejudice and without giving any reason for so doing. No disadvantage will arise from any decision to participate or not.
The results of the research may be published, but your name will not be used, and no individual identifying information will be provided. All data collected will be coded to retain anonymity, and any personal details will be stored in a locked filing cabinet with access limited to the investigator.
As a participant in this study you will be given confidential feedback about your test results which will be your maximal physical fitness ($\dot{V}_{O_2max}$) and time to exhaustion on each test. This information may aid you in your training.

If necessary continue overleaf

If you have any questions concerning the procedures or any other aspects of the project, feel free contact the principal investigator in person or by telephone on the number given. Some test sessions may be video taped however the video will only be used for further analysis by the investigator and study supervisors. Access to the tapes will be limited to the investigator and the study supervisor. Any further use of the video taped tests will not be undertaken without the express permission of the participant filmed who will of course remain anonymous.

interests are otherwise being ignored, neglected or denied, I should inform Professor Edward Winter, Chair of the School of Sport and Leisure Management Research Ethics Committee (Tel: 0114 225 4333) who will undertake to investigate my complaint.

Sheffield Hallam University

School of Sport and Leisure Management

Research Ethics Committee

INFORMED CONSENT FORM

TITLE OF PROJECT:
Validity of a squash specific movement test for measurement of physiological responses and time to fatigue.

The participant should complete the whole of this sheet himself/herself

Have you read the Participant Information Sheet?	YES/NO
Have you had an opportunity to ask questions and discuss this study?	YES/NO
Have you received satisfactory answers to all of your questions?	YES/NO
Have you received enough information about the study?	YES/NO
To whom have you spoken? .... Do you understand that you are free to withdraw from the study: • at any time • without having to give a reason for withdrawing • and without affecting your future medical care	YES/NO
Have you had sufficient time to consider the nature of this project?	YES/NO
Do you agree to take part in this study?	YES/NO

Signed .... Date ....

(NAME IN BLOCK LETTERS)...

Signature of Parent / Guardian in the case of a minor

....

Sheffield Hallam University

Direct dial +44 (0) 114 225 4333
Direct fax +44 (0) 114 225 4341

9 March 2004

Mr M Wilkinson
29 Sycamore Close
Skelton
York
YO30 1YU

Dear Mick

Title of investigation: Validity of a squash specific movement test for measurement of physiological responses and time to fatigue.

Approval Number : SLM/2003/Physiology/03/02/b

Thank you for providing the information requested.

I am pleased to inform you that full approval has now been granted for this study.

Yours sincerely

Professor Edward Winter
Chair, SLM Research Ethics Committee

***Note:** Approval applies until the anticipated date of completion unless there are changes to the procedures, in which case another application should be made.*

The Centre for Sport and Exercise Science
Collegiate Crescent Campus Sheffield S10 2BP UK
Telephone +44 (0)114 225 2544 Fax +44 (0)114 225 4341
E-mail cses@shu.ac.uk
www.shu.ac.uk/cses
Director of Centre Professor Roger Bartlett

theCentrefor sport and exercise science

13.2 Appendix two - Study one SPSS output

T-Test

Group Statistics

	group	N	Mean	Std. Deviation	Std. Error Mean
squash TTF	squash	8	774.7500	102.51934	36.24606
	runner	8	606.6250	81.09771	28.67237
squash test peak VO2	squash	8	52.2287	7.13693	2.52329
	runner	8	56.6063	4.75261	1.68030
squash test peak HR	squash	8	189.6250	7.44384	2.63179
	runner	8	181.8750	10.76287	3.80525
treadmill TTF	squash	8	343.0000	114.96583	40.64656
	runner	8	521.2500	135.26139	47.82212
treadmill peak VO2	squash	8	49.5850	7.25784	2.56603
	runner	8	58.5850	7.52476	2.66041
treadmill peak HR	squash	8	190.8750	12.98832	4.59206
	runner	8	182.5000	10.21204	3.61050

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
squash TTF	Equal variances assumed	1.527	.237	3.638	14	.003	168.12500	46.21560	69.00240	267.24760
	Equal variances not assumed			3.638	13.295	.003	168.12500	46.21560	68.50735	267.74265
squash test peak VO2	Equal variances assumed	2.341	.148	-1.444	14	.171	-4.37750	3.03157	-10.87956	2.12456
	Equal variances not assumed			-1.444	12.188	.174	-4.37750	3.03157	-10.97143	2.21643
squash test peak HR	Equal variances assumed	.504	.489	1.675	14	.116	7.75000	4.62669	-2.17326	17.67326
	Equal variances not assumed			1.675	12.450	.119	7.75000	4.62669	-2.29044	17.79044
treadmill TTF	Equal variances assumed	.163	.692	-2.840	14	.013	-178.25000	62.76224	-312.8616	-43.63839
	Equal variances not assumed			-2.840	13.646	.013	-178.25000	62.76224	-313.1903	-43.30966
treadmill peak VO2	Equal variances assumed	.029	.868	-2.435	14	.029	-9.00000	3.69625	-16.92767	-1.07233
	Equal variances not assumed			-2.435	13.982	.029	-9.00000	3.69625	-16.92864	-1.07136
treadmill peak HR	Equal variances assumed	.068	.798	1.434	14	.174	8.37500	5.84147	-4.15371	20.90371
	Equal variances not assumed			1.434	13.262	.175	8.37500	5.84147	-4.21946	20.96946

T-Test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	squash pVO2 squash players	52.2287	8	7.13693	2.52329
	treadmill pVO2 squash players	49.5850	8	7.25784	2.56603
Pair 2	squash HRmax squash players	189.6250	8	7.44384	2.63179
	Treadmill HRmax squash players	190.8750	8	12.98832	4.59206
Pair 3	squash pVO2 runners	56.6063	8	4.75261	1.68030
	treadmill pVO2 runners	58.5850	8	7.52476	2.66041
Pair 4	squash HRmax runners	181.8750	8	10.76287	3.80525
	treadmill HRmax runners	182.5000	8	10.21204	3.61050

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	squash pVO2 squash players & treadmill pVO2 squash players	8	.944	.000
Pair 2	squash HRmax squash players & Treadmill HRmax squash players	8	.723	.043
Pair 3	squash pVO2 runners & treadmill pVO2 runners	8	.412	.310
Pair 4	squash HRmax runners & treadmill HRmax runners	8	.170	.688

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence interval of the Difference Lower	95% Confidence interval of the Difference Upper			
Pair 1	squash pVO2 squash players - treadmill pVO2 squash players	2.64375	2.40793	.85133	.63067	4.65683	3.105	7	.017
Pair 2	squash HRmax squash players - Treadmill HRmax squash players	-1.25000	9.17683	3.24450	-8.92203	6.42203	-.385	7	.711
Pair 3	squash pVO2 runners - treadmill pVO2 runners	-1.97875	7.05133	2.49302	-7.87381	3.91631	-.794	7	.453
Pair 4	squash HRmax runners - treadmill HRmax runners	-.62500	13.52181	4.78068	-11.92951	10.67951	-.131	7	.900

13.3 Appendix three – Study two ethics documents and letter of approval

CONFIDENTIAL

Sheffield Hallam University

Faculty of Health and Wellbeing
Sport and Exercise
Research Ethics Committee

APPLICATION FOR APPROVAL OF RESEARCH

In designing research involving humans, principal investigators should be able to demonstrate a clear intention of benefit to society and the research should be based on sound principles. These criteria will be considered by the Ethics Committee before approving a project. ALL of the following details must be provided, either typewritten or word-processed preferably at least in 11 point font.

Please either tick the appropriate box or provide the information required.

1. Date of Application	January 2005

2. Anticipated Date of Completion	August 2005

3. Title of Investigation	Reproducibility of physiological measures in a squash-specific movement test.

4. Subject Area	Physiology of Exercise

5. Principal Investigator	Mr Michael Wilkinson
Email address	M.wilkinson@hull.ac.uk
Telephone/mobile number	01482 465168 wk 07754 870997 mb

6. Is this

6.1 a research project? [ ]

	Module Name	**Module Number**
6.2 an undergraduate project? [ ] 6.3 a postgraduate project? [X]		

8. Intended duration and timing of project	Begin data collection mid July for completion by the end of August 2005

	PhD	

7. Director of Studies/ Supervisor/Tutor	Professor Edward M Winter

9. Location of project (If parts are external to SHU, provide evidence in support in section 19)	Data will be colleted at the University of Hull.

10. Is this study	
10.1 Collaborative? [ ]	**If yes please include appropriate agreements in section 19**
10.2.1 Replication [ ] of	
10.2.2 New [X]	

11. Participants	
11.1 Number	24 (12 squash players and 12 distance runners)
11.2 Rationale for this number: (eg calculations of sample size)	Calculation of sample size using a method described by Vincent (1999) and Samuel and Witmer (1999), and SD and SE values of previous studies.
11.3 Criteria for inclusion and exclusion for example age and gender:	Squash players will be frequently competitive (≥ 3 times per wk), and playing in division 1 or 2 of the regional county leagues. Selection criteria for inclusion will be age 18-40 yrs, a minimum of 5 yrs experience at the specified level, and satisfactory medical pre-screening results. All players will be males. Selection criteria for the male distance running participants will include similarity of age to the squash participants, at least 5 years experience of competitive distance running at county standard, a frequency of training of at least 3 sessions weekly, and a satisfactory medical pre-screening result.
11.4 Procedures for recruitment for example location and methods:	Participants will be volunteers through contacts at local squash and athletics clubs. The nature and aims of the study will be explained in a group presentation to the players at each club.

11.5 Does the study have *minors or ‡vulnerable adults as participants?	Yes [ ] No [X]
11.6 Is CRB disclosure required for the Principal Investigator? *(To be determined by risk assessment)*	Yes [ ] No [X] If yes, is standard [ ] or enhanced [ ] disclosure required?
*Minors are participants under the age of 18 years. ‡Vulnerable adults are participants over the age of 16 years who are likely to exhibit: a) learning difficulties b) physical illness/impairment c) mental illness/impairment d) advanced age e) any other condition that might render them vulnerable	

12. Purpose and benefit of investigation

Statement of the research problem with any necessary background information.
(No more than 1 side of A4)

Squash imposes diverse physiological demands including cardio-pulmonary endurance, muscle endurance, muscle strength, speed, and flexibility (Sharp, 1998). At elite standard, squash has been classed as a high-intensity intermittent activity with mean rally lengths of 16 s and roughly equal recovery times between rallies (Montpetit, 1990). Matches at the elite level can last up to 3 hr in which players are active for up to 67% of the time (Montpetit, 1990). This obviously places extreme demands on energy supply. Studies into heart rate responses have demonstrated that despite the intermittent nature of play, heart rate quickly reaches a steady state which is equivalent to 80-90% of predicted maximum (Blanksby et al., 1980; Docherty, 1982; Mercier et al., 1987; Brown and Winter, 1995). Measurement of oxygen uptake during competitive play has revealed mean values of approximately 60% of individual maxima (Montpetit et al., 1987). When viewed in conjunction with mean lactate levels of between 2-4 $\text{mmol}\cdot\text{l}^{-1}$ (Beauchamp and Montpetit, 1980; Noakes et al., 1982; Mercier et al., 1987) there is clear evidence that squash is a predominantly aerobic endurance based activity.

Importance of Movement Economy in Squash.

Match analysis data have shown that a common tactic employed to win squash rallies is speed of movement to take the ball early and so attempt to put the opponent under pressure thereby forcing errors (Hughes and Franks, 1994). The ability to sustain high speed movement with minimum expenditure of energy points to the importance of movement economy. As stated by Cooke (2001), economy of energy expenditure is important in any activity that stresses aerobic energy supply. An athlete who consumes less oxygen for a given exercise intensity can sustain performance longer, or can maintain a higher speed for the same period. This has obvious advantages in the employment of the 'early ball' tactic shown to be the preference of elite squash players.

Research Problem.

In light of the theoretical and practical significance of the problem, and the lack of such investigations in squash, there is a need to develop ways of quantifying economy in squash movement. There are no scientific investigations of movement economy in squash to date. The principle of specificity fro squash training is well understood and reported (Todd *et al.*, 1995). Specificity is no less important in physiological measurement and dictates the need for a valid and reproducible squash-specific test of movement economy.

13. Details of the research design and protocol(s

13.1 provide details.

If a Mode B support project is being proposed please state the protocols under the following headings: a. needs analysis; b. potential outcome; c proposed interventions.

All participants will complete a test that is designed to assess movement economy in an on-court procedure. This will be based on the procedure developed and used by Damon Leedale-Brown with the England Squash program (personal communication). Unpublished data suggest the on-court test is a valid replication of game specific physiological demand. With modifications, the test will allow squash-specific movement patterns to be performed at controlled intensities whilst oxygen uptake is measured using the Cortex Metamax 3B portable gas analyser. In addition, blood lactate will be measured in duplicate from finger prick samples, and heart rate will be recorded online via a chest belt transmitter. The movements are performed in a 'semi random' manner with the pattern of movement to each portion of the court repeated nominally every minute. This element of randomness is essential to replicate specific squash demands.

On arrival at the test venue, body weight and stature will be measured using calibrated balance beam scales and a stadiometer respectively.

The on-court test will consist of 6-8 × 4 minute exercise intervals performed at increasing submaximal intensities in a discontinuous manner. Finger prick blood samples will be taken in short rest periods between stages, with oxygen uptake and heart rate monitored continuously using portable gas analysis and heart rate telemetry respectively. The submaximal stages will end when a blood lactate value of ≥ 4 mMol·L^{-1} is obtained in an end stage measurement, and the lactate curve will be used to calculate lactate threshold. Following a 10-15 minute rest interval, participants will complete further 1 minute stages beginning from level 2 of the test with a speed increase every minute until volitional fatigue for assessment of maximal oxygen uptake. A finger prick blood sample will be taken again 3 minutes after the end of the test.

In a second test seven days later, the participants will complete all levels of the test that fell below their lactate threshold with stages lasting four minutes in a discontinuous fashion as in the first test. Again, oxygen uptake and heart rate will be monitored continuously, and blood [lactate] will be assessed by finger prick at the end of each stage.

Movement economy will be assessed for all sub-lactate threshold test levels by averaging oxygen uptake breath by breath data for minutes 3 – 4 of each level, then calculating Δ economy (increase in oxygen uptake from consecutive sub-lactate threshold test levels). Sub-lactate threshold oxygen cost, and blood [lactate] values from the two test days will be used to assess reproducibility.

Squash participants will be ranked by their Δ economy scores, and the most , least, and mid economical particpants will be required to perform a squash specific test of Maximal Accumulated Oxygen Deficit (MAOD) on two separate test occasions. A modified MAOD test will be performed where the players will be required to complete a single exhaustive trial on the squash movement test at a speed equal to that which would elicit ~ 120% of their maximal oxygen uptake . This speed will be calculated by deriving a linear regression equation for oxygen uptake against movement speed from the sub-lactate threshold oxygen uptake values, and solving for test speed using 120% of the maximal oxygen uptake measured from the 1 minute incremental phase of the first test. Oxygen uptake will be measured continuously during the exhaustive trial, and time to exhaustion will be recorded using a digital stopclock. The MAOD will be added to actual oxygen cost to give an estimate of total oxygen (energy) cost of high intensity squash movement. This will be used to assess the relationship of sub-lactate threshold energy expenditure (economy measure) to the total energy cost (aerobic plus anaerobic, expressed in units of oxygen cost) of squash movement at high intensities such as those commonly experienced in match play.

All participants will be habituated with the movement test and data collection methods to ensure valid data are collected. Test time, footwear, and clothing will be standardised between that first and second trials. Test environment will be controlled as far as is possible.

13.2 Are these "minor" procedures as defined in Appendix I of the ethics guidelines?	Yes [ ]	No [X]

13.3 If you answered 'No' in Section 13.2, list the procedures that are <u>not</u> minor.	$\dot{V}O_{2max}$ assessment, second phase of MAOD (i.e. above $\dot{V}O_{2max}$ continuous bout)

14. Indicative methods of analysis

14.1 Provide details of the quantitative and qualitative analysis to be used.
Data will be analysed using Limits of Agreement, test-retest coefficient of variation, Technical Error of Measurement, least products regression, pearson's correlation coefficient, Bland-Altman plots, and T-tests for paired samples, with the most appropriate statistic being used to ascertain reproducibility of anthropometric, submaximal and maximal physiological measures. Currently, there is no agreement about which of the above tests it is best to use. Similarly, allometric scaling of the $\dot{V}O_2$ scores to remove any influences of body size differences between the subjects will occur using the procedures described by Winter and Nevill (2001). On the basis of economy measures, players will be separated into low and high economy groups by rank for later studies.

15. Substances to be administered (Refer to Appendix V of the ethics guidelines)

15.1 The protocol does not involve the administration of pharmacologically active substances or nutritional supplements. *(Please tick the box if this statement applies and go to section 16)* [ ]

15.2 Name and state the risk category for each substance. If a COSHH assessment is required state how the risks are to be managed.

N/A

16. Degree of discomfort that participants might experience

16.1 To consider the degree of physical or psychological discomfort that will be experienced by the participants. State the details which must be included in the participant information sheet to ensure that the participants are fully informed about any discomfort that they may experience.

There will be minimal discomfort associated with finger prick blood sampling. Participants will experience generalised discomfort associated with maximal exertion in the assessment of $\dot{V}O_{2max}$ and MAOD.

17. Outcomes of Risk Assessment	

17.1 Provide details of the control measures arising out of the assessment of risk including the nature of supervision and support required during the experimental phase of the project.

General control measures for capillary blood sampling (for details see risk assessment docs).

1. pre-screening medical questionnaire. 2. Investigator trained in blood sampling and handling. 3. Documented procedures for disposal of contaminated waste products are followed. 4. Venepuncturist is inoculated against Hep B.

General control measures for maximum intensity squash movement assessment.

1. Pre- screening medical questionnaire. 2. Strict adherence to the agreed protocol which includes a warm-up and cool-down. 3. The participant is monitored by a trained first aider following the test. 4. Heart rate is continually monitored to identify when the participant is exercising maximally. 5. Visual communication is maintained between investigator and participant throughout the exercise test. 6. all breathing apparatus are sterilised prior to and after use. 7. shoe laces are secured. 8. at least 2 people are present at the exercise test.

18. Safe System of Work

18.1 Indicate how the control measures outlined in section 17.1 will be implemented to minimise the risks in undertaking the research protocol (refer to 13.1). State the technical skills needed by the Principal Investigator to ensure safe working.

