THE VALIDITY, RELIABILITY AND OBJECTIVITY OF A FIELD TEST OF SQUASH FITNESS

by

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ABSTRACT

The purpose was to establish the validity, reliability and objectivity of a field test of squash fitness. It involved running a prescribed pattern in a squash court similar to that used in the CSRA fitness test. Thirty volunteer females performed an aerobic power test, an anaerobic endurance test and three squash field tests. Correlation coefficients were determined between the laboratory tests and total repetition time, drop-off index and recovery heart rate of the field tests. Total repetition time correlated with the VO_2 max ($r=-0.52$, $P<0.01$) and anaerobic endurance ($r=-0.63$, $P<0.01$). The correlation between recovery heart rate and VO_2 max was $r=0.38$ ($P<0.05$). The test did not discriminate between A, B and C level players with respect to aerobic and anaerobic fitness. Thus criterion related validity was shown but not construct validity. Intraclass correlation coefficients of 0.89 and 0.94 attested to the reliability and objectivity of the test.

RESUME

Le but de cette etude etait de determiner la validite, la fiabilite et l'objectivite d'un test pratique mesurant la condition physique au squash. Ce test impliquait des deplacements rapides suivant un parcours donne similaire a celui utilise dans le test de condition physique de la CSRA. Trente volontaires de sexe feminin ont participe au projet, en se pretant a un test de puissance aerobic, un test d'endurance anaerobic, et trois tests pratiques. Des coefficients de correlation ont ete determines entre les tests en laboratoire, et la duree totale de repetition, l'index de diminuation et le rythme cardiaque de recuperation observes dans les tests pratiques. Des relations significatives ont ete calculees entre la duree totale de repetition et le VO max ($r=-0.52$, $P<0.01$) et l'endurance anaerobic ($r=-0.63$, $P<0.01$). La relation entre le rythme cardiaque de recuperation et le VO max a ete calculee a $r=0.38$ ($P<0.05$). Le test n'a pu distinguer entre les joueuses de calibres A, B et C en rapport avec le niveau des systemes energetiques aerobic et anaerobic. Consequemment, la validite interne du test a ete etablie, pendant que la validite externe n'a pu etre demontree. Des coefficients de correlation intra-classe de l'ordre de 0.89 et de 0.94 attestaient de la fiabilite et de l'objectivite du test.

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CHAPTER I

INTRODUCTION

During the 20th century, squash has achieved great popularity in many parts of the world. The game of squash originated with the ancient Egyptians and by 1850 the birth of "squash racquets" was a fact (Horry, 1978). The first national squash championships were held in the United States in 1907. The first Canadian championships occured in 1912 followed by the British national championships in 1922. While the official game of squash was a British invention, both Canada and the United States had published formal rules and court specifications for the North American (hard ball) game many years before any rules were formalized in Great Britain for the international (soft ball) game (Stewart, 1979).

Squash is an easy game to play ; it is a difficult game to play well. Despite its complexity, the game is one of the world's fastest growing sports (Zuber, 1980). The popularity of the sport has to do with the health benefits obtained from participating, as well as with a number of factors such as: 1) it can be pursued in any weather, day or night, 2) a great deal of exercise can be gained in a short time, 3) equipment is comparatively inexpensive and 4) a number of courts can be built in a small area (Zuber, 1980).

Participation of squash in Canada has increased in recent years. Many organizations have been founded in order to further develop the game. The Canadian Squash Racquets

Association (CSRA) is the national organization, while organizations such as Squash Quebec and Ontario Squash offer leadership at the provincial level.

The Quebec Squash Racquets Association was formed in the late 1920's. At that time only half a dozen clubs existed in Quebec. The growing interest in squash has led to the establishment of 46 clubs in Quebec including 185 courts and over 20,000 amateur squash players and officials (Quebec Squash, 1983).

As in all forms of exercise, physical fitness is very important for successful participation in squash, as well as for the enjoyment of the game (Sharp, 1977, 1978a; Farr, 1980; CSRA, 1982). This is true for recreational squash players as well as national and international calibre players.

The evaluation of physical fitness, as it relates to sport performance, has been a major topic in the applied area of sport physiology for many years. A number of tests have been devised in order to measure physical fitness components specific to different activities. They include laboratory tests using sophisticated equipment as well as field tests in which the investigator attempts to simulate actual activity patterns. For scientific acceptance of these tests, their validity, reliability and objectivity must be established. It is important to determine whether a test evaluates what it purports to measure, is dependable and is objective.

1.1 Nature and Scope of the Problem

The nature of the game of squash is such that it requires repeated short bouts of work interrupted by short periods of active rest. This specific pattern of activity results in a series of unique physiological adaptations which are associated with it.