The principal investigator is a trained first aider and a qualified venepuncturist, they are also aware of the correct implementation of control measures stated in the risk assessment documentation

19. Attachments

(Place a tick in the appropriate description)

19.1 Risk Assessment(s) [X]
(Include CRB risk assessment)

19.2 COSHH Assessment [ ]

19.2 Participant Information Sheet [X]

19.3 Informed Consent Form [X]

19.4 Pre-Test Medical Questionnaire [X]

19.5 Collaboration evidence/support (see 10) [ ]

19.6 Collaboration facilities (see 9) [ ]

19.7 Clinical Trials Form (FIN 12) [ ]

20. Signature Principal Investigator	**Once this application is approved, I will undertake the study as approved. If circumstances necessitate that changes are made to the approved protocol, I will discuss these with my Project Supervisor. If the supervisor advises that there should be a resubmission to the Ethics Committee, I agree that no work will be carried out using the changed protocol until approval has been sought and formally received.** **...Principal Investigator** **Name ....**
21. Approval Project Supervisor to sign off **EITHER** box A **OR** box B as applicable. *(refer to Appendix I and the flowchart in appendix VI of the ethics guidelines)*	**Box A:** **I confirm that the experimental protocol contained in this proposal is based solely on 'minor' procedures, as outlined in Appendix 1 of the HWB Sport and Exercise Research Ethics Committee Procedures for the Use of Humans in Research document, and therefore does not need to be submitted to the HWB Sport and Exercise Research Ethics Committee.** **In terms of ethics approval, I agree the 'minor' procedures proposed here and confirm that the Principal Investigator may proceed with the study as designed.** **Project Supervisor ....Date ....** **Name ....**
	Box B: **I confirm that the experimental protocol contained in this proposal is not based solely on 'minor' procedures, as outlined in Appendix 1 of the HWB Sport and Exercise Research Ethics Committee Procedures for the Use of Humans in Research document, and therefore must be submitted to the HWB Sport and Exercise Research Ethics Committee for approval.** **I confirm that the appropriate preparatory work has been undertaken and that this document is in a fit state for submission to the HWB Sport and Exercise Research Ethics Committee.** **Project Supervisor... Date ....** **Name ....**
22. Signature Technician	**I confirm that I have seen the full and approved application for ethics approval and technical support will be provided.** **Technician .... Date ....** **Name ....**

Sheffield Hallam University

Faculty of Health and Wellbeing
Sport and Exercise Research Ethics Committee

Participant Information Sheet

Project Title	Reproducibility of physiological measures in a squash-speci movement test

Name of Participant	

Supervisor/Director of Studies	Professor Edward M Winter The Centre for Sport and Exercise Science Sheffield Hallam University Collegiate Hall Sheffield, S10 2BP

Principal Investigator	Mick Wilkinson Division of Sport Science Northumbria University Newcastle-Upon-Tyne, NE1 8ST 0191 2273717

Purpose of Study and Brief Description of Procedures *(See overleaf)*

Squash is a high-intensity, intermittent activity with short recovery intervals in which players are active for around 67% of play. Despite This intermittent nature, physiological responses such as heart rate quickly rise to 80-90% of maximum and remain steady for the remainder of play. This and other physiological measures provide clear evidence that squash is a predominantly aerobic, endurance based activity.

A common tactic used to win squash rallies is to employ fast movement to take the ball early and so attempt to pressure an opponent into errors. The ability to sustain high-speed movement with minimum expenditure of energy highlights the importance of movement economy for successful players, as economy of energy expenditure is important in any endurance based activity. Essentially, a player who uses less energy to move at a given speed can sustain this speed for longer, or can move at a higher speed for the same period of time. This has obvious advantages for use of the 'early ball' tactic shown to be the preference of elite squash players.

Purpose of the study.

To determine which players are economical and uneconomical movers, and to understand what makes a player an economical mover, an accurate and reliable test that mimics the movements involved in squash must be developed. The purposes of this study are to:

1. examine various physiological measures of squash players and distance runners (for comparison) undertaking a squash movement test on two occasions to assess reproducibility of test scores.
2. to assess the movement economy and maximum physiological capacity of each player on the squash test.

Procedures.

As a participant in this study, you will be required to attend two habituation sessions to experience the on-court movement test and become accustomed to the wearing of some test apparatus whilst moving on court. You will then be required to attend two test sessions separated by 7 days for various physiological measures to be taken during and immediately after the on-court squash movement test.

- On arrival at the test venue, your weight and height will be measured, and you will be asked to complete a pre-test medical questionnaire to ensure you are healthy enough to carry out the testing.
- Following this procedure, you will be prepared for the on-court test by being fitted with a small shoulder harness holding a portable gas analyser, a nose and mouth mask for collection of your expired breath during the test, and a chest belt transmitter to record heart rate during the test.
- The test will consist of 5 – 8 × 4 minute bouts of submaximal court movement at progressively faster speeds with short recovery intervals (less than 2 minutes) in between.
- After a 10 - 15 minute recovery following the submaximal stages, you will be asked to begin the test again. But this time the speed will be increased every minute without rest intervals between stages. You must keep pace with the test for a long as possible until you feel you cannot continue. This portion of the test will feel particularly strenuous, however fatigue will disappear shortly after finishing.
- During the short recovery interval between submax stages, and at completion of the test, small blood samples will be collected from a finger prick by a qualified investigator for analysis of chemical markers of physiological effort.
- 7 days later, you will be required to complete a second test comprising a number of (not more than) the submaximum stages you completed in the first test, followed by a repeat of the one minute increment portion of the test, but this time starting at the level at which the submax portion of the test finished. The test will occur at the same time of day as the first, and you must wear the same footwear and type of clothing.

Squash player only:

Depending on your results, you may be asked to complete a third test which will comprise continuous movement on the squash test at a speed higher than the final speed you attained at the end of the first exercise visit until you cannot sustain the speed anymore. You will need to wear the portable analyser and heart rate transmitter again during the test. This test will feel very strenuous from beginning to end but will last only a few minutes with fatigue disappearing soon afterwards.

Your rights as a participant.

Your participation in this study is voluntary. You are free to refuse to start the testing or withdraw at any time in the proceedings without penalty or prejudice and without giving any reason for so doing. No disadvantage will arise from any decision to participate or not.

The results of the research may be published, but your name will not be used, and no individual identifying information will be provided. All data collected will be coded to retain anonymity, and any personal details will be stored in a locked filing cabinet with access limited to the investigator.

As a participant in this study you will be given confidential feedback about your test results which will be your maximal physical fitness ($\dot{V}_{O_2max}$) and your movement economy score. This information may aid you in your training.

If you have any questions concerning the procedures or any other aspects of the project, feel free contact the principal investigator in person or by telephone on the number given.

Some test sessions may be video taped however the video will only be used for further analysis by the investigator and study supervisors. Access to the tapes will be limited to the investigator and the study supervisor. Any further use of the video taped tests will not be undertaken without the express permission of the participant filmed who will of course remain anonymous.

It has been made clear to me that, should I feel that these Regulations are being infringed or that my interests are otherwise being ignored, neglected or denied, I should inform Professor Edward Winter, Chair of the Faculty of Health and Wellbeing Sport and Exercise Research Ethics Committee (Tel: 0114 225 4333) who will undertake to investigate my complaint.

Sheffield Hallam University

Faculty of Health and Wellbeing
Sport and Exercise Research Ethics Committee

INFORMED CONSENT FORM

TITLE OF PROJECT:
Reproducibility of physiological measures in a squash-specific movement test.

The participant should complete the whole of this sheet himself/herself

Have you read the Participant Information Sheet?	YES/NO
Have you had an opportunity to ask questions and discuss this study?	YES/NO
Have you received satisfactory answers to all of your questions?	YES/NO
Have you received enough information about the study?	YES/NO
To whom have you spoken? .... Do you understand that you are free to withdraw from the study: • at any time • without having to give a reason for withdrawing • and without affecting your future medical care	YES/NO
Have you had sufficient time to consider the nature of this project?	YES/NO
Do you agree to take part in this study?	YES/NO

Signed .... Date ....

(NAME IN BLOCK LETTERS)..

Signature of Parent / Guardian in the case of a minor

....

Sheffield Hallam University

Direct dial +44 (0) 114 225 4333
Direct fax +44 (0) 114 225 4341

21 January 2005

Mr M Wilkinson
29 Sycamore Close
Skelton
York
YO30 1YU

Dear Mick

Title of investigation: Reproducibility of physiological measures in a squash-specific movement test.

Application Number: SLM/2004/Physiology/03/06

Thank you for providing the information requested.

I am pleased to inform you that full approval has now been granted for this study. However, please note that the risk assessments should be signed by yourself on the front page.

Yours sincerely

Professor Edward Winter
Chair, HWB Sport & Exercise Research Ethics Committee

Note: *Approval applies until the anticipated date of completion unless there are changes to the procedures, in which case another application should be made.*

The Centre for Sport and Exercise Science
Collegiate Crescent Campus Sheffield S10 2BP UK
Telephone +44 (0)114 225 2544 Fax +44 (0)114 225 4341
E-mail cses@shu.ac.uk
www.shu.ac.uk/cses
Director of Centre Professor Roger Bartlett

theCentrefor sport and exercise science

13.4 Appendix four – Study two SPSS output

Movement economy

```
All the derivatives will be calculated numerically.
▽



  Iteration  Loss funct           a           b

     0.1     156.5859000  .000000000  1.00000000
     1.1     22.44414794  .004405436  1.14247165
     2.1     18.74297486  -2.1205539  1.20964624
     3.1     14.13617274  -6.9386532  1.37353691
     4.1     13.30042576  -9.2250766  1.45515110
     5.1     13.20556431  -10.057501  1.48596148
     6.1     13.20252826  -10.145678  1.48961884
     7.1     13.20234558  -10.133165  1.48934618
     8.1     13.20233150  -10.122089  1.48899475
     9.1     13.20233134  -10.120676  1.48894470
    10.1     13.20233134  -10.120610  1.48894206

Run stopped after 10 major iterations.
Optimal solution found.
```

Peak heart rate

```
All the derivatives will be calculated numerically.
▽



  Iteration  Loss funct           a           b

     0.1     123.0000000  .000000000  1.00000000
     1.1     77.81371098  .000067255  1.01268812
     2.1     77.81182802  .203456408  1.01154075
     3.1     77.81118298  .380042934  1.01058237
     4.1     77.80958326  .448519585  1.01026422
     5.1     77.80929201  .492661426  1.01005927
     6.1     77.80929201  .492575442  1.01005972

Run stopped after 6 major iterations.
Optimal solution found.
```

Performance time to exhaustion

```
All the derivatives will be calculated numerically.
▽




  Iteration  Loss funct            a           b

      0.1    14636.00000  .000000000  1.00000000
      1.1    9439.289308  -.00005463  .954935277
      2.1    8766.467672  11.7672782  .941790641
      3.1    7902.575529  37.3770707  .910076922
      4.1    7579.180845  65.6496265  .876301342
      5.1    7574.963983  62.3588868  .880634396
      6.1    7574.950915  62.4816847  .880505547
      7.1    7574.950889  62.4822352  .880507060
      8.1    7574.950889  62.4820885  .880507302

Run stopped after 8 major iterations.
Optimal solution found.
```

Maximal oxygen uptake

```
All the derivatives will be calculated numerically.
▽




  Iteration  Loss funct            a           b

      0.1    81.80740000  .000000000  1.00000000
      1.1    80.76299836  -.00016071  .990651014
      2.1    80.28744289  .656115222  .980048177
      3.1    79.82032112  2.19225033  .951681123
      4.1    79.75902550  2.66595114  .941804795
      5.1    79.75458924  2.70679907  .940601833
      6.1    79.75457141  2.69907997  .940730427
      7.1    79.75457139  2.69875227  .940736531
      8.1    79.75457139  2.69875137  .940736550

Run stopped after 8 major iterations.
Optimal solution found.
```

13.5 Appendix five – Study three ethics documents and letter of approval

northumbria
UNIVERSITY

ETHICS SUBMISSION FORM

1. Project Title: Validity of a squash-specific speed and agility test

2. Name of Applicant: Andrew Sutherland

3. Who is conducting the project (delete as appropriate)?

UNDERGRADUATE ~~POSTGRADUATE~~

4. If a student please state your programme of study: Applied sport and exercise science

State your supervisor: Mick Wilkinson

5. Where will the research be conducted?

on University property ■
outside of the University ☐

If the study is being conducted at a different institution (e.g. another University, a School etc) then you must produce proof that you have received appropriate permission (e.g. a letter, an email) from the relevant institution(s), before your submission can be approved. Give this to your supervisor when you submit your final documentation.

If the study is being conducted outside of the University but not in an institution (e.g. someone's home, a public place) then you must ensure that you have conducted an appropriate risk assessment and submitted this with your application (see item 16).

6. Rationale for the study or programme (approx 300 words):

Squash places demands on multiple elements of fitness including endurance, speed, agility flexibility and strength (Sharp, 1998). Squash is a high-intensity, intermittent sport involving frequent and rapid changes of direction (Vuckovic, 2004). As such, speed and agility are recognised as important elements of performance in squash (Behm, 1992). Despite the importance of speed and agility in squash, there are currently no specific tests of this aspect of fitness. This surprising as the importance of specific testing is recognised (Muller, 2000) and agility is known to be specific quality that does not transfer to movement patterns that differ from those used in training (Young, 2001).

Squash-specific fitness tests have been developed (Steininger and Wodick, 1987) but only to assess endurance fitness. Furthermore, with the exception of Brookes and Winter (1985) and Chin *et al* (1995), few studies on squash have quantified the high-intensity exercise capabilities of squash players. Therefore, the purpose of this study is to validate a squash-specific test designed to assess speed and agility.

7. Detailed description of the proposed methodology (e.g. procedure, materials,

software, measurement tools etc) for the study/programme (approx 500 words):

On arrival at the test venue, body mass and stature will be measured using calibrated balance beam scales and a stadiometer respectively.

Participants will attend two habituation visits prior to data collection where they will perform two speed and agility tests (one squash-specific and the other a general field-based test) without data being collected.
Following habituation, participants will attend four test sessions in total. In random order, participants will complete two test sessions on a squash-specific speed and agility test, 24 hours apart and two test sessions of the Illinois agility again separated by 24 hours. Tests will be performed at approximately the same time of day and in the same footwear and clothing.

All participants will complete a standardised warm-up comprising five minutes of jogging, followed by four runs through the test being performed that day at approximately 50, 60, 70 and 80 % of perceived maximum effort to warm-up the specific muscle groups required for the movements involved. Each run through will be separated by 60 s recovery. A four-minute period of static stretching of the quadriceps, hamstrings, gastrocnemius and soleus muscle groups will follow the sub-maximal runs. Particpants will then perform three all-out efforts on each test with two minutes recovery between efforts. Performance time will be recorded using an electronic stopclock.

The squash-specific test will involve squash-specific movements around a set of cones on a squash court. The precise movements patterns will be devised through consultation with a qualified coach and from match analysis studies. The Illinois test will be carried out in accordance with the original test description by Cureton (1951).

Independent T-tests will be used to examine differences in test performance on both tests between a group of trained squash players and a group of trained footballers. Pearson's correlation will examine the association between test performances. Spearman's rank will examine relationships between squash player rank and performance on both tests. Typical error will be used to assess reproducibility of scores.

8. Will an undergraduate be involved in data collection, e.g. as a research assistant? **YES** **~~NO~~**

If so it is the supervisor's responsibility to ensure that they are fully aware of all ethical procedures and issues.

9. Is approval required from another Ethics Committee (e.g. NHS)? **~~YES~~** **NO**

If approval is required from another Ethics Committee what is the current status of your application?

10. Is the proposed study a continuation of an existing study that has already received ethical approval? ~~YES~~ NO

11. Participant information (number, age, sex, and whether vulnerable):
If more than one study is proposed provide separate information for each.
Approximately 10 men county-standard squash players and 10 men University first team football players aged 18-30 will be recruited for the study. No vulnerable persons will be sought.

12. In the case of healthy volunteers how and from where will they be sought?
Participants will be sought though contacts in the Northumbria University sports clubs and via posters in the University sports centre.

13. Will participants receive any payments/expenses? **~~YES~~**
NO
If so please describe:

14. What significant discomfort (physical, social, or psychological), inconvenience, or danger may be caused?
All-out sprints will result in transient feelings of general exertion but these will disappear after completion of the tests.

15. What measures will be adopted to protect participant anonymity, and where appropriate confidentiality?
All data will be coded to retain anonymity. Paper copies will be stored in a locked filing cabinet and electronic data will be pass word protected. Only the supervisor and investigator will have access to the data.

16. Have you consulted the appropriate Risk Assessment Form(s)? YES ~~NO~~

If YES, which document(s) (insert the relevant code numbers): Exercise_04

What is the overall risk rating? Moderate

What are the main risks and their control measures for the Risk Assessment(s) referred to above? (list below)

Musculoskeletal injury
Minor. (C2xL1=R2) Extra demand is placed on the musculoskeletal system when performing all-out physical activity. Control measures: pre-screening for old/existing injuries and a thorough warm up prior to exercise.

Cardiovascular complications
Acceptable. (C3xL1=R3) Extra strain is placed on the cardiovascular system when exercising. Control measures: pre-screening questionnaire to assess the participant's current level of fitness and status of health. At least one trained first aider to be present during the test.

Subject vomiting
Moderate. (C2xL2=R4) When exercising maximally a participant may vomit. Control measures: A bucket and spillage kit are present to collect any vomit and clean any spillage.

Subject fainting or feeling nauseous
Moderate. (C2xL2=R4) Following maximal intensity exercise a participant may feel faint/nauseous. Control measures: the participant is closely monitored after the test and is instructed to lie prone with feet elevated if they feel nauseous.

Subject stumbling during the test Moderate. (C2xL2=R4) The participant will be moving at high speeds during and when changing direction. Control measures: allow the participant accustomisation trials before the exercise test.

If NO, you will need to complete a new Risk Assessment Form and include it with

your submission
17. Proposed start date(s) and approximate duration: February 2006 – March 2006

Declaration by the researcher
I confirm that the information provided in this form is accurate. I have considered the ethical/risk issues and I am satisfied that the project does not violate the ethical guidelines of the University or cause undue harm to investigator and participants. I understand that I may not proceed with data collection until this form has been formally approved, and until all participants have provided written first-person informed consent (where appropriate). I understand that I may not make any changes to the project without prior approval from the Chair of the SEC.

Signature of proposer: Date: 28 11-06

This submission has been assessed by two independent reviewers, and all ethical issues have been addressed. A Risk Assessment has been conducted. This submission has now been passed by the Division of Sport Science Ethics Committee

Signature of Supervisor: Date: 6/11/06

Signature of 2nd Reviewer: Date: 6.11.06

PARTICIPANT INFORMATION.

TITLE OF PROJECT: ______________________________

Participant ID Number: ☐

Principal Investigator: Andrew Sutherland
Investigator contact details: Email: a.sutherland@unn.ac.uk

INFORMATION TO POTENTIAL PARTICIPANTS

1. What is the purpose of the project?
The aim of this project is to examine the usefulness of a new test of speed and agility designed for squash players

2. Why have I been selected to take part?
You are either a male county-standard squash player or University first team footballer (comparison group) aged 18-30 and are regularly training and competing.

3. What will I have to do?
You will be required to attend the university two times to be shown and experience two speed and agility tests that you will undertake, then you will be required to make another four visits to perform each of two tests twice. The two test sessions on each test will be 24 hours apart.

Following a standard warm-up, your height and body weight will be measured. You will then have three attempts at the test being performed that day. Your time to complete the test course will be recorded and your best score used for analysis. Both tests involve short sprints with changes of direction around sets of cones. Both tests will be performed indoors. One of these tests is a general agility test (that will be performed in a sports hall), the other has been designed to replicate the movements patterns used in squash (this will be performed on one of the Univeristy squash courts).

Each test session will last approximately 30 minutes .

4. What are the exclusion criteria (i.e. are there any reasons why I should not take part)?
If you are injured or have any other medical condition that will prevent you form performing all-out, short-duration exercise with rapid diection changes.

5. Will my participation involve any physical discomfort?
You will experience general feelings of exertion during the tests, but these feelings will dissappear after completion.

6. Will my participation involve any psychological discomfort or embarrassment?
No

7. Will I have to provide any bodily samples (i.e. blood, saliva)?
No

8. How will confidentiality be assured?
Your data will be coded with the key code accessible only to the investigator and stored separately from your data.

9. Who will have access to the information that I provide?
The investigator and the supervisor

10. How will my information be stored / used in the future?
The data might be published in a peer reviewed journal and / or presented at a conference but no individual identifying information will be used. Data and consent forms will normally be stored for three years then destroyed.

11. Has this investigation received appropriate ethical clearance?
Yes

12. Will I receive any financial rewards / travel expenses for taking part?
No

13. How can I withdraw from the project?
You can withdraw at any time simply by contacting the investigator on the email provided below.

14. If I require further information who should I contact and how?
Andrew Sutherland email : a.sutherland@unn.ac.uk

northumbria
UNIVERSITY

INFORMED CONSENT FORM

TITLE OF PROJECT: Validity of a squash-specific speed and agility test

Participant ID Number: ☐

Please read and complete this form carefully.

	please tick if applicable
I have read and understood the Participant Information Sheet.	☐
I have had an opportunity to ask questions and discuss this study and I have received satisfactory answers.	☐
I understand I am free to withdraw from the study at any time, without having to give a reason for withdrawing, and without prejudice.	☐
I agree to take part in this study.	☐
I would like to receive feedback on the overall results of the study at the email address given below. I understand that I will not receive individual feedback on my own performance.	☐
Email address..	

Signature of participant.. Date........................

(NAME IN BLOCK LETTERS)...

Signature of Parent / Guardian in the case of a minor

....

Signature of researcher.. Date........................

(NAME IN BLOCK LETTERS)...

PARTICIPANT DEBRIEF

TITLE OF PROJECT: Validity of a squash-specific speed and agility test
Principal Investigator: Andrew Sutherland

Investigator contact details: Email: a.sutherland@unn.ac.uk

Participant Identification Number: __________

1. What was the purpose of the project?
To assess the usefulness of squash-specific test of speed and agility

2. How will I find out about the results?
a summary of the results can be emailed to you if you have requested this on the consent form

3. Will I receive any individual feedback
No

4. What will happen to the information I have provided?
The data will be used in an undergraduate dissertation and might also be published and / or presented at a conference but there will be no way of linking the output to you

5. How will the results be disseminated?
Peer reviewed journal and / or conference presentation

6. Have I been deceived in any way during the project?
No

7. If I change my mind and wish to withdraw the information I have provided, how do I do this?
Contact the investigator on the email provided above within one month of your final test session

If you have any concerns or worries concerning the way in which this research has been conducted, or if you have requested, but did not receive feedback from the principal investigator concerning the general outcomes of the study within a few weeks after the study has concluded, then please contact Professor Kenny Coventry via email at kenny.coventry@unn.ac.uk, or via telephone on 0191 2437027.

13.6 Appendix six – Study three SPSS output

Least Products Regression output.

Performance time to exhaustion – squash-specific change-of-direction speed test.

```
All the derivatives will be calculated numerically.
▽



  Iteration  Loss funct            a           b

     0.1     1.220100000  .000000000  1.00000000
     1.1     1.169537254  -.00045417  .994366154
     2.1     1.154973792  .105854790  .986565411
     3.1     1.141741011  .331765984  .968095001
     4.1     1.137008499  .496688011  .953835267
     5.1     1.136454287  .526514798  .950960106
     6.1     1.136438731  .522970563  .951194158
     7.1     1.136438671  .522342978  .951245353
     8.1     1.136438671  .522326672  .951246765

Run stopped after 8 major iterations.
Optimal solution found.
```

Performance time to exhaustion – Illinois Agility Run.

```
All the derivatives will be calculated numerically.
▽



  Iteration  Loss funct            a           b

     0.1     3.009400000  .000000000  1.00000000
     1.1     2.719484266  .000525903  1.00807148
     2.1     2.632591598  -.79293610  1.06123344
     3.1     2.614925817  -1.1630031  1.08804119
     4.1     2.549885271  -2.7564600  1.19339383
     5.1     2.549743114  -2.7869107  1.19560241
     6.1     2.549740833  -2.7930686  1.19603708
     7.1     2.549740829  -2.7933737  1.19605743
     8.1     2.549740829  -2.7934087  1.19605973

Run stopped after 8 major iterations.
Optimal solution found.
```

T-Test

Group Statistics

	group	N	Mean	Std. Deviation	Std. Error Mean
illinois	squash	10	14.7450	.66078	.20896
	non squash	10	14.7880	.41421	.13099
squaspec	squash	10	10.9020	.43749	.13835
	non squash	10	12.1960	.34069	.10774

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
illinois	Equal variances assumed	.360	.556	-.174	18	.864	-.04300	.24662	-.56112	.47512
	Equal variances not assumed			-.174	15.127	.864	-.04300	.24662	-.56827	.48227
squaspec	Equal variances assumed	1.332	.264	-7.380	18	.000	-1.29400	.17535	-1.66239	-.92561
	Equal variances not assumed			-7.380	16.981	.000	-1.29400	.17535	-1.66398	-.92402

```
CORRELATIONS
  /VARIABLES=illsqbest sqpsqbest
  /PRINT=TWOTAIL NOSIG
  /MISSING=PAIRWISE .
```

Correlations

```
[DataSet1] C:\Documents and Settings\Mic\My Documents\My Safe\PhD Nov
08\Study 3 - squash speed and agility test\test data.sav
```

Correlations

		illionois squash player best score	squash player suash tst best
illionois squash player best score	Pearson Correlation	1	.321
	Sig. (2-tailed)		.365
	N	10	10
squash player suash tst best	Pearson Correlation	.321	1
	Sig. (2-tailed)	.365	
	N	10	10

```
NONPAR CORR
  /VARIABLES=illsqbest sqpsqbest SPrank
  /PRINT=SPEARMAN TWOTAIL NOSIG
  /MISSING=PAIRWISE .
```

Nonparametric Correlations

```
[DataSet1] C:\Documents and Settings\Mic\My Documents\My Safe\PhD Nov
08\Study 3 - squash speed and agility test\test data.sav
```

Correlations

			illionois squash player best score	squash player suash tst best	squash player rank
Spearman's rho	illionois squash player best score	Correlation Coefficient	1.000	.673*	.430
		Sig. (2-tailed)	.	.033	.214
		N	10	10	10
	squash player suash tst best	Correlation Coefficient	.673*	1.000	.770**
		Sig. (2-tailed)	.033	.	.009
		N	10	10	10
	squash player rank	Correlation Coefficient	.430	.770**	1.000
		Sig. (2-tailed)	.214	.009	.
		N	10	10	10

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

13.7 Appendix seven – Study four ethics documents and letter of approval

CONFIDENTIAL

Sheffield Hallam University **Faculty of Health and Wellbeing Research Ethics Committee** **Sport and Exercise Research Ethics Review Group** APPLICATION FOR APPROVAL OF RESEARCH	

In designing research involving humans, principal investigators should be able to demonstrate a clear intention of benefit to society and the research should be based on sound principles. These criteria will be considered by the Ethics Committee before approving a project. ALL of the following details must be provided, either typewritten or word-processed preferably at least in 11 point font.

Please either tick the appropriate box or provide the information required.

1. Date of Application	12 th November 2007

2. Anticipated Date of Completion	January 2008

3. Title of Investigation	Validity and reproducibility of a squash-specific repeated sprint test.

4. Subject Area	Physiology of exercise

5. Principal Investigator	
Name	Mick Wilkinson
Email address	Mic.wilkinson@unn.ac.uk
Telephone/mobile number	0191 2437097 / 07754 870997
Student number	10044067

6. Is this

6.1 a research project? [ ]

	Module Name	**Module Number**
6.2 an undergraduate project? [ ]		

8. Intended duration and timing of project	Data collection is planned to commence in December 2007 for completion be the end of January 2008. Subsequent analysis and write-up are planned for completion by February 2008 with intended submission in May 2008.

6.3 a postgraduate project? [√]	PhD	

7. Director of Studies/ Supervisor/Tutor	Professor Edward M Winter

9. Location of project (If parts are external to SHU, provide evidence in support in section 19)	All testing will be carried out in the exercise physiology laboratories at Northumbria University.

10. Is this study	
10.1 Collaborative? [√]	**If yes please include appropriate agreements in section 19** For facilities only
10.2.1 Replication [ ] of	
10.2.2 New [√]	

11. Participants	
11.1 Number	16-20
11.2 Rationale for this number: (eg calculations of sample size)	A power calculation based on effect size of performance time differences between squash and non-squash players on a squash-specific speed and agility test revealed an ES of 3.33. The squash specific repeated sprint test is simply the speed and agility test repeated. The resulting estimation of sample size for a power of 0.8 was 4 subjects per group which clearly will not be a representative sample. A such group sizes of between 8-10 will be sought
11.3 Criteria for inclusion and exclusion for example age and gender:	Inclusion: male, 18-35 yrs of age, University 1st team standard in squash or football, a minimum of 5 years playing experience at the specified competitive levels, a frequency of participation of at least 3 sessions weekly, and satisfactory medical pre-screening results. Exclusion: participants of the required standard in both sports, non-satisfaction of any of the above inclusion criteria.

11.4 Procedures for recruitment for example location and methods:	Participants will be sought via contacts with the University sports teams. Teams will be given a verbal presentation of the purpose and procedures of the study. Participant information sheets and informed consent forms will be disseminated with a seven day cooling off period allowed between signature and commencement of testing.
11.5 Does the study have *minors or ‡vulnerable adults as participants?	Yes [ ] No [√]
11.6 Is CRB disclosure required for the Principal Investigator? *(To be determined by risk assessment)*	Yes [ ] No [√] If yes, is standard [ ] or enhanced [ ] disclosure required?

11.7 If you ticked 'Yes' in 11.5 and 'No' in 11.6 please explain why:

*Minors are participants under the age of 18 years.
‡Vulnerable adults are participants over the age of 16 years who are likely to exhibit:
a) learning difficulties
b) physical illness/impairment
c) mental illness/impairment
d) advanced age
e) any other condition that might render them vulnerable

12. Purpose and benefit of investigation
Statement of the research problem with any necessary background information.
(No more than 1 side of A4)

characterised by a high-intensity intermittent activity pattern with mean rally lengths of 16-21 s and recovery times of 10 - 16 s between rallies (Montpetit, 1990; Hughes and Robertson, 1998).. Heart rate quickly reaches a steady state equivalent to 80-90% of predicted maximum Brown and Winter, 1995) mean $\dot{V}O_2$ values are approximately 42 $ml \cdot kg^{-1} \cdot min^{-1}$ (74 %$\dot{V}O_{2max}$) (Gillam *et al.* 1990; Todd *et al.* 1998), and mean blood lactate concentrations are between 2 and 4 $mmol \cdot l^{-1}$ (Beauchamp and Montpetit, 1980; Noakes et al., 1982; Mercier et al., 1987). These responses suggest that intramuscular phosphates and O_2 stores are used during the short duration, high intensity rallies and are replenished by oxidative metabolism during the short recovery periods. The $\dot{V}O_{2max}$ values of 62 – 66 $ml \cdot kg^{-1} \cdot min^{-1}$ and Wingate peak powers of 12.5 – 13.5 $W \cdot kg^{-1}$ in élite male players confirm the importance of both high anaerobic and aerobic power for successful performance (Chin *et al.*, 1995; Brown *et al.*, 1998).

In common with multiple-sprint activities such as soccer, basketball and other racket sports, the specific movement patterns and demands of squash provide a unique challenge to physiologists in their attempts to produce valid and reliable assessments of physiological factors relevant to squash performance. Only specific yet controlled tests can provide truly useful data from which to assess players' strengths and weaknesses for training purposes and to track sport-specific training adaptations that might otherwise go undetected by conventional non-specific laboratory procedures (Müller *et al.* 2000).

Research problem.

While there have been published protocols for the assessment of squash-specific aerobic capabilities (Steininger and Wodick, 1987; Girard *et al.*, 2005), currently there appear to be no published squash-specific tests for repeated sprint capabilities that might be a more powerful performance predictor due to similarity with game specific movement patterns, rest: exercise ratios, and energy systems interplay . A repeated sprint test developed for hockey showed significant and strong relationships to performance measures from match play and could also discriminate between players of different standards (Boddington *et al.*, 2004). An appropriate test for assessment of squash-specific repeated sprint capability needs to consider the multi-directional, short distance nature of squash movements. Vučković *et al.* (2004) reported that more than 40% of movements in a rally occurred within 1 m of the T position, and the maximum single movement distance is unlikely to be more than 3.5 m (the diagonal distance from T to one racquet length from the court corner). In fact most squash movements are not in a straight line, so a truly specific test would also need to encompass an element of agility or the ability to control multiple changes of direction at speed.

Purpose of the study.

The purpose of the study is to examine the validity and reproducibility of a squash-specific repeated sprint test.

Benefits.

The test can be examined for its ability to predict performance and could also be used as an outcome measure in studies to investigate physiological determinants of squash-specific repeated sprint ability.

13. Details of the research design and protocol(s

13.1 provide details.

Following habituation with test procedures, participants (8-10 trained squash players and 8-10 trained footballers) will undertake three tests including a treadmill assessment of $\dot{V}O_{2max}$, Bakers 8 × 40 m shuttle test (BST), and the squash-specific repeated sprint test (SSRST). All tests will be performed on separate days with the treadmill test occurring first and the order of the other two tests randomised and counterbalanced. Approximately 7 days later, participants will undertake the BST and the SSRST a second time to examine reproducibility of test performance.

On arrival at the test venue, body mass and stature will be measured using calibrated balance beam scales and a stadiometer respectively.

Treadmill Test.
After a standardised warm-up, participants will run on a motorised treadmill at a starting speed of 13 km/h with the speed increasing every minute up to 16 km/h after which the speed remains constant but the gradient of the treadmill increases by 1% every minute. The participant continues on the test until they reach volitional fatigue. Throughout the test expired air is collected breath by breath for subsequent calculation of $\dot{V}O_{2max}$ using the Quark B^2 (Cosmed, Italy) and heart rate is recorded beat by beat using a heart rate telemetry (Polar OY, Finland). Performance time for the test is also recorded using an electronic timer. $\dot{V}O_{2max}$ will be used to characterise the general training status of the participants.

Baker's 8 × 40 m shuttle test.
Participants complete a standardised warm-up of four minutes jogging the shuttle course at 50 % of maximum effort, then a final minute containing one completion of the course at 70 % maximum effort and one completion of the course at 90 % maximum effort with jog recoveries. The Baker's shuttle course comprises two cones placed 20 m apart with a central cone at 10 m between them. Participants start at the central cone and after a 3-2-1 countdown sprint all-out to one end cone, change direction and sprint to the opposite end cone before again changing direction to finish at the central cone. Twenty seconds recovery is allowed before commencing the next sprint. Time to complete each sprint is recorded to the nearest 100th of a second using an electronic timer.

Squash-specific repeated sprint test.
After a standardised warm-up as stated above, participants complete a repetition of the SSRST course which comprises two laps of the course marked out using cones. The layout and path through the SSRST course are shown on the appended diagram. Participants must move between and around the large inner cones to reach out and touch the smaller outer cones with the fingers of one hand. Participants are allowed twenty seconds recovery between each sprint and must complete 10 sprints. Each sprint is performed all-out with performance time to the nearest 100th of a second recorded using an electronic timer.

Physiological measures.
Heart rate will be recorded continuously during each repeated sprint test and blood lactate concentration will be measured pre and post each test from a finger prick blood sample.

13.2 Are these "minor" procedures as defined in Appendix I of the ethics guidelines?	Yes [ ] No [√]
13.3 If you answered 'No' in Section 13.2, list the procedures that are not minor.	All-out SSRST and BST runs, $\dot{V}O_{2max}$ assessment.

14. Indicative methods of analysis

14.1 Provide details of the quantitative and qualitative analysis to be used.

$\dot{V}O_{2max}$ will be calculated as the highest 30 –s stationary retrograde time mean of the breath-by-breath data from the treadmill test. Fatigue index from the SSRST and the BST will be calculated as the percentage change from the mean of the first two sprints and the mean of the final two sprints. Following verification of underlying assumptions, independent samples T-tests will be performed between squash and non-squash players to examine differences between total performance time, fatigue index, peak and mean heart rate and pre and post test blood lactate on both the SSRST and the BST. Differences in peak and mean heart rate and pre and post test blood lactate concentration within groups across the two tests will be examined using paired samples T-tests.