Several squash authorities have commented on the nature of the game and consequently have identified the important factors that are necessary for successful participation in the sport (Griffiths, 1978; Sharp, 1978a; Zuber, 1980). Whereas different characteristics are cited by these authors, one quality is found in every list: FITNESS. Although it has various connotations, physical fitness can be defined, in general terms, as the capacity to meet present and potential physical challenges of life with success (Lamb, 1981). A health oriented definition, as stated by Clarke (1976), describes physical fitness as the ability to carry out daily tasks with vigor and alertness, without undue fatigue, and with ample energy to enjoy leisure-time pursuits and to meet unforeseen emergencies. DiGennaro (1974) states that physical fitness consists of three components: lean body weight, neuromuscular efficiency, and cardiovascular-respiratory efficiency. Farr (1980) defines fitness as a 'global' term consisting of strength, speed, stamina, suppleness and agility.

Recent literature on various sport activities supports the notion of specificity in the assessment of physical fitness. In general, when devising a training program and/or assessing physiological parameters, one must establish the relative importance of the various energy systems for the sport. Investigators have expressed varied positions regarding the contribution of specific energy systems for the game of squash. For example, Broadhead (1967) and Sharp (1977) described physical fitness in terms of aerobic power. Sharp (1978c) acknowledged the importance of the anaerobic lactic acid system but in a later publication, Sharp (1979) concluded that squash is a predominantly aerobic activity.

Physical fitness assessments can assist the coach and athlete if the evaluation is specific to the sport. The results may reveal strengths and weaknesses which can be used to guide the athlete's training. Laboratory tests using simple as well as sophisticated equipment have been conventionally used for the measurement of physiological variables. In many instances it is possible to obtain valid, reliable and objective measures in competitive conditions with the use of field tests, which, when carefully constructed, are no less scientific than the more traditional laboratory tests (Reed, 1982). Reed states that field tests should not replace the laboratory tests but should compliment the laboratory findings.

Recently, in an effort to improve the fitness training of national team members, the CSRA commissioned the development of a squash specific training program (CSRA, 1982). The fitness requirements of squash were assessed using time-motion analysis. Since the rallies varied from 10 to 25 seconds in length and were performed at high intensities, it was concluded that "... the squash player depends heavily on the anaerobic energy system. At the same time, high level players can tolerate these rallies quickly removing lactic acid and demonstrating rapid heart rate recovery. These phenomena indicate a reliance on the aerobic system" (CSRA, 1982).

As part of the CSRA training program, a field fitness test specific to squash patterns was developed (CSRA, 1982). This on-court fitness test (six-point test) was based on 10 criteria recommended in the Canadian Association of Sport Sciences (CASS) manual (1982), Physiological Testing of the Elite Athlete (Appendix B). Time-motion studies were conducted during several tournaments involving players of different levels (CSRA, 1982). From these data, the six-point test pattern was developed in which diagonal and lateral movements were established (figure 3.1, p.48). The pattern was designed to last about 20-25 seconds and provide approximately equal recovery time before the next repetition was initiated. Each pattern was repeated six times, 40 seconds apart, in order to tax the anaerobic system. At the end of the sixth repetition, recovery heart rate data were recorded for assessment of aerobic fitness (A.Reed, personal communication, September 17, 1984).

The literature on intermittent exercise, suggests that the critical factor for the subsequent pattern of energy system utilization is the length of the work periods. The duration of the recovery pause is reported to be of secondary importance (Astrand et al., 1960a; Edwards et al., 1973).

Contrary to the CSRA data , previous time-motion studies of squash matches revealed different values (Docherty and Howe, 1978; Beauchamp, 1980; Montgomery et al., 1981; Constantinides, 1984). In these studies an exercise to recovery ratio of 1:1 was reported. Discrepancy, however, exists with respect to the length of the work and rest periods.

Because of these findings, this study proposes to examine a modified field test of squash fitness which will more accurately simulate the specific time patterns of squash play. This test utilizes a similar court pattern to that developed for the CSRA test but provides for a reduced work and recovery time to replicate game conditions. The deviation from the CSRA test is suggested because of the importance of task specificity in the utilization of a test. Its validity, reliability and objectivity must be established before the test can be used in evaluation and/or prescription of training regimes.

1.2 Significance of the Study

Fitness evaluation can be useful in recognizing an athlete's potential, in predicting future performance and in monitoring an athlete's training program (CSRA, 1982). Laboratory tests, as well as field tests, provide a variety of measurement techniques from which investigators may proceed. The CSRA (1982) developed a six-point squash fitness test based on time-motion analysis of squash matches but the duration of the work intervals in this test is not consistent with those reported in actual squash matches by a number of investigators (Docherty and Howe, 1978; Beauchamp, 1980; Montgomery et al., 1981; Constantinides, 1984). Consequently, the CSRA test does not appear to satisfy some of the criteria proposed for field tests in the CASS manual (Appendix B). Simulation of game conditions is not reproduced accurately since the average duration of a game rally is shorter than the duration of the work intervals in the CSRA squash test. Furthermore, if the work periods of the CSRA test are too long, then the intensity of the test places higher demands on total energy expenditure resulting in prolonged recovery.