15. Substances to be administered (Refer to Appendix V of the ethics guidelines)

15.1 The protocol does not involve the administration of pharmacologically active substances or nutritional supplements. *(Please tick the box if this statement applies and go to section 16)* [√]

15.2 Name and state the risk category for each substance. If a COSHH assessment is required state how the risks are to be managed.

16. Degree of discomfort that participants might experience

16.1 To consider the degree of physical or psychological discomfort that will be experienced by the participants. State the details which must be included in the participant information sheet to ensure that the participants are fully informed about any discomfort that they may experience.

Participants will experience feelings associated with maximal exertion near the end of $\dot{V}O_{2max}$ testing which will dissipate quickly after completion. There will also be local muscular and general sensations of fatigue associated with maximal exertion in the SSRST and the BST however these tests are of short duration and fatigue will dissipate quickly after completion. Participants may also experience slight discomfort associated with the finger prick blood sampling.

17. Outcomes of Risk Assessment

17.1 Provide details of the control measures arising out of the assessment of risk including the nature of supervision and support required during the experimental phase of the project.

General control measures for $\dot{V}O_{2max}$ and all-out repeated sprint tests.

1. Pre- screening medical questionnaire. 2. Strict adherence to the agreed protocol which includes a warm-up and cool-down. 3. The participant is monitored by a trained first aider following the test. 4. Heart rate is continually monitored. 5. Visual communication is maintained between investigator and participant throughout the exercise test. 6. all breathing apparatus are sterilised prior to and after use. 7. shoe laces are secured. 8. at least 2 people are present at the exercise test. 8. capillary blood sampling is performed by a trained phlebotomist in accordance with the risk assessed and approved procedures for the correct handling of human blood.

18. Safe System of Work

18.1 Indicate how the control measures outlined in section 17.1 will be implemented to minimise the risks in undertaking the research protocol (refer to 13.1). State the technical skills needed by the Principal Investigator to ensure safe working.

The principal investigator is a trained first aider and phlebotomist, he is also aware of the correct implementation of control measures stated in the risk assessment documentation

19. Attachments

(Place a tick in the appropriate description)

19.1 Risk Assessment(s) (Include CRB risk assessment)	[√]
19.2 COSHH Assessment	[ ]
19.2 Participant Information Sheet	[√]
19.3 Informed Consent Form	[√]
19.4 Pre-Test Medical Questionnaire	[√]
19.5 Collaboration evidence/support (see 10)	[ ]
19.6 Collaboration facilities (see 9)	[√]
19.7 Clinical Trials Form (FIN 12)	[ ]

20. Signature Principal Investigator	**Once this application is approved, I will undertake the study as approved. If circumstances necessitate that changes are made to the approved protocol, I will discuss these with my Project Supervisor. If the supervisor advises that there should be a resubmission to the Ethics Committee, I agree that no work will be carried out using the changed protocol until approval has been sought and formally received.** **…………………………………………………………………………Principal Investigator** **Name ………………………………………………….**
21. Approval Project Supervisor to sign off EITHER box A OR box B as applicable. *(refer to Appendix I and the flowchart in appendix VI of the ethics guidelines)*	**Box A:** **I confirm that the experimental protocol contained in this proposal is based solely on 'minor' procedures, as outlined in Appendix 1 of the HWB Sport and Exercise Research Ethics Operating Group Procedures for the Use of Humans in Research document, and therefore does not need to be submitted to the HWB Sport and Exercise Research Ethics Operating Group.** **In terms of ethics approval, I agree the 'minor' procedures proposed here and confirm that the Principal Investigator may proceed with the study as designed.** **Project Supervisor …………………………………………………Date …………….** **Name ………………………………………………….**
	Box B: **I confirm that the experimental protocol contained in this proposal is not based solely on 'minor' procedures, as outlined in Appendix 1 of the HWB Sport and Exercise Research Ethics Operating Group Procedures for the Use of Humans in Research document, and therefore must be submitted to the HWB Sport and Exercise Research Ethics Operating Group for approval.** **I confirm that the appropriate preparatory work has been undertaken and that this document is in a fit state for submission to the HWB Sport and Exercise Research Ethics Operating Group.** **Project Supervisor……………………………………………… Date …………….** **Name ………………………………………………….**
22. Signature Technician	**I confirm that I have seen the full and approved application for ethics approval and technical support will be provided.** **Technician ………………………………………………………… Date …………….** **Name ………………………………………………….**

Sheffield Hallam University

Faculty of Health and Wellbeing Research Ethics Committee
Sport and Exercise Research Ethics Review Group

Participant Information Sheet

Project Title	Validity and reproducibility of a squash-specific repeated sprint test.
Supervisor/Director of Studies	Professor Edward M Winter
Principal Investigator	Mick Wilkinson
Principal Investigator telephone/mobile number	0191 2437097 / 07754 870997

Purpose of Study and Brief Description of Procedures
(Not a legal explanation but a simple statement)

Background to the Study.

In common with multiple-sprint activities such as soccer, basketball and other racket sports, the specific movement patterns and demands of squash provide a unique challenge to physiologists in their attempts to produce valuable and consistent assessments of elements of fitness relevant to squash performance. Only sport-specific yet controlled tests can provide truly useful data from which to assess players' strengths and weaknesses for training purposes and to track sport-specific training adaptations that might otherwise go undetected by conventional non-specific fitness tests.

Currently there are no squash-specific tests for repeated sprint ability that might be a powerful performance predictor due to similarity with movement patterns and rest to exercise ratios of actual game play.

Purpose of the Study.

Therefore, the purpose of this study is to examine the value and consistency of a squash-specific repeated sprint test.

Procedures.

You will be required to make 5 visits in total to the University for laboratory testing (3 visits in one week then 2 visits in the following week). On arrival for your first visit, your height and body weight will be measured.

Following these basic measures and a standardised warm-up the following tests will be completed in this order:

Visit 1.

You will be required to complete a treadmill test to assess your maximum aerobic fitness level. The treadmill test will take place on a motorised treadmill. Following a standard warm-up, you will be fitted with a nose and mouth mask for collection of your expired breath during the tests, and a chest belt to record heart rate during the test. You will then be required to run at 13 km/h with the speed increasing every minute up to 16 km/h, then continuing to run at that speed with the treadmill slope increasing by 1% every minute until you feel you cannot continue. The latter test stages will feel particularly tough but fatigue will disappear quickly afterwards.

Visits 2 and 3.

In the second and third visits you will be required to complete a squash-specific repeated sprint test and a non-squash specific repeated sprint test. You will only perform one of these on each day.

The squash-specific repeated sprint test involves all-out squash-related movements around a course of cones with frequent and rapid changes of direction. The course is very short and takes around than 20 seconds to complete. You are allowed twenty seconds recovery between each sprint and must complete 10 sprints. Your time to complete each sprint will be recorded.

The non-squash specific test has two cones placed 20 m apart with a central cone at 10 m between them. Starting at the central cone and after a 3-2-1 countdown you sprint all-out to one end cone, change direction and sprint to the opposite end cone before again changing direction to finish at the central cone. Twenty seconds recovery is allowed before commencing the next sprint. Time to complete each sprint is recorded.

Prior to and immediately after each test a small blood sample will be taken from a finger prick by a qualified blood sampler to examine levels of a physiological marker of fatigue. You will also be required to wear a chest strap and wrist watch receiver that will record your heart rate during each test.

Visits 4 and 5.

You will be required to perform the tests described in visits 2 and 3 a second time approximately 7 days later and at the same time of day, with all the same measurements being taken in order to assess consistency of test results.

There will be local muscular and general sensations of fatigue associated with maximal exertion in the repeated sprint tests however these tests are of short duration and fatigue will dissipate quickly after completion. You may also experience slight discomfort associated with the finger prick blood samples.

Your rights as a participant.
Your participation in this study is voluntary. You are free to refuse to start the testing or withdraw at any time in the proceedings without penalty or prejudice and without giving any reason for so doing. No disadvantage will arise from any decision to participate or not.
The results of the research may be published, but your name will not be used, and no individual identifying information will be provided. All data collected will be coded to retain anonymity, and any personal details will be stored in a locked filing cabinet with access limited to the investigator.

If you have any questions concerning the procedures or any other aspects of the project, feel free contact the principal investigator in person or by telephone on the number given.
Some test sessions may be video taped however the video will only be used for further analysis by the investigator and study supervisors. Access to the tapes will be limited to the investigator and the study supervisor. Any further use of the video taped tests will not be undertaken without the express permission of the participant filmed who will of course remain anonymous.

It has been made clear to me that, should I feel that these Regulations are being infringed or that my interests are otherwise being ignored, neglected or denied, I should inform Professor Edward Winter, Chair of the Faculty of Health and Wellbeing Research Ethics Committee (Tel: 0114 225 4333) who will undertake to investigate my complaint.

Sheffield Hallam University

Faculty of Health and Wellbeing Research Ethics Committee
Sport and Exercise Research Ethics Review Group

INFORMED CONSENT FORM

TITLE OF PROJECT: Validity and reproducibility of a squash-specific repeated sprint test.

The participant should complete the whole of this sheet himself/herself

Have you read the Participant Information Sheet?	YES/NO
Have you had an opportunity to ask questions and discuss this study?	YES/NO
Have you received satisfactory answers to all of your questions?	YES/NO
Have you received enough information about the study?	YES/NO
To whom have you spoken? .... Do you understand that you are free to withdraw from the study: • at any time • without having to give a reason for withdrawing • and without affecting your future medical care	YES/NO
Have you had sufficient time to consider the nature of this project?	YES/NO
Do you agree to take part in this study?	YES/NO

Signed .... Date ....

(NAME IN BLOCK LETTERS)...

Signature of Parent / Guardian in the case of a minor

....

Faculty of Health and Wellbeing Research Ethics Committee
Sport and Exercise Research Ethics Review Group
Report Form

Principal Investigator: Mick Wilkinson

Title: Validity and reproducibility of a squash-specific repeated sprint test.

Checklist:

Application form	√
Informed consent form	√
Risk assessment form	√
Participant information sheet	√
Pre-screening form	√
Pre-screening form (under 18)	n/a
Collaboration evidence/support	√
CRB Disclosure form	n/a

Recommendation:

Acceptable: ☐

Not acceptable, see comments: ☐

Acceptable, but see comments: ☑

Comments:

1. We advise you to include a group of racket sport players, preferably tennis players as part of the validation.

Signature : .... Date: 5th Dec 2007

Professor Edward Winter, Chair
Faculty of Health and Wellbeing Research Ethics Committee
Sport and Exercise Research Ethics Review Group

***Note:** Approval applies until the anticipated date of completion unless there are changes to the procedures, in which case another application should be made.*

Name of Tutor / Director of Studies / Supervisor : Edward Winter

13.8 Appendix eight – Study four SPSS output

```
T-TEST
  GROUPS = group(1 2)
  /MISSING = ANALYSIS
  /VARIABLES = BTT STTT BHRmax STHRmax Blac STlac Bmass height
  /CRITERIA = CI(.95) .
```

T-Test

```
[DataSet0] C:\Documents and Settings\User\My Documents\My Safe\PhD Dec
07\Study 4 - repeated sprint test\Independent T-test data.sav
```

Group Statistics

	group	N	Mean	Std. Deviation	Std. Error Mean
bakers total time	footballers	8	72.9575	2.78662	.98522
	squash players	8	72.8913	3.88577	1.37383
squash test total time	footballers	8	264.0625	14.43756	5.10445
	squash players	8	232.1050	32.28528	11.41457
BHRmax	footballers	8	189.5000	17.40279	6.15282
	squash players	8	171.7500	7.94175	2.80783
STHRmax	footballers	8	186.5000	12.95046	4.57868
	squash players	8	180.0000	7.55929	2.67261
Blac	footballers	8	7.2750	2.86444	1.01273
	squash players	8	4.1625	1.24434	.43994
STlac	footballers	8	7.1375	1.40808	.49783
	squash players	8	5.5500	1.94569	.68791
Bmass	footballers	8	81.9375	11.75438	4.15580
	squash players	8	72.8125	7.85883	2.77852
height	footballers	8	1.7938	.09471	.03348
	squash players	8	1.7725	.03536	.01250

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
bakers total time	Equal variances assumed	1.934	.186	.039	14	.969	.06625	1.69058	-3.55968	3.69218
	Equal variances not assumed			.039	12.694	.969	.06625	1.69058	-3.59500	3.72750
squash test total time	Equal variances assumed	8.599	.011	2.556	14	.023	31.95750	12.50391	5.13928	58.77572
	Equal variances not assumed			2.556	9.692	.029	31.95750	12.50391	3.97658	59.93842
BHRmax	Equal variances assumed	4.424	.054	2.624	14	.020	17.75000	6.76321	3.24435	32.25565
	Equal variances not assumed			2.624	9.794	.026	17.75000	6.76321	2.63762	32.86238
STHRmax	Equal variances assumed	1.339	.267	1.226	14	.240	6.50000	5.30162	-4.87084	17.87084
	Equal variances not assumed			1.226	11.274	.245	6.50000	5.30162	-5.13429	18.13429
Blac	Equal variances assumed	3.435	.085	2.819	14	.014	3.11250	1.10416	.74431	5.48069
	Equal variances not assumed			2.819	9.551	.019	3.11250	1.10416	.63651	5.58849
STlac	Equal variances assumed	1.172	.297	1.870	14	.083	1.58750	.84915	-.23374	3.40874
	Equal variances not assumed			1.870	12.754	.085	1.58750	.84915	-.25057	3.42557
Bmass	Equal variances assumed	2.707	.122	1.825	14	.089	9.12500	4.99908	-1.59697	19.84697
	Equal variances not assumed			1.825	12.216	.092	9.12500	4.99908	-1.74576	19.99576
height	Equal variances assumed	1.720	.211	.595	14	.562	.02125	.03574	-.05541	.09791
	Equal variances not assumed			.595	8.914	.567	.02125	.03574	-.05972	.10222

```
T-TEST
  PAIRS = SHRst slst fhrst flst  WITH shrbt slbt fhrbt flbt (PAIRED)
  /CRITERIA = CI(.95)
  /MISSING = ANALYSIS.
```

T-Test

```
[DataSet0] C:\Documents and Settings\User\My Documents\My Safe\PhD Dec
07\Study 4 - repeated sprint test\paired sample and correlation
data.sav
```

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	sq max HR ST	180.0000	8	7.55929	2.67261
	sq max HR BT	171.7500	8	7.94175	2.80783
Pair 2	sq lactate ST	5.5500	8	1.94569	.68791
	sq lactate BT	4.1625	8	1.24434	.43994
Pair 3	ftb max HR ST	186.5000	8	12.95046	4.57868
	ftb max HR BT	189.5000	8	17.40279	6.15282
Pair 4	ftb lactate ST	7.1375	8	1.40808	.49783
	ftb lacate BT	7.2750	8	2.86444	1.01273

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	sq max HR ST & sq max HR BT	8	.593	.122
Pair 2	sq lactate ST & sq lactate BT	8	.773	.025
Pair 3	ftb max HR ST & ftb max HR BT	8	.408	.316
Pair 4	ftb lactate ST & ftb lacate BT	8	.623	.099

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	sq max HR ST - sq max HR BT	8.25000	7.00510	2.47668	2.39359	14.10641	3.331	7	.013
Pair 2	sq lactate ST - sq lactate BT	1.38750	1.26201	.44619	.33243	2.44257	3.110	7	.017
Pair 3	ftb max HR ST - ftb max HR BT	-3.00000	16.93686	5.98808	-17.15957	11.15957	-.501	7	.632
Pair 4	ftb lactate ST - ftb lacate BT	-.13750	2.27152	.80311	-2.03654	1.76154	-.171	7	.869

```
NONPAR CORR
  /VARIABLES=rank SRST1 BK1
  /PRINT=SPEARMAN TWOTAIL NOSIG
  /MISSING=PAIRWISE .
```

Nonparametric Correlations

```
[DataSet1] C:\Documents and Settings\User\My Documents\My Safe\PhD Dec
07\Study 4 - repeated sprint test\Spearmans data - study 4.sav
```

Correlations

			rank	SRST1	BK1
Spearman's rho	rank	Correlation Coefficient	1.000	.786*	.548
		Sig. (2-tailed)	.	.021	.160
		N	8	8	8
	SRST1	Correlation Coefficient	.786*	1.000	.833*
		Sig. (2-tailed)	.021	.	.010
		N	8	8	8
	BK1	Correlation Coefficient	.548	.833*	1.000
		Sig. (2-tailed)	.160	.010	.
		N	8	8	8

*. Correlation is significant at the 0.05 level (2-tailed).

```
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Correlations

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07\Study 4 - repeated sprint test\paired sample and correlation
data.sav
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Correlations

		sq total time ST	sq total time BT	ftb total time ST	ftb total time BT
sq total time ST	Pearson Correlation	1	.978**	-.211	-.130
	Sig. (2-tailed)		.000	.615	.758
	N	8	8	8	8
sq total time BT	Pearson Correlation	.978**	1	-.140	-.179
	Sig. (2-tailed)	.000		.741	.672
	N	8	8	8	8
ftb total time ST	Pearson Correlation	-.211	-.140	1	-.067
	Sig. (2-tailed)	.615	.741		.875
	N	8	8	8	8
ftb total time BT	Pearson Correlation	-.130	-.179	-.067	1
	Sig. (2-tailed)	.758	.672	.875	
	N	8	8	8	8

**. Correlation is significant at the 0.01 level (2-tailed).

13.9 Appendix nine – Study five ethics documents and letter of approval

CONFIDENTIAL

Sheffield Hallam University

Faculty of Health and Wellbeing
Research Ethics Committee

Sport and Exercise Research Ethics
Review Group

APPLICATION FOR APPROVAL OF RESEARCH

In designing research involving humans, principal investigators should be able to demonstrate a clear intention of benefit to society and the research should be based on sound principles. These criteria will be considered by the Ethics Committee before approving a project. ALL of the following details must be provided, either typewritten or word-processed preferably at least in 11 point font.

Please either tick the appropriate box or provide the information required.

1. Date of Application	8th January 2007

2. Anticipated Date of Completion	30th March 2007

3. Title of Investigation	Physiological determinants of squash-specific movement economy

4. Subject Area	Physiology of exercise

5. Principal Investigator **Name** **Email address** **Telephone/mobile number** **Student number**	Mick Wilkinson Mic.wilkinson@unn.ac.uk 0191 2437097 10044067

6. Is this

6.1 a research project? [ ]

	Module Name	**Module Number**
6.2 an undergraduate project? [ ]		

8. Intended duration and timing of project	Data collection is planned to commence in February 2007 for completion be the end of March 2007. Subsequent analysis and write-up are planned for completion by May 2007 with intended submission in June 2007.

6.3 a postgraduate project? [√]	PhD	

7. Director of Studies/ Supervisor/Tutor	Professor Edward M Winter

9. Location of project (If parts are external to SHU, provide evidence in support in section 19)	All testing will be carried out in the exercise physiology laboratories at Northumbria University.

10. Is this study	
10.1 Collaborative? [√]	**If yes please include appropriate agreements in section 19** For facilities only
10.2.1 Replication [ ] of	
10.2.2 New [√]	

11. Participants	
11.1 Number	6-10
11.2 Rationale for this number: (eg calculations of sample size)	Power calculation based on means and SD for poor and good squash-specific economy from previous unpublished study data. The estimated sample n for a two group design was calculated using the equation of Vincent (1999). The lower estimated *n* is derived using the smaller of the two group standard deviations from the previous study data, the higher estimated *n* is derived from a calculation using the largest SD.
11.3 Criteria for inclusion and exclusion for example age and gender:	Inclusion: Male squash players aged 18-40 with at least 5 years playing experience in division one of local leagues or higher, and a competitive playing frequency of at least 3 times per week. Satisfactory pre-test medical screening results Exclusion: absence of any of the above.

11.4 Procedures for recruitment for example location and methods:	Participants will be volunteers through contacts at local squash clubs. The nature and aims of the study will be explained in a group presentation to the players at each club.
11.5 Does the study have *minors or ‡vulnerable adults as participants?	Yes [ ] No [√]
11.6 Is CRB disclosure required for the Principal Investigator? *(To be determined by risk assessment)*	Yes [ ] No [√] If yes, is standard [ ] or enhanced [ ] disclosure required?

11.7 If you ticked 'Yes' in 11.5 and 'No' in 11.6 please explain why:

*Minors are participants under the age of 18 years.
‡Vulnerable adults are participants over the age of 16 years who are likely to exhibit:
a) learning difficulties
b) physical illness/impairment
c) mental illness/impairment
d) advanced age
e) any other condition that might render them vulnerable

12. Purpose and benefit of investigation

Statement of the research problem with any necessary background information.
(No more than 1 side of A4)

are similar to that of a continuous endurance type performance. The high and steady heart rates (Brown and Winter, 1995) and oxygen uptakes ($\dot{V}O_2$) (Gillam *et al.*, 1990) together with the low concentrations of blood lactate (Mercier *et al.*, 1987) confirm that despite the intermittent activity pattern, squash is an endurance-based activity.
As such, physiological determinants should be the same as for other continuous endurance activities and with professional matches lasting in excess of 90 minutes, economy could well be a crucial performance determinant.

Movement economy is a well recognised determinant of endurance-based sports performance and has been shown to be a powerful predictor of performance in homogenous groups of elite endurance athletes (Conley and Krahenbuhl, 1980). However most research has focussed on distance running that is continuous in nature. Although the relative importance of mechanical, anthropometric and physiological factors cannot be agreed, it is generally accepted that the ability to use stored elastic energy on each foot strike is a determinant of economy in running and in fact in most types of weight bearing locomotion (Martin and Morgan, 1992; Craib *et al.*, 1996; Jones, 2002; Alexander and Goldspink, 1977; McMahon, 1984). There are also findings supporting explosive strength as a factor leading to improved running economy (Paavolainen *et al.*, 1999).

Movement patterns in squash are varied and unique. When viewed in conjunction with the intermittent nature of activity, the assessment of squash-specific economy becomes a challenging task, however pilot studies have indicated this is possible. Given the importance of economy as a performance determinant in endurance sports there is a need to devise a method of measuring squash-specific movement economy so that physiological factors that underpin economy in squash can be determined.

Research problem.
There is currently no literature examining either economy or physiological determinants of economy in squash or any other multiple sprint activity. As such it is unclear if those factors related to running economy will also be important in high intensity intermittent activity. However, as squash movement is a weight bearing activity, there is at least a theoretical basis for examining the utilisation of elastic energy as potential determinant. The explosive nature of squash movements often from a static start also suggests that muscular factors related to impulse generation are also important. Furthermore, the rapid and regular changes of direction involved in squash movement suggest that neuromuscular factors such as speed and agility are also important. The determination of physiological factors underlying squash-specific economy could lead to specific training to improve this aspect of performance.

Research questions.
Can economy be measured in squash-specific movements with an intermittent activity pattern? Pilot work has suggested it is measurable, but this needs confirming.
Is the ability to utilise the stretch-shortening cycle related to squash-specific economy?
Is explosive strength related to squash-specific economy?
Are speed and agility related to squash-specific economy?

Benefits
Identification of factors determining squash movement economy could lead to more effective training methods and could also be used for talent identification.

13. Details of the research design and protocol(s

13.1 provide details.

Following habituation with test procedures, participants will undertake tests of factors speed, explosive strength, repeat-sprint ability and reactive muscle strength (ability to use the stretch shortening cycle) and one test of squash-specific economy including assessment of $\dot{V}O_{2max}$.

On arrival at the test venue, body mass and stature will be measured using calibrated balance beam scales and a stadiometer respectively. Percentage body fat will be estimated using skinfold callipers and the procedures of Durnin and Wormesley (1974).

Squash Speed and Agility Test (SSAT).
Following a suitable standardised warm-up, participants will complete three all-out runs through the SSAT. The SSAT is designed to assess speed and agility in squash specific movements. Unpublished data suggest that the SSAT is a valid and reliable test of squash-specific agility and speed. The best / fastest time through the course will be recorded. Performance time will be measured with a laser timing gate.

Squash repeat-sprint test (SRST).
This is similar to the SSAT and is performed on the same course. However, one repetition comprises two laps of the course and a twenty-second recovery is allowed between efforts. The test comprises ten efforts in total. Timing is a described above.

Explosive strength testing.
Using protocols described by Young (1995), participants will complete three drop jumps onto a force plate from three different heights (30, 45 and 60 cm). A reactive strength performance score will calculated from maximum jump height (estimated from flight time) divided by contact time on the force plate. Subjects will be instructed to jump for maximum height but with minimum contact time. This test is reported to measure the ability to utilise the SSC reflex in fast SSC activities (< 250 ms) (Young, 1995).

Following a suitable recovery, participants will be required to complete 3 static vertical jumps on a force plate from a standardised starting position for maximum jump height (best score recorded), and 3 counter movement jumps (again best score recorded). Counter movement jump height minus static vertical jump height is another reported measure of SSC ability but in slow SSC activities (> 500 ms) (Young, 1995).

Economy and $\dot{V}O_{2max}$ testing.
All participants will complete a test that is designed to assess movement economy and $\dot{V}O_{2max}$ in an on-court procedure. This will be based on the procedure developed and used by Damon Leedale-Brown with the England Squash program (personal communication). Unpublished data suggest the on-court test is a valid replication of game specific physiological demand. With modifications, the test allows squash-specific movement patterns to be performed at controlled intensities whilst oxygen uptake is measured using the Cortex Metamax 3B portable gas analyser. In addition heart rate will be recorded online via a chest belt transmitter. The movements are performed in a ‘semi random’ manner with the pattern of movement to each portion of the court repeated nominally every minute. This element of randomness is essential to replicate specific squash demands.
Participants will complete two stages of the on-court test. The first stage (level 7) will be performed in a continuous fashion for four minutes. Following a short rest (approx 30 s to allow change of test CD), participants will complete a six minute stage at level 8 of the test (representing the average movement speed of competitive match play). This stage will be performed in an intermittent fashion with 20 s of movement followed by 10 s of rest repeated for the duration of the stage. The continuous exercise stage at level 7 prior to the intermittent stage was adopted as pilot testing showed it attenuated a delayed achievement of steady state ($\dot{V}O_2$) otherwise present in the intermittent exercise stage. It also allows a comparison of economy predictors in squash movement performed continuously and intermittently. Economy will be taken as the mean of the final minute $\dot{V}O_2$ in each exercise stage. Following completion of level 8, the speed of movement (test level) will be increased every minute until volitional fatigue for the assessment of $\dot{V}O_{2max}$.

13.2 Are these "minor" procedures as defined in Appendix I of the ethics guidelines?	Yes [ ] No [√]
13.3 If you answered 'No' in Section 13.2, list the procedures that are not minor.	All-out SSAT and SRST runs, $\dot{V}O_{2max}$ assessment, all-out vertical jumps.

14. Indicative methods of analysis

14.1 Provide details of the quantitative and qualitative analysis to be used.

A median split will be performed on the predictor variables (strength SRST and SSAT scores) separating participants into high and low scoring groups. ANCOVA's will then be carried out with high vs low score on the predictors as the independent variables, movement economy as the dependent (outcome) variable, and the actual strength, SRST and SSAT scores as covariates. If the covariate does predict the outcome variable, the adjusted means will differ from the non-adjusted means.

The possibility of performing a multiple linear regression analysis with economy as the dependent variable and strength and SSAT scores as independent variables was excluded as a power analysis estimated a sample size of 66 which was deemed unattainable.

15. Substances to be administered (Refer to Appendix V of the ethics guidelines)

15.1 The protocol does not involve the administration of pharmacologically active substances or nutritional supplements. *(Please tick the box if this statement applies and go to section 16)* [√]

15.2 Name and state the risk category for each substance. If a COSHH assessment is required state how the risks are to be managed.

16. Degree of discomfort that participants might experience

16.1 To consider the degree of physical or psychological discomfort that will be experienced by the participants. State the details which must be included in the participant information sheet to ensure that the participants are fully informed about any discomfort that they may experience.

Participants will experience moderate feelings of exertion associated with the economy and $\dot{V}O_{2max}$ testing which will dissipate quickly after completion. There will also be local muscular sensations of fatigue associated with maximal exertion in the SSAT, SRST and the maximum jumping tests, however these tests are of very short duration and fatigue will dissipate quickly after completion.

17. Outcomes of Risk Assessment

17.1 Provide details of the control measures arising out of the assessment of risk including the nature of supervision and support required during the experimental phase of the project.

General control measures for sub-maximum and maximum intensity squash movement tests.

1. Pre- screening medical questionnaire. 2. Strict adherence to the agreed protocol which includes a warm-up and cool-down. 3. The participant is monitored by a trained first aider following the test. 4. Heart rate is continually monitored. 5. Visual communication is maintained between investigator and participant throughout the exercise test. 6. all breathing apparatus are sterilised prior to and after use. 7. shoe laces are secured. 8. at least 2 people are present at the exercise test.

General control measures for explosive strength and speed and agility testing.

1. pre-screening medical questionnaire. 2. Strict adherence to the agreed protocol which includes a warm-up and cool-down. 3. The participant is monitored by a trained first aider following the test. 4. shoe laces are secured. 5. at least 2 people are present at the exercise test.

18. Safe System of Work

18.1 Indicate how the control measures outlined in section 17.1 will be implemented to minimise the risks in undertaking the research protocol (refer to 13.1). State the technical skills needed by the Principal Investigator to ensure safe working.

The principal investigator is a trained first aider, he is also aware of the correct implementation of control measures stated in the risk assessment documentation

19. Attachments

(Place a tick in the appropriate description)

19.1 Risk Assessment(s) [√]
(Include CRB risk assessment)

19.2 COSHH Assessment [ ]

19.2 Participant Information Sheet [√]

19.3 Informed Consent Form [√]

19.4 Pre-Test Medical Questionnaire [√]

19.5 Collaboration evidence/support (see 10) [ ]

19.6 Collaboration facilities (see 9) [√]

19.7 Clinical Trials Form (FIN 12) [ ]

20. Signature Principal Investigator	**Once this application is approved, I will undertake the study as approved. If circumstances necessitate that changes are made to the approved protocol, I will discuss these with my Project Supervisor. If the supervisor advises that there should be a resubmission to the Ethics Committee, I agree that no work will be carried out using the changed protocol until approval has been sought and formally received.** **..Principal Investigator** **Name ....**
21. Approval Project Supervisor to sign off EITHER box A OR box B as applicable. *(refer to Appendix I and the flowchart in appendix VI of the ethics guidelines)*	Box A: **I confirm that the experimental protocol contained in this proposal is based solely on 'minor' procedures, as outlined in Appendix 1 of the HWB Sport and Exercise Research Ethics Operating Group Procedures for the Use of Humans in Research document, and therefore does not need to be submitted to the HWB Sport and Exercise Research Ethics Operating Group.** **In terms of ethics approval, I agree the 'minor' procedures proposed here and confirm that the Principal Investigator may proceed with the study as designed.** **Project Supervisor ....Date ....** **Name ....**
	Box B: **I confirm that the experimental protocol contained in this proposal is not based solely on 'minor' procedures, as outlined in Appendix 1 of the HWB Sport and Exercise Research Ethics Operating Group Procedures for the Use of Humans in Research document, and therefore must be submitted to the HWB Sport and Exercise Research Ethics Operating Group for approval.** **I confirm that the appropriate preparatory work has been undertaken and that this document is in a fit state for submission to the HWB Sport and Exercise Research Ethics Operating Group.** **Project Supervisor.. Date ....** **Name ....**
22. Signature Technician	**I confirm that I have seen the full and approved application for ethics approval and technical support will be provided.** **Technician .... Date ....** **Name ....**

Sheffield Hallam University

Faculty of Health and Wellbeing Research Ethics Committee
Sport and Exercise Research Ethics Review Group

Participant Information Sheet

Project Title	Physiological determinants of squash-specific movement economy
Supervisor/Director of Studies	Professor Edward M Winter
Principal Investigator	Mick Wilkinson
Principal Investigator telephone/mobile number	0191 2437097 / 07754 870997

Purpose of Study and Brief Description of Procedures
(Not a legal explanation but a simple statement)

Background to the Study.
Although the activity pattern of squash is intermittent, the body responses to play are similar to other continuous type endurance sports. In endurance sports, movement economy or the ability to minimise the energy cost of movement is recognised as a powerful predictor of performance and seems to be related to (among other things) aspects of explosive muscle strength.

There have been no investigations of movement economy in squash, probably due to the difficulty of actually measuring it with the unique movements involved in the sport. However, finding a way to measure squash-specific movement economy and aspects of explosive muscle performance could result in the design of specific forms of training to improve this aspect of performance.

Purpose of the Study.
The purpose of this investigation is to measure movement economy in controlled squash-specific movements and to assess links between economy and various measures of speed and explosive muscle strength.

Procedures.
You will be required to make one visit to the University for laboratory testing. On arrival, your height and body weight will be measured
Following these basic measures and a standardised warm-up the following tests will be completed in this order:

1. A squash-specific test of speed and agility – This test involves all-out squash-related movements around a course of cones with frequent and rapid changes of direction. The course is very short and takes less than 15 seconds to complete. This test will be repeated 3 times with appropriate recovery between each attempt and your best score will be recorded.
2. Squash-specific movement economy and maximum endurance fitness – for this test you will be required to perform ghosting type movements (movements without a ball) to four marked corners from a T position. The corners are numbered and a CD calls out the numbers of the corners you must move to. You need to move to the specified corner and return back to the T before the next number is called. During this test you will be wearing a small shoulder harness carrying an analyser to measure the carbon dioxide and oxygen concentrations of your exhaled breath. Your breath is collected by wearing a latex mask that fits over your nose and mouth. You will also be wearing a chest strap against your skin to record your heart rate.
   The ghosting exercise has two parts. In part 1 of testing you will be required to move in a continuous fashion for four minutes while your oxygen use is analysed as a measurement of your economy.
   In part 2, movements will be continuous and the speed of movement will be increased every minute until you cannot continue. This portion of the test will commence one test level above part 1, and following a short recovery from part one. It will feel very strenuous near the end of the test though this will not be different from feelings of exertion you will have experienced during very hard rallies or training. The feelings of fatigue will disappear shortly after test completion.
3. A racket accuracy task that requires you to hit a squash ball to a target on the wall from a self-hand feed ten times.
4. Completion of a questionnaire that assesses your attitude towards and preference for exercising at different intensities.
5. A squash-specific repeated sprint test – This test involves all-out squash-related movements around a course of cones with frequent and rapid changes of direction. The course is very short and takes around 20-30 seconds to complete. You are allowed twenty seconds recovery between each sprint and must complete 10 sprints. Your time to complete each sprint will be recorded. This test is very strenuous and you will feel out of breath for a short while after you finish.

Your rights as a participant.

Your participation in this study is voluntary. You are free to refuse to start the testing or withdraw at any time in the proceedings without penalty or prejudice and without giving any reason for so doing. No disadvantage will arise from any decision to participate or not.

The results of the research may be published, but your name will not be used, and no individual identifying information will be provided. All data collected will be coded to retain anonymity, and any personal details will be stored in a locked filing cabinet with access limited to the investigator.

As a participant in this study you will be given confidential feedback about your test results which will be your maximal physical fitness ($\dot{V}_{O_2max}$) your movement economy score, and your speed and repeated sprint scores. This information may aid you in your training.

If you have any questions concerning the procedures or any other aspects of the project, feel free contact the principal investigator in person or by telephone on the number given.

Some test sessions may be video taped however the video will only be used for further analysis by the investigator and study supervisors. Access to the tapes will be limited to the investigator and the study supervisor. Any further use of the video taped tests will not be undertaken without the express permission of the participant filmed who will of course remain anonymous.

It has been made clear to me that, should I feel that these Regulations are being infringed or that my interests are otherwise being ignored, neglected or denied, I should inform Professor Edward Winter, Chair of the Faculty of Health and Wellbeing Research Ethics Committee (Tel: 0114 225 4333) who will undertake to investigate my complaint.

Sheffield Hallam University

Faculty of Health and Wellbeing Research Ethics Committee
Sport and Exercise Research Ethics Review Group

INFORMED CONSENT FORM

TITLE OF PROJECT: Physiological determinants of squash-specific movement economy

The participant should complete the whole of this sheet himself/herself

Have you read the Participant Information Sheet?	YES/NO
Have you had an opportunity to ask questions and discuss this study?	YES/NO
Have you received satisfactory answers to all of your questions?	YES/NO
Have you received enough information about the study?	YES/NO
To whom have you spoken? .... Do you understand that you are free to withdraw from the study: • at any time • without having to give a reason for withdrawing • and without affecting your future medical care	YES/NO
Have you had sufficient time to consider the nature of this project?	YES/NO
Do you agree to take part in this study?	YES/NO

Signed .... Date ....

(NAME IN BLOCK LETTERS)..

Signature of Parent / Guardian in the case of a minor

....

Faculty of Health and Wellbeing Research Ethics Committee
Sport and Exercise Research Ethics Review Group
Report Form

Principal Investigator: Mick Wilkinson

Title: Physiological determinants of squash-specific movement economy.

Checklist:

Application form	√
Informed consent form	√
Risk assessment form	√
Participant information sheet	√
Pre-screening form	√
Pre-screening form (under 18)	n/a
Collaboration evidence/support	√
CRB Disclosure form	n/a

Recommendation:

Acceptable: ☐

Not acceptable, see comments: ☐

Acceptable, but see comments: ☑

Comments:

See reviewers comments attached.

Risk assessment should be signed by yourself.

Signature : .... Date: 27th March 2007

Professor Edward Winter, Chair
Faculty of Health and Wellbeing Research Ethics Committee
Sport and Exercise Research Ethics Review Group

Note: *Approval applies until the anticipated date of completion unless there are changes to the procedures, in which case another application should be made.*

Comments from the Review Group have been addressed.

Signature of Tutor / Director of Studies / Supervisor

.... Date: ....

Name of Tutor / Director of Studies / Supervisor : Edward Winter

13.10 Appendix ten – Study five SPSS output

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Correlations

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07\study 5 - performance and fitnes determinants\Study 5 data.sav
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Correlations

		VO2max	TTF	SSAT	SRST
VO2max	Pearson Correlation	1	.489	-.436	-.565*
	Sig. (2-tailed)		.090	.137	.044
	N	13	13	13	13
TTF	Pearson Correlation	.489	1	-.485	-.629*
	Sig. (2-tailed)	.090		.093	.021
	N	13	13	13	13
SSAT	Pearson Correlation	-.436	-.485	1	.840**
	Sig. (2-tailed)	.137	.093		.000
	N	13	13	13	13
SRST	Pearson Correlation	-.565*	-.629*	.840**	1
	Sig. (2-tailed)	.044	.021	.000	
	N	13	13	13	13

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

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Nonparametric Correlations

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Correlations

			rank	VO2max	TTF	SSAT	SRST	Raskill	econ7	Pretol	Prepref
Spearman's rho	rank	Correlation Coefficient	1.000	-.407	-.709**	.527	.819**	-.484	.176	.092	-.006
		Sig. (2-tailed)	.	.166	.007	.064	.001	.094	.566	.764	.986
		N	13	13	13	13	13	13	13	13	13
	VO2max	Correlation Coefficient	-.407	1.000	.599*	-.363	-.648*	.423	.495	-.176	.459
		Sig. (2-tailed)	.168	.	.031	.223	.017	.150	.086	.565	.115
		N	13	13	13	13	13	13	13	13	13
	TTF	Correlation Coefficient	-.709**	.599*	1.000	-.511	-.736**	.275	.000	-.067	.135
		Sig. (2-tailed)	.007	.031	.	.074	.004	.364	1.000	.827	.659
		N	13	13	13	13	13	13	13	13	13
	SSAT	Correlation Coefficient	.527	-.363	-.511	1.000	.797**	-.473	-.181	.168	.072
		Sig. (2-tailed)	.064	.223	.074	.	.001	.103	.553	.584	.816
		N	13	13	13	13	13	13	13	13	13
	SRST	Correlation Coefficient	.819**	-.648*	-.736**	.797**	1.000	-.588*	-.121	.067	-.017
		Sig. (2-tailed)	.001	.017	.004	.001	.	.035	.694	.827	.957
		N	13	13	13	13	13	13	13	13	13
	Raskill	Correlation Coefficient	-.484	.423	.275	-.473	-.586*	1.000	.132	-.478	.227
		Sig. (2-tailed)	.094	.150	.364	.103	.035	.	.668	.098	.457
		N	13	13	13	13	13	13	13	13	13
	econ7	Correlation Coefficient	.176	.495	.000	-.181	-.121	.132	1.000	.050	.594*
		Sig. (2-tailed)	.566	.086	1.000	.553	.694	.666	.	.870	.032
		N	13	13	13	13	13	13	13	13	13
	Pretol	Correlation Coefficient	.092	-.176	-.067	.168	.067	-.478	.050	1.000	-.038
		Sig. (2-tailed)	.764	.565	.827	.584	.827	.098	.870	.	.902
		N	13	13	13	13	13	13	13	13	13
	Prepref	Correlation Coefficient	-.006	.459	.135	.072	-.017	.227	.594*	-.038	1.000
		Sig. (2-tailed)	.986	.115	.659	.816	.957	.457	.032	.902	.
		N	13	13	13	13	13	13	13	13	13

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

13.11 Appendix eleven – Study six ethics documents and letter of approval

CONFIDENTIAL

Sheffield Hallam University

Faculty of Health and Wellbeing
Research Ethics Committee

Sport & Exercise Research Ethics Review Group

APPLICATION FOR ETHICS APPROVAL OF RESEARCH

In designing research involving humans, principal investigators should be able to demonstrate a clear intention of benefit to society and the research should be based on sound principles. These criteria will be considered by the Sport and Exercise Research Ethics Review Group before approving a project. **ALL** of the following details must be provided, either typewritten or word-processed preferably at least in 11 point font.

Please either tick the appropriate box or provide the information required.

1) Date of application	19th June 2008

2) Anticipated date of completion of project	31st August 2008

3) Title of research	Determinants and trainability of squash fitness and performance in elite-standard players

4) Subject area	Physiology of exercise

5) Principal Investigator	
Name	Mick Wilkinson
Email address @ SHU	Mic.wilkinson@unn.ac.uk
Telephone/Mobile number	0191 2437097 / 07754 870997
Student number (if applicable)	10044067

6) State if this study is: (If the project is undergraduate or postgraduate please state module name anc number)	[ ] Research [ ] Undergraduate [√] Postgraduate Module name: PhD Module number:

7) Director of Studies/Supervisor/ Tutor name	Edward M Winter

8) Intended duration and timing of project?	Data collection will take place between July 1st and August 31st 2008. Write-up of the study and completed thesis will be completed by 31st October 2008.

9) Location of project If external to SHU, provide evidence in support (see section 17)	All testing will be carried out at the National Squash Centre, Manchester.

10) State if this study is:	[√] New [√] Collaborative (please include appropriate agreements in section 17) [ ] Replication of :

11) Purpose and benefit of the research
Statement of the research problem with any necessary background information (no more than 1 side of A4)

Squash is a repeat-sprint sport, where success depends on physical, technical, tactical and motor skills (Lees, 2003). However, it is unclear which of these factors best relate to performance or which fitness components determine squash-specific repeat-sprint capability. Furthermore, there appear to be no studies investigating these factors in elite performers. Also unknown is the malleability of squash-specific fitness in response to the type of training undertaken by world class players.

Recently devised squash-specific fitness tests have been used to examine determinants of fitness and performance in high-standard players but not elite-standard players (Wilkinson *et al.*, 2008a, Wilkinson *et al.*, 2008b). The opportunity to assess the utility of recently validated procedures with international-standard players in England Squash's squads has been presented only in the last two weeks.

Research questions.
What are key determinants of squash-specific repeat-sprint capability in elite players?
Which measures of fitness are most related to elite squash performance?

Aims of the study.
The aim of the study is to apply squash-specific procedures recently validated and used with high-standard, but non-elite players to elite performers to examine determinants of performance and repeat-sprint capability in elite-standard squash players.

Benefits
Identification of factors determining squash performance and repeat-sprint capability could lead to more effective training methods and could also be used for talent identification. It is intended that use of the recently developed tests will improve the practices of players and coaches.

Dissemination of findings
Results of this study will form part of my PhD thesis and will also be published in a peer reviewed journal.

Lees, A. (2003). Science and the major racket sports: a review. *Journal of Sports Science*, **21**, 707-732.

Wilkinson, M., Leedale-Brown, D. and Winter, E.M. (2008a). Validity of a squash-specific test of change-of-direction speed. *International Journal of Sports Physiology and Performance.* (in review)

Wilkinson, M., McCord, A. and Winter, E.M. (2008b). Validity of a squash-specific test of repeat sprint capability. (abstract accepted for BASES 2008)

12) Participants	
12.1 Number	20
12.2 Rationale for this number	This is the number of squash players attending

(eg calculations of sample size, practical considerations)	the national development squad summer training camps. Twenty represents the minimum number of players who will definitely complete testing.
12.3 Criteria for inclusion and exclusion (eg age and sex)	Inclusion: Male and female elite squash players who are members of the world class transition squads. Satisfactory pre-test medical screening results. All players are aged between 18 – 25 years. The transition squad comprises caucasian and ethnic minority players. Exclusion: absence of any of the above.
12.4 Procedures for recruitment (eg location and methods)	All players will be attending the national squad training camps which include summer training fitness assessment. All players will complete fitness testing but have the right to choose whether their data are included in the study.
12.5 Does the study have *minors or ‡vulnerable adults as participants?	[ ] Yes [√] No
12.6 Is CRB Disclosure required for the Principal Investigator? (to be determined by Risk Assessment)	[ ] Yes [√] No If yes, is standard [ ] or enhanced [ ] disclosure required?
12.7 If you ticked 'yes' in 12.5 and 'no' in 12.6 please explain why:	

*Minors are participants under the age of 18 years.
‡Vulnerable adults are participants over the age of 16 years who are likely to exhibit:
a) learning difficulties
b) physical illness/impairment
c) mental illness/impairment
d) advanced age
e) any other condition that might render them vulnerable

13) Details of the research design

13.1 Provide details of intended methodological procedures and data collection. (For MSc students conducting a scientific support project please provide the following information: a. needs analysis; b. potential outcome; c proposed interventions).

Following habituation with test procedures, participants will undertake a battery of tests to assess explosive capabilities of the leg musculature, sport-specific change-of-direction speed, squash-specific repeat-sprint capability, tolerance for high-intensity sprint-running and aerobic fitness.

On arrival at the test venue, body mass and stature will be measured using calibrated balance beam scales and a stadiometer respectively. Following a standardised warm-up and suitable recovery intervals, these test will be completed in the following order:

Reactive strength testing.

Using protocols described by Young (1995), participants will complete three drop jumps onto a jump mat from a height of 30 cm. A reactive strength performance score will calculated from maximum jump height (estimated from flight time) divided by contact time on the jump mat. Subjects will be instructed to jump for maximum height but with minimum contact time. This test is reported to measure the ability to utilise the SSC reflex in fast SSC activities (< 250 ms) (Young, 1995).
Following a suitable recovery, participants will be required to complete 3 counter movement jumps (best score recorded). Counter movement jump height is another reported measure of SSC ability but in slow SSC activities (> 500 ms) (Young, 1995).

Squash Change-of-Direction-Speed Test (SCODS).

Following a suitable standardised warm-up, participants will complete three all-out runs through the SCODS test. The SCODS test is designed to assess change of direction speed in squash-specific movements. Data suggest that the SCODS is a valid and reliable test of squash-specific change-of-direction-speed (Wilkinson *et al.*, in review). The best / fastest time through the course will be recorded. Performance time will be measured with a laser timing gate. The layout of the test course is shown in the appended diagram.

Squash-specific repeat-sprint test (SRST).
The layout and path through the SRST course are shown on the appended diagram (the course is the same as the SCODS test). Participants must move between and around the large inner cones to reach out and touch the smaller outer cones with the fingers of one hand with one repetition comprising two laps of the course. Participants are allowed twenty seconds recovery between each repetition and must complete ten repetitions. Each repetition is performed all-out with performance time recorded using an electronic timing gate. Unpublished data suggest the SRST is a valid and reliable test of squash-specific repeat-sprint capability (Wilkinson *et al.*, accepted for BASES conference 2008)

Twenty metre maximal shuttle run test.
Participants sprint with maximal effort between two cones spaced twenty metres apart continuously for one minute. Total distance covered is recorded.

Aerobic fitness testing.
Participants will complete the progressive 20-m shuttle run test (Leger and Lambert, 1982) to volitional exhaustion. Performance time and final shuttle and level will be used to estimate maximal oxygen uptake.

13.2 Are these "minor" procedures as defined in Appendix 1 of the ethics guidelines?

[ ] Yes [√] No

13.3 If you answered 'no' in section 13.2, list the procedures that are <u>not</u> minor

All-out SCODS runs, SRST, 20-m SRT, all-out vertical jumps, aerobic testing.

13.4 Provide details of the quantitative and qualitative analysis to be used

Pearson's correlation coefficient will examine relationships between fitness test measures and squash-specific repeat-sprint capability. Spearman's rho will examine relationships between fitness measures and player national rank. Independent t-tests will examine differences in test performance between male and female players. Separate correlation analyses will also be carried out for transition male and female players as described above.

14) Substances to be administered (refer to Appendix V of the ethics procedures)

14.1 The protocol does not involve the administration of pharmacologically active substances or nutritional supplements.

Please tick box if this statement applies and go to section 15) [√]

14.2 Name and state the risk category for each substance. If a COSHH assessment is required state how the risks are to be managed.

15) Degree of discomfort that participants might experience

Consider the degree of physical and psychological discomfort that will be experienced by the participants. State the details which must be included in the participant information sheet to ensure that the participants are fully informed about any discomfort that they may experience.

Participants will experience moderate feelings of exertion associated with the aerobic testing that will dissipate quickly after completion. There will also be local muscular sensations of fatigue associated with maximal exertion in the SCODS, repeat-sprint test, 20-m SRT and maximum jumping tests, however these tests are of short duration and fatigue will dissipate quickly after completion

16) Outcomes of Risk Assessment

Provide details of the risk and explain how the control measures will be implemented to manage the risk.

General control measures for all tests.

1. Pre- screening medical questionnaire. 2. Strict adherence to the agreed protocol which includes a warm-up and cool-down. 3. The participant is monitored by a trained first aider following the test. 4. Heart rate is continually monitored. 5. Visual communication is maintained between investigator and participant throughout the exercise test. 6. shoe laces are secured. 7. at least 2 people are present at the exercise test.

17) Attachments	**Tick box**
17.1 Risk assessment (including CRB risk assessment)	√
17.2 COSHH assessment	

17.3 Participant information sheet (this should be addressed directly to the participant (ie you will etc) and in a language they will understand)	√
17.4 Informed consent form	√
17.5 Pre-screening questionnaire	√
17.6 Collaboration evidence/support correspondence from the organisation consenting to the research (this must be on letterhead paper and signed) See sections 9 & 10.	
17.7 CRB Disclosure certificate or where not available **CRB application form**	
17.8 Clinical Trails form (FIN 12)	

18. Signature Principal Investigator	Once this application is approved, I will undertake the research study as approved. If circumstances necessitate that changes are made to the approved protocol, I will discuss these with my Project Supervisor. If the supervisor advises that there should be a resubmission to the Sport and Exercise Research Ethics Review Group, I agree that no work will be carried out using the changed protocol until approval has been sought and formally received. ______________________ Date ___________ Principal Investigator signature Name _______________________________
19. Approval Project Supervisor to sign **either** box A **or** box B as applicable (refer to Appendix I and the flowchart in appendix VI of the ethics guidelines)	**Box A:** I confirm that the research proposed is based solely on 'minor' procedures, as outlined in Appendix 1 of the HWB Sport and Exercise Research Ethics Review Group 'Ethics Procedures for Research with Humans as Participants' document, and therefore does not need to be submitted to the HWB Sport and Exercise Research Ethics Review Group. In terms of ethics approval, I agree the 'minor' procedures proposed here and confirm that the Principal Investigator may proceed with the study as designed. ______________________ Date __________ Project Supervisor signature Name _______________________________
	Box B: I confirm that the research proposed is not based solely on 'minor' procedures, as outlined in Appendix 1 of the HWB Sport and Exercise Research Ethics Review Group 'Ethics Procedures for Research with Humans as Participants' document, and therefore must be submitted to the HWB Sport and Exercise Research Ethics Review Group for approval. I confirm that the appropriate preparatory work has been undertaken and that this document is in a fit state for submission to the HWB Sport and Exercise Research Ethics Review Group. ______________________ Date __________ Project Supervisor signature Name _______________________________
20. Signature Technician	I confirm that I have seen the full and approved application for ethics approval and technical support will be provided. ______________________ Date __________ Technician signature Name ________________________________

Sheffield Hallam University

Faculty of Health and Wellbeing Research Ethics Committee

Sport and Exercise Research Ethics Review Group

Participant Information Sheet

Project Title	Determinants and trainability of squash fitness and performance in elite-standard players

Supervisor/Director of Studies	Professor Edward M Winter

Principal Investigator	Mick Wilkinson

Principal Investigator telephone/mobile number	0191 2437097 / 07754 870997

Purpose of Study and Brief Description of Procedures
(Not a legal explanation but a simple statement)

Background to the Study.

Squash is a repeat-sprint sport, where success depends on physical, technical, tactical and motor skills (Lees, 2003). However, it is unclear which of these factors best relate to performance or which fitness components determine squash-specific repeat-sprint capability. Furthermore, there appear to be no studies investigating these factors in elite performers. Also unknown is the malleability of squash-specific fitness in response to the type of training undertaken by world class players.

Purposes of the Study.

The purpose of this investigation is to examine aspects of fitness that predict squash-specific repeat sprint capability, to examine the ability of a battery of squash and non-squash-specific fitness tests to predict squash performance and to examine the trainability of squash-specific fitness in elite-standard players.

Procedures.

You will be required to make two visits to the National Squash Centre for testing, one before and one after your summer training period. On arrival, your height and body weight will be measured.

Following these basic measures and a standardised warm-up, the following tests will be completed in this order:

1. Three drop jumps onto a jump mat from a height of 30 cm. A reactive strength performance score will calculated from maximum jump height (estimated from flight time) divided by contact time on the jump mat. You will be instructed to jump for maximum height but with minimum contact time. Following a suitable recovery, you will be required to complete 3 counter movement jumps (again best score recorded).
2. A squash-specific test of change-of-direction speed – This test involves all-out squash-related movements around a course of cones with frequent and rapid changes of direction. The course is very short and takes less than 15 seconds to complete. This test will be repeated 3 times with appropriate recovery between each attempt and your best score will be recorded.
3. A squash-specific repeated-sprint test – This test involves all-out squash-related movements around a course of cones with frequent and rapid changes of direction. The course is very short and takes around 20 seconds to complete. You are allowed twenty seconds recovery between each sprint and must complete 10 sprints. Your time to complete each sprint will be recorded. This test is very strenuous and you will feel out of breath for a short while after you finish.
4. The 20-m shuttle run test (bleep test). This involves running between cones 20-m apart in time with an audio signal. The speed of running gets progressively faster as the test proceeds and you must keep pace for as long as you can. This test is used to assess your endurance fitness

Your rights as a participant.

Your participation in this study is voluntary. You are free to refuse to start the testing or withdraw at any time in the proceedings without penalty or prejudice and without giving any reason for so doing. No disadvantage will arise from any decision to participate or not.

The results of the research may be published, but your name will not be used, and no individual identifying information will be provided. All data collected will be coded to retain anonymity, and any personal details will be stored in a locked filing cabinet with access limited to investigators.

It has been made clear to me that, should I feel that these Regulations are being infringed or that my interests are otherwise being ignored, neglected or denied, I should inform Professor Edward Winter, Chair of the Faculty of Health and Wellbeing Research Ethics Committee (Tel: 0114 225 4333) who will undertake to investigate my complaint.

Sheffield Hallam University

Faculty of Health and Wellbeing Research Ethics Committee
Sport and Exercise Research Ethics Review Group

INFORMED CONSENT FORM

TITLE OF PROJECT: Determinants and trainability of squash fitness and performance in elite-standard players

The participant should complete the whole of this sheet himself/herself

Have you read the Participant Information Sheet?	YES/NO
Have you had an opportunity to ask questions and discuss this study?	YES/NO
Have you received satisfactory answers to all of your questions?	YES/NO
Have you received enough information about the study?	YES/NO
To whom have you spoken? .... Do you understand that you are free to withdraw from the study: • at any time • without having to give a reason for withdrawing • and without affecting your future medical care	YES/NO
Have you had sufficient time to consider the nature of this project?	YES/NO
Do you agree to take part in this study?	YES/NO

Signed .... Date ....

(NAME IN BLOCK LETTERS)...

Signature of Parent / Guardian in the case of a minor

....

Faculty of Health and Wellbeing Research Ethics Committee
Report Form

Principal Investigator: Mick Wilkinson

Title: Determinants and trainability of squash fitness and performance in elite-standard players.

Checklist:

Application form	✓
Informed consent form	✓
Risk assessment forms	✓
Participant information sheet	✓
Pre-screening form	✓
Pre-screening form (under 18)	n/a
Collaboration evidence/support	✓
CRB Disclosure form	n/a

Recommendation:

Acceptable: ☑

Not acceptable, see comments: ☐

Acceptable, but see comments: ☐

Comments:

Signature : .... Date: 2nd July 2008

Professor Edward Winter, Chair
Faculty of Health and Wellbeing Research Ethics Committee

Please remember that an up-to-date project file must be maintained for the duration of the project and afterwards. The project file might be inspected at any time.

Note: *Approval applies until the anticipated date of completion unless there are changes to the procedures, in which case another application should be made.*

Name of Director of Studies / Supervisor : Edward Winter

13.12 Appendix twelve – Study six SPSS output

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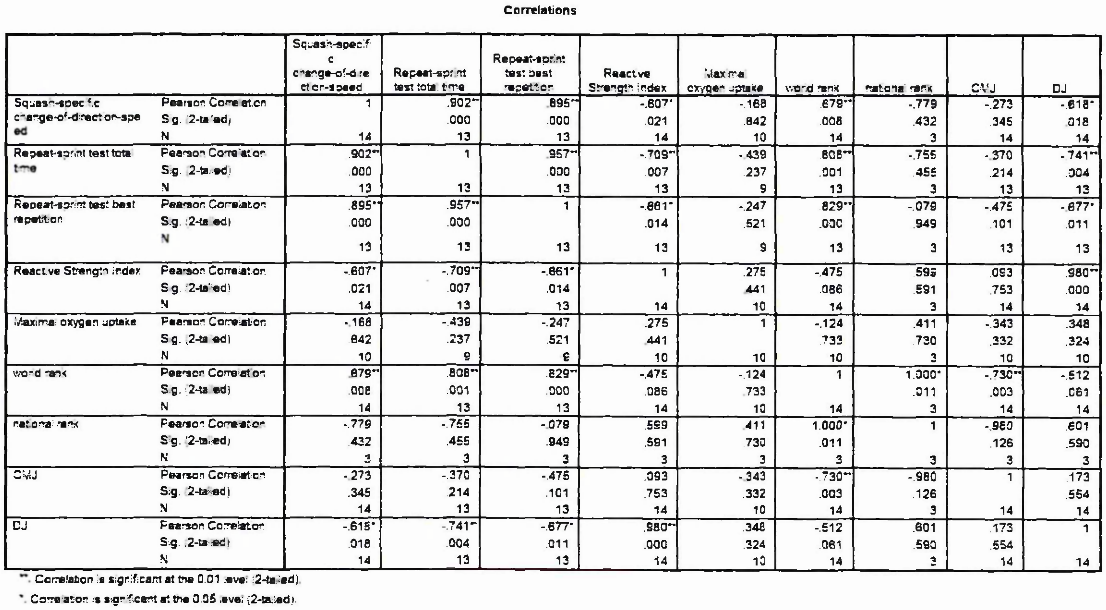

Correlations

		Squash-specific change-of-direction-speed	Repeat-sprint test total time	Repeat-sprint test best repetition	Reactive Strength index	Maximal oxygen uptake	world rank	national rank	CMJ	DJ
Squash-specific change-of-direction-speed	Pearson Correlation	1	.902**	.895**	-.607*	-.168	.679**	-.779	-.273	-.618*
	Sig. (2-tailed)		.000	.000	.021	.642	.008	.432	.345	.018
	N	14	13	13	14	10	14	3	14	14
Repeat-sprint test total time	Pearson Correlation	.902**	1	.957**	-.709**	-.439	.808**	-.755	-.370	-.741**
	Sig. (2-tailed)	.000		.000	.007	.237	.001	.455	.214	.004
	N	13	13	13	13	9	13	3	13	13
Repeat-sprint test best repetition	Pearson Correlation	.895**	.957**	1	-.661*	-.247	.829**	-.079	-.475	-.677*
	Sig. (2-tailed)	.000	.000		.014	.521	.000	.949	.101	.011
	N	13	13	13	13	9	13	3	13	13
Reactive Strength index	Pearson Correlation	-.607*	-.709**	-.661*	1	.275	-.475	.599	.093	.980**
	Sig. (2-tailed)	.021	.007	.014		.441	.086	.591	.753	.000
	N	14	13	13	14	10	14	3	14	14
Maximal oxygen uptake	Pearson Correlation	-.168	-.439	-.247	.275	1	-.124	.411	-.343	.348
	Sig. (2-tailed)	.642	.237	.521	.441		.733	.730	.332	.324
	N	10	9	9	10	10	10	3	10	10
world rank	Pearson Correlation	.679**	.808**	.829**	-.475	-.124	1	1.000*	-.730**	-.512
	Sig. (2-tailed)	.008	.001	.000	.086	.733		.011	.003	.061
	N	14	13	13	14	10	14	3	14	14
national rank	Pearson Correlation	-.779	-.755	-.079	.599	.411	1.000*	1	-.980	.601
	Sig. (2-tailed)	.432	.455	.949	.591	.730	.011		.126	.590
	N	3	3	3	3	3	3	3	3	3
CMJ	Pearson Correlation	-.273	-.370	-.475	.093	-.343	-.730**	-.980	1	.173
	Sig. (2-tailed)	.345	.214	.101	.753	.332	.003	.126		.554
	N	14	13	13	14	10	14	3	14	14
DJ	Pearson Correlation	-.615*	-.741**	-.677*	.980**	.348	-.512	.601	.173	1
	Sig. (2-tailed)	.018	.004	.011	.000	.324	.061	.590	.554	
	N	14	13	13	14	10	14	3	14	14

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

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Nonparametric Correlations

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Correlations

			Squash-specific change-of-direction-speed	Repeat-sprint test total time	Repeat-sprint test best repetition	Reactive Strength Index	Maximal oxygen uptake	world rank	national rank	CMJ	DJ
Spearman's rho	Squash-specific change-of-direction-speed	Correlation Coefficient	1.000	.896**	.883**	-.477	-.006	.591*	-1.000**	-.305	-.538*
		Sig. (2-tailed)	.	.000	.000	.085	.987	.026	.000	.288	.047
		N	14	13	13	14	10	14	3	14	14
	Repeat-sprint test total time	Correlation Coefficient	.896**	1.000	.940**	-.533	-.167	.780**	-1.000**	-.418	-.626*
		Sig. (2-tailed)	.000	.	.000	.061	.667	.002	.000	.156	.022
		N	13	13	13	13	9	13	3	13	13
	Repeat-sprint test best repetition	Correlation Coefficient	.883**	.940**	1.000	-.538	-.067	.883**	-.500	-.533	-.643*
		Sig. (2-tailed)	.000	.000	.	.058	.864	.000	.667	.061	.018
		N	13	13	13	13	9	13	3	13	13
	Reactive Strength Index	Correlation Coefficient	-.477	-.533	-.538	1.000	.407	-.323	1.000**	.051	.965**
		Sig. (2-tailed)	.085	.061	.058	.	.243	.260	.	.864	.000
		N	14	13	13	14	10	14	3	14	14
	Maximal oxygen uptake	Correlation Coefficient	-.006	-.167	-.067	.407	1.000	.012	-.500	-.395	.395
		Sig. (2-tailed)	.987	.667	.864	.243	.	.973	.667	.258	.258
		N	10	9	9	10	10	10	3	10	10
	world rank	Correlation Coefficient	.591*	.780**	.883**	-.323	.012	1.000	1.000**	-.780**	-.456
		Sig. (2-tailed)	.026	.002	.000	.260	.973	.	.	.001	.078
		N	14	13	13	14	10	14	3	14	14
	national rank	Correlation Coefficient	-1.000**	-1.000**	-.500	1.000**	-.500	1.000**	1.000	-.500	1.000**
		Sig. (2-tailed)	.000	.000	.667	.	.667	.	.	.667	.
		N	3	3	3	3	3	3	3	3	3
	CMJ	Correlation Coefficient	-.305	-.418	-.533	.051	-.395	-.780**	-.500	1.000	.187
		Sig. (2-tailed)	.288	.156	.061	.864	.258	.001	.667	.	.523
		N	14	13	13	14	10	14	3	14	14
	DJ	Correlation Coefficient	-.538*	-.626*	-.643*	.965**	.395	-.456	1.000**	.187	1.000
		Sig. (2-tailed)	.047	.022	.018	.000	.258	.078	.	.523	.
		N	14	13	13	14	10	14	3	14	14

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

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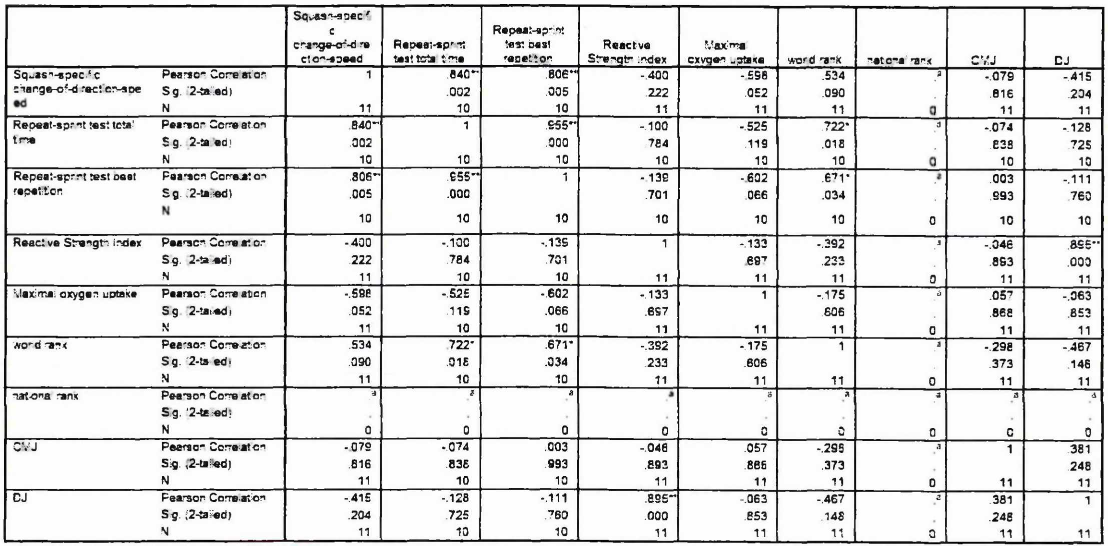

		Squash-specific change-of-direction-speed	Repeat-sprint test total time	Repeat-sprint test best repetition	Reactive Strength index	Maximal oxygen uptake	world rank	national rank	CMJ	DJ
Squash-specific change-of-direction-speed	Pearson Correlation	1	.840**	.806**	-.400	-.598	.534	.[a]	-.079	-.415
	Sig. (2-tailed)		.002	.005	.222	.052	.090	.	.816	.204
	N	11	10	10	11	11	11	0	11	11
Repeat-sprint test total time	Pearson Correlation	.840**	1	.955**	-.100	-.525	.722*	.[a]	-.074	-.128
	Sig. (2-tailed)	.002		.000	.784	.119	.018	.	.838	.725
	N	10	10	10	10	10	10	0	10	10
Repeat-sprint test best repetition	Pearson Correlation	.806**	.955**	1	-.139	-.602	.671*	.[a]	.003	-.111
	Sig. (2-tailed)	.005	.000		.701	.066	.034	.	.993	.760
	N	10	10	10	10	10	10	0	10	10
Reactive Strength index	Pearson Correlation	-.400	-.100	-.135	1	-.133	-.392	.[a]	-.046	.895**
	Sig. (2-tailed)	.222	.784	.701		.697	.233	.	.893	.000
	N	11	10	10	11	11	11	0	11	11
Maximal oxygen uptake	Pearson Correlation	-.598	-.525	-.602	-.133	1	-.175	.[a]	.057	-.063
	Sig. (2-tailed)	.052	.119	.066	.697		.606	.	.868	.853
	N	11	10	10	11	11	11	0	11	11
world rank	Pearson Correlation	.534	.722*	.671*	-.392	-.175	1	.[a]	-.298	-.467
	Sig. (2-tailed)	.090	.018	.034	.233	.606		.	.373	.146
	N	11	10	10	11	11	11	0	11	11
national rank	Pearson Correlation	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.	.	.	.	.	.		.	.
	N	0	0	0	0	0	0	0	0	0
CMJ	Pearson Correlation	-.079	-.074	.003	-.046	.057	-.298	.[a]	1	.381
	Sig. (2-tailed)	.816	.838	.993	.893	.868	.373	.		.248
	N	11	10	10	11	11	11	0	11	11
DJ	Pearson Correlation	-.415	-.128	-.111	.895**	-.063	-.467	.[a]	.381	1
	Sig. (2-tailed)	.204	.725	.760	.000	.853	.148	.	.248	
	N	11	10	10	11	11	11	0	11	11

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

a. Cannot be computed because at least one of the variables is constant.

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Nonparametric Correlations

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08\study 5 - performance and fitnes determinants\Elites documents
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Correlations

			Squash-specific change-of-direction-speed	Repeat-sprint test total time	Repeat-sprint test best repetition	Reactive Strength Index	Maximal oxygen uptake	world rank	national rank	CMJ	DJ
Spearman's rho	Squash-specific change-of-direction-speed	Correlation Coefficient	1.000	.772**	.663*	-.337	-.497	.392	.	-.223	-.397
		Sig. (2-tailed)	.	.009	.037	.311	.120	.233	.	.509	.226
		N	11	10	10	11	11	11	0	11	11
	Repeat-sprint test total time	Correlation Coefficient	.772**	1.000	.976**	-.018	-.467	.612	.	-.103	-.018
		Sig. (2-tailed)	.009	.	.000	.960	.174	.060	.	.777	.960
		N	10	10	10	10	10	10	0	10	10
	Repeat-sprint test best repetition	Correlation Coefficient	.663*	.976**	1.000	.055	-.515	.648*	.	-.103	.036
		Sig. (2-tailed)	.037	.000	.	.881	.128	.043	.	.777	.920
		N	10	10	10	10	10	10	0	10	10
	Reactive Strength Index	Correlation Coefficient	-.337	-.018	.055	1.000	-.209	-.255	.	-.082	.856**
		Sig. (2-tailed)	.311	.960	.881	.	.537	.450	.	.811	.001
		N	11	10	10	11	11	11	0	11	11
	Maximal oxygen uptake	Correlation Coefficient	-.497	-.467	-.515	-.209	1.000	-.264	.	.236	-.073
		Sig. (2-tailed)	.120	.174	.128	.537	.	.433	.	.484	.831
		N	11	10	10	11	11	11	0	11	11
	world rank	Correlation Coefficient	.392	.612	.648*	-.255	-.264	1.000	.	-.045	-.287
		Sig. (2-tailed)	.233	.060	.043	.450	.433	.	.	.894	.392
		N	11	10	10	11	11	11	0	11	11
	national rank	Correlation Coefficient	.	.	.	.	.	.	.	.	.
		Sig. (2-tailed)	.	.	.	.	.	.	.	.	.
		N	0	0	0	0	0	0	0	0	0
	CMJ	Correlation Coefficient	-.223	-.103	-.103	-.082	.236	-.045	.	1.000	.405
		Sig. (2-tailed)	.509	.777	.777	.811	.484	.894	.	.	.216
		N	11	10	10	11	11	11	0	11	11
	DJ	Correlation Coefficient	-.397	-.018	.036	.856**	-.073	-.287	.	.405	1.000
		Sig. (2-tailed)	.226	.960	.920	.001	.831	.392	.	.216	.
		N	11	10	10	11	11	11	0	11	11

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

```
UNIANOVA
  CMJ  BY Standard Sex
  /METHOD = SSTYPE(3)
  /INTERCEPT = INCLUDE
  /POSTHOC = Standard ( LSD )
  /PRINT = DESCRIPTIVE HOMOGENEITY
  /CRITERIA = ALPHA(.05)
  /DESIGN = Standard Sex Standard*Sex .
```

Univariate Analysis of Variance

```
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08\study 5 - performance and fitnes determinants\Elites documents
\ANOVA\ANOVA data sheet.sav
```

Between-Subjects Factors

		Value Label	N
Playing standard	1.00	Senior	12
	2.00	Transition	7
	3.00	TASS	12
Sex	.00	female	11
	1.00	male	20

Descriptive Statistics

Dependent Variable: Counter Movement Jump

Playing standard	Sex	Mean	Std. Deviation	N
Senior	female	730.4800	172.01124	5
	male	1229.9714	121.50074	7
	Total	1021.8500	291.48680	12
Transition	female	627.9667	70.30351	3
	male	1065.9500	67.92979	4
	Total	878.2429	242.41113	7
TASS	female	728.0000	176.59346	3
	male	988.7444	163.15029	9
	Total	923.5583	197.31997	12
Total	female	701.8455	145.99083	11
	male	1088.6150	169.68322	20
	Total	951.3742	246.42781	31

Levene's Test of Equality of Error Variances[a]

Dependent Variable: Counter Movement Jump

F	df1	df2	Sig.
1.033	5	25	.420

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept+Standard+Sex+Standard * Sex

Tests of Between-Subjects Effects

Dependent Variable: Counter Movement Jump

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1315830.818[a]	5	263166.164	13.003	.000
Intercept	21047800.17	1	21047800.169	1039.974	.000
Standard	108557.801	2	54278.901	2.682	.088
Sex	1047492.111	1	1047492.111	51.757	.000
Standard * Sex	74720.233	2	37360.117	1.846	.179
Error	505969.221	25	20238.769		
Total	29880298.58	31			
Corrected Total	1821800.039	30			

a. R Squared = .722 (Adjusted R Squared = .667)

Post Hoc Tests

Playing standard

Multiple Comparisons

Dependent Variable: Counter Movement Jump
LSD

(I) Playing standard	(J) Playing standard	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Senior	Transition	143.6071*	67.65957	.044	4.2597	282.9546
	TASS	98.2917	58.07864	.103	-21.3235	217.9069
Transition	Senior	-143.6071*	67.65957	.044	-282.9546	-4.2597
	TASS	-45.3155	67.65957	.509	-184.6630	94.0320
TASS	Senior	-98.2917	58.07864	.103	-217.9069	21.3235
	Transition	45.3155	67.65957	.509	-94.0320	184.6630

Based on observed means.

*. The mean difference is significant at the .05 level.

```
UNIANOVA
  DJ  BY Standard Sex
  /METHOD = SSTYPE(3)
  /INTERCEPT = INCLUDE
  /POSTHOC = Standard ( LSD )
  /PRINT = DESCRIPTIVE HOMOGENEITY
  /CRITERIA = ALPHA(.05)
  /DESIGN = Standard Sex Standard*Sex .
```

Univariate Analysis of Variance

```
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08\study 5 - performance and fitnes determinants\Elites documents
\ANOVA\ANOVA data sheet.sav
```

Between-Subjects Factors

		Value Label	N
Playing standard	1.00	Senior	12
	2.00	Transition	7
	3.00	TASS	12
Sex	.00	female	11
	1.00	male	20

Descriptive Statistics

Dependent Variable: Drop Jump

Playing standard	Sex	Mean	Std. Deviation	N
Senior	female	1782.5000	356.71219	5
	male	2683.5571	508.50922	7
	Total	2308.1167	634.50176	12
Transition	female	1677.2000	348.56041	3
	male	2656.2000	597.79286	4
	Total	2236.6286	702.15138	7
TASS	female	1312.7667	219.65861	3
	male	1905.3556	455.62857	9
	Total	1757.2083	481.22878	12
Total	female	1625.6727	356.80984	11
	male	2327.8950	615.92035	20
	Total	2078.7194	631.94056	31

Levene's Test of Equality of Error Variances[a]

Dependent Variable: Drop Jump

F	df1	df2	Sig.
.540	5	25	.744

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept+Standard+Sex+Standard * Sex

Tests of Between-Subjects Effects

Dependent Variable: Drop Jump

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	6847665.362[a]	5	1369533.072	6.670	.000
Intercept	105368841.6	1	105368841.6	513.213	.000
Standard	2195296.347	2	1097648.174	5.346	.012
Sex	4460690.667	1	4460690.667	21.726	.000
Standard * Sex	178861.648	2	89430.824	.436	.652
Error	5132800.666	25	205312.027		
Total	145933764.9	31			
Corrected Total	11980466.03	30			

a. R Squared = .572 (Adjusted R Squared = .486)

Post Hoc Tests

Playing standard

Multiple Comparisons

Dependent Variable: Drop Jump
LSD

(I) Playing standard	(J) Playing standard	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Senior	Transition	71.4881	215.49855	.743	-372.3395	515.3157
	TASS	550.9083*	184.98289	.006	169.9289	931.8877
Transition	Senior	-71.4881	215.49855	.743	-515.3157	372.3395
	TASS	479.4202*	215.49855	.035	35.5927	923.2478
TASS	Senior	-550.9083*	184.98289	.006	-931.8877	-169.9289
	Transition	-479.4202*	215.49855	.035	-923.2478	-35.5927

Based on observed means.

*. The mean difference is significant at the .05 level.

```
UNIANOVA
  SCODS  BY Standard Sex
  /METHOD = SSTYPE(3)
  /INTERCEPT = INCLUDE
  /POSTHOC = Standard ( LSD )
  /PRINT = DESCRIPTIVE HOMOGENEITY
  /CRITERIA = ALPHA(.05)
  /DESIGN = Standard Sex Standard*Sex .
```

Univariate Analysis of Variance

```
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08\study 5 - performance and fitnes determinants\Elites documents
\MANOVA\MANOVA data sheet.sav
```

Between-Subjects Factors

		Value Label	N
Playing standard	1.00	Senior	12
	2.00	Transition	7
	3.00	TASS	12
Sex	.00	female	11
	1.00	male	20

Descriptive Statistics

Dependent Variable: Squash-specific change-of-direction-speed

Playing standard	Sex	Mean	Std. Deviation	N
Senior	female	9.0220	.32492	5
	male	8.8029	.43904	7
	Total	8.8942	.39530	12
Transition	female	9.3433	1.03751	3
	male	9.1500	.56845	4
	Total	9.2329	.72874	7
TASS	female	10.4500	.54525	3
	male	9.3589	.64241	9
	Total	9.6317	.77311	12
Total	female	9.4991	.84222	11
	male	9.1225	.59154	20
	Total	9.2561	.70115	31

Levene's Test of Equality of Error Variances[a]

Dependent Variable: Squash-specific change-of-direction-speed

F	df1	df2	Sig.
1.248	5	25	.317

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept+Standard+Sex+Standard * Sex

Tests of Between-Subjects Effects

Dependent Variable: Squash-specific change-of-direction-speed

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	6.151[a]	5	1.230	3.577	.014
Intercept	2298.387	1	2298.387	6683.549	.000
Standard	5.049	2	2.525	7.341	.003
Sex	1.649	1	1.649	4.796	.038
Standard * Sex	1.177	2	.589	1.712	.201
Error	8.597	25	.344		
Total	2670.702	31			
Corrected Total	14.748	30			

a. R Squared = .417 (Adjusted R Squared = .300)

Post Hoc Tests

Playing standard

Multiple Comparisons

Dependent Variable: Squash-specific change-of-direction-speed
LSD

(I) Playing standard	(J) Playing standard	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Senior	Transition	-.3387	.27890	.236	-.9131	.2357
	TASS	-.7375*	.23940	.005	-1.2306	-.2444
Transition	Senior	.3387	.27890	.236	-.2357	.9131
	TASS	-.3988	.27890	.165	-.9732	.1756
TASS	Senior	.7375*	.23940	.005	.2444	1.2306
	Transition	.3988	.27890	.165	-.1756	.9732

Based on observed means.

*. The mean difference is significant at the .05 level.

```
UNIANOVA
  RSI  BY Standard Sex
  /METHOD = SSTYPE(3)
  /INTERCEPT = INCLUDE
  /POSTHOC = Standard ( LSD )
  /PRINT = DESCRIPTIVE HOMOGENEITY
  /CRITERIA = ALPHA(.05)
  /DESIGN = Standard Sex Standard*Sex .
```

Univariate Analysis of Variance

```
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\MANOVA\MANOVA data sheet.sav
```

Between-Subjects Factors

		Value Label	N
Playing standard	1.00	Senior	12
	2.00	Transition	7
	3.00	TASS	12
Sex	.00	female	11
	1.00	male	20

Descriptive Statistics

Dependent Variable: Reactive Strength Index

Playing standard	Sex	Mean	Std. Deviation	N
Senior	female	250.6000	30.92410	5
	male	291.4286	45.32055	7
	Total	274.4167	43.70450	12
Transition	female	251.6667	56.30571	3
	male	293.7500	50.75677	4
	Total	275.7143	53.39386	7
TASS	female	186.0000	20.66398	3
	male	234.7778	53.90681	9
	Total	222.5833	51.74669	12
Total	female	233.2727	44.98909	11
	male	266.4000	56.04359	20
	Total	254.6452	54.06943	31

Levene's Test of Equality of Error Variances[a]

Dependent Variable: Reactive Strength Index

F	df1	df2	Sig.
.638	5	25	.673

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept+Standard+Sex+Standard * Sex

Tests of Between-Subjects Effects

Dependent Variable: Reactive Strength Index

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	33385.210[a]	5	6677.042	3.073	.027
Intercept	1659622.582	1	1659622.582	763.819	.000
Standard	22737.813	2	11368.907	5.232	.013
Sex	12652.656	1	12652.656	5.823	.023
Standard * Sex	86.531	2	43.266	.020	.980
Error	54319.887	25	2172.795		
Total	2097874.000	31			
Corrected Total	87705.097	30			

a. R Squared = .381 (Adjusted R Squared = .257)

Post Hoc Tests

Playing standard

Multiple Comparisons

Dependent Variable: Reactive Strength Index
LSD

		Mean Difference			95% Confidence Interval	
(I) Playing standard	(J) Playing standard	(I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
Senior	Transition	-1.2976	22.16902	.954	-46.9556	44.3603
	TASS	51.8333*	19.02978	.012	12.6408	91.0259
Transition	Senior	1.2976	22.16902	.954	-44.3603	46.9556
	TASS	53.1310*	22.16902	.024	7.4730	98.7889
TASS	Senior	-51.8333*	19.02978	.012	-91.0259	-12.6408
	Transition	-53.1310*	22.16902	.024	-98.7889	-7.4730

Based on observed means.

*. The mean difference is significant at the .05 level.

```
UNIANOVA
  SRSTtot  BY Standard Sex
  /METHOD = SSTYPE(3)
  /INTERCEPT = INCLUDE
  /POSTHOC = Standard ( LSD )
  /PRINT = DESCRIPTIVE HOMOGENEITY
  /CRITERIA = ALPHA(.05)
  /DESIGN = Standard Sex Standard*Sex .
```

Univariate Analysis of Variance

```
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\MANOVA\MANOVA data sheet.sav
```

Between-Subjects Factors

		Value Label	N
Playing standard	1.00	Senior	11
	2.00	Transition	7
	3.00	TASS	10
Sex	.00	female	10
	1.00	male	18

Descriptive Statistics

Dependent Variable: Repeat-sprint test total time

Playing standard	Sex	Mean	Std. Deviation	N
Senior	female	212.5400	5.90653	5
	male	203.7317	9.31985	6
	Total	207.7355	8.86254	11
Transition	female	235.1100	18.90091	3
	male	212.5075	3.11312	4
	Total	222.1943	16.42836	7
TASS	female	245.2200	12.99662	2
	male	219.3838	14.47607	8
	Total	224.5510	17.33278	10
Total	female	225.8470	18.00113	10
	male	212.6383	12.76557	18
	Total	217.3557	15.87948	28

Levene's Test of Equality of Error Variances[a]

Dependent Variable: Repeat-sprint test total time

F	df1	df2	Sig.
3.151	5	22	.027

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

[a] Design: Intercept+Standard+Sex+Standard * Sex

Tests of Between-Subjects Effects

Dependent Variable: Repeat-sprint test total time

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3855.049[a]	5	771.010	5.744	.002
Intercept	1120567.257	1	1120567.257	8347.667	.000
Standard	2578.575	2	1289.287	9.605	.001
Sex	2080.780	1	2080.780	15.501	.001
Standard * Sex	361.419	2	180.710	1.346	.281
Error	2953.218	22	134.237		
Total	1329626.449	28			
Corrected Total	6808.266	27			

a. R Squared = .566 (Adjusted R Squared = .468)

Post Hoc Tests

Playing standard

Multiple Comparisons

Dependent Variable: Repeat-sprint test total time
LSD

(I) Playing standard	(J) Playing standard	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Senior	Transition	-14.4588*	5.60180	.017	-26.0762	-2.8414
	TASS	-16.8155*	5.06232	.003	-27.3142	-6.3169
Transition	Senior	14.4588*	5.60180	.017	2.8414	26.0762
	TASS	-2.3567	5.70968	.684	-14.1979	9.4844
TASS	Senior	16.8155*	5.06232	.003	6.3169	27.3142
	Transition	2.3567	5.70968	.684	-9.4844	14.1979

Based on observed means.

*. The mean difference is significant at the .05 level.

```
UNIANOVA
  SRSTbest  BY Standard Sex
  /METHOD = SSTYPE(3)
  /INTERCEPT = INCLUDE
  /POSTHOC = Standard ( LSD )
  /PRINT = DESCRIPTIVE HOMOGENEITY
  /CRITERIA = ALPHA(.05)
  /DESIGN = Standard Sex Standard*Sex .
```

Univariate Analysis of Variance

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\MANOVA\MANOVA data sheet.sav
```

Between-Subjects Factors

		Value Label	N
Playing standard	1.00	Senior	11
	2.00	Transition	7
	3.00	TASS	10
Sex	.00	female	10
	1.00	male	18

Descriptive Statistics

Dependent Variable: Repeat-sprint test best repetition

Playing standard	Sex	Mean	Std. Deviation	N
Senior	female	20.4900	.84528	5
	male	19.5050	.87267	6
	Total	19.9527	.96498	11
Transition	female	22.0867	1.56020	3
	male	20.3400	.77816	4
	Total	21.0886	1.40920	7
TASS	female	23.8600	1.44250	2
	male	21.1238	1.34417	8
	Total	21.6710	1.72265	10
Total	female	21.6430	1.72804	10
	male	20.4100	1.26680	18
	Total	20.8504	1.53875	28

Levene's Test of Equality of Error Variances[a]

Dependent Variable: Repeat-sprint test best repetition

F	df1	df2	Sig.
1.079	5	22	.399

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept+Standard+Sex+Standard * Sex

Tests of Between-Subjects Effects

Dependent Variable: Repeat-sprint test best repetition

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	35.850[a]	5	7.170	5.618	.002
Intercept	10306.121	1	10306.121	8074.825	.000
Standard	25.520	2	12.760	9.997	.001
Sex	18.983	1	18.983	14.873	.001
Standard * Sex	3.109	2	1.554	1.218	.315
Error	28.079	22	1.276		
Total	12236.577	28			
Corrected Total	63.929	27			

a. R Squared = .561 (Adjusted R Squared = .461)

Post Hoc Tests

Playing standard

Multiple Comparisons

Dependent Variable: Repeat-sprint test best repetition
LSD

(I) Playing standard	(J) Playing standard	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Senior	Transition	-1.1358*	.54623	.049	-2.2686	-.0030
	TASS	-1.7183*	.49362	.002	-2.7420	-.6946
Transition	Senior	1.1358*	.54623	.049	.0030	2.2686
	TASS	-.5824	.55675	.307	-1.7370	.5722
TASS	Senior	1.7183*	.49362	.002	.6946	2.7420
	Transition	.5824	.55675	.307	-.5722	1.7370

Based on observed means.

*. The mean difference is significant at the .05 level.

```
UNIANOVA
  VO2max  BY Standard Sex
  /METHOD = SSTYPE(3)
  /INTERCEPT = INCLUDE
  /POSTHOC = Standard ( LSD )
  /PRINT = DESCRIPTIVE HOMOGENEITY
  /CRITERIA = ALPHA(.05)
  /DESIGN = Standard Sex Standard*Sex .
```

Univariate Analysis of Variance

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\MANOVA\MANOVA data sheet.sav
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Between-Subjects Factors

		Value Label	N
Playing standard	1.00	Senior	8
	2.00	Transition	7
	3.00	TASS	11
Sex	.00	female	11
	1.00	male	15

Descriptive Statistics

Dependent Variable: Maximal oxygen uptake

Playing standard	Sex	Mean	Std. Deviation	N
Senior	female	49.2600	3.15405	5
	male	56.2000	2.12838	3
	Total	51.8625	4.45868	8
Transition	female	49.3000	3.30454	3
	male	59.4250	2.88487	4
	Total	55.0857	6.09027	7
TASS	female	45.5333	5.02029	3
	male	55.2500	5.32809	8
	Total	52.6000	6.74626	11
Total	female	48.2545	3.77607	11
	male	56.5533	4.46972	15
	Total	53.0423	5.86291	26

Levene's Test of Equality of Error Variances[a]

Dependent Variable: Maximal oxygen uptake

F	df1	df2	Sig.
1.685	5	20	.184

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept+Standard+Sex+Standard * Sex

Tests of Between-Subjects Effects

Dependent Variable: Maximal oxygen uptake

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	514.557[a]	5	102.911	5.970	.002
Intercept	62987.334	1	62987.334	3653.704	.000
Standard	62.317	2	31.158	1.807	.190
Sex	455.402	1	455.402	26.416	.000
Standard * Sex	11.223	2	5.612	.326	.726
Error	344.786	20	17.239		
Total	74009.990	26			
Corrected Total	859.343	25			

a. R Squared = .599 (Adjusted R Squared = .498)

Post Hoc Tests

Playing standard

Multiple Comparisons

Dependent Variable: Maximal oxygen uptake
LSD

(I) Playing standard	(J) Playing standard	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Senior	Transition	-3.2232	2.14888	.149	-7.7057	1.2593
	TASS	-.7375	1.92928	.706	-4.7619	3.2869
Transition	Senior	3.2232	2.14888	.149	-1.2593	7.7057
	TASS	2.4857	2.00748	.230	-1.7018	6.6732
TASS	Senior	.7375	1.92928	.706	-3.2869	4.7619
	Transition	-2.4857	2.00748	.230	-6.6732	1.7018

Based on observed means.