It is therefore proposed that a new test be developed in order to replicate the work periods during an actual squash match. It is believed that the modified test will be more representative of the actual length of game rallies for the majority of competitive players. Even though the CSRA test was originally designed for elite squash players, the

CSRA recommends its use for all levels of players. Its application to a broader population is questioned. If the validity, reliability and objectivity of the modified test can be established, the test should have a broader application than the existing CSRA test.

1.3 Statement of the Problem

The purpose of this study is to establish the validity, reliability and objectivity of a field test of squash fitness. The study will therefore seek to confirm the following hypotheses:

1) A statistically significant correlation will exist between the recovery measurement from the modified field test and the aerobic power laboratory test ($\dot{V}O_2$ max values).

2) A statistically significant correlation will exist between the performance times (total repetition time and drop-off index) from the modified field test and the anaerobic endurance laboratory test.

3) The modified test will discriminate between squash players of varying squash ability (A, B and C players).

4) A statistically significant and positive correlation will be found between test-retest scores of the modified test of squash fitness.

5) A statistically significant correlation will be found between the test results of two investigators.

The first and second hypotheses will test criterion related validity while the third hypothesis will test construct validity. Reliability will be verified in the fourth hypothesis and objectivity will be examined in the last hypothesis.

1.4 Operational Definitions

International court (English): the official court in which squash is played in most countries of the world. Its length is 32 ft (9.75 m) and its width is 21 ft (6.10 m) as compared with the American court in which the length and width are 32 ft (9.75 m) and 18 ft (5.49 m), respectively.

T spot: the intersection of the short line and half court line on the floor of the squash court. This spot is six feet (1.83 m) behind the midpoint of the court.

'A' level player: one who is placed in the A division by the Quebec Squash Association and/or has played during the previous year in at least one A level tournament organized by Squash Quebec.

'B' level player: one who is placed in the B division by the Quebec Squash Association and/or has played during the previous year in at least one B level tournament organized by Squash Quebec.

'C' level player: one who is placed in the C division by the Quebec Squash Association and/or has played during the previous year in at least one C level tournament organized by Squash Quebec.

Construct validity: is concerned with the extent to which a particular measure relates to other measures consistent with theoretically derived hypotheses concerning the concepts (or constructs) that are being measured (Carmines and Zeller, 1983).

Criterion related validity: compares test or scale scores with one or more external variables, or criteria, known or believed to measure the attribute under study (Kerlinger, 1964).

Reliability: the extent to which a test or any measuring procedure yields the same results on repeated trials (Carmines and Zeller, 1983).

Objectivity: an estimation of rater reliability (Baumgartner and Jackson, 1975).

Maximal Anaerobic Endurance: the run time during a short exhaustive run on the treadmill set at 188 m/min with a 20% grade (Cunningham and Faulkner, 1969).

Maximal Aerobic Power: the highest level of oxygen consumption which can be consumed per unit of time by a person during a progressive exercise test performed to the point of volitional exhaustion (Thoden et al., 1982).

Total Repetition Time: the sum of the six repetitions in the six-point squash fitness test and the sum of the 10 repetitions in the modified test of squash fitness.

Drop-off index: the difference between the fastest repetition time and the slowest repetition time.

1.5 Delimitations

This study was delimited in the following respects:

1) Only female players from the Montreal area served as subjects.

2) Three levels of squash ability (A, B, C level players) were represented by 10 subjects from each category.

3) The 30 subjects ranged in age from 19 to 42 years.

4) Data were collected during the middle part of the competitive season.

1.6 Limitations

1) No attempt was made to control the diet pattern of the subjects in this study.

2) No attempt was made to control the exercise pattern of the subjects in the study.

3) Throughout the tests, warm-up procedure was not standardized. Subjects were, however, encouraged to warm-up either by stretching and on court-running, or by hitting the ball for four to five minutes in the court.

CHAPTER II

REVIEW OF LITERATURE

The review of literature is divided into five sections:

2.1 Nature of the Game

2.2 Energy System Utilization

2.3 Racquetball, Similarities and Differences

2.4 Physiology of Intermittent Exercise

2.5 Field Tests in Squash

2.1 Nature of the Game

The game of squash racquets has changed considerably in the last one hundred years. The rules have undergone certain modifications and the use of the soft ball has been adopted by nearly every squash playing country in the world (Swift, 1980). Squash has gained popularity because of its appeal to a wide range of persons. It has become the game of the '70s and the '80s. In a period when the pressures of modern life demand a game which gives maximum exercise in the minimum time, at a reasonable cost, at any time of day and in any environmental conditions, the game of squash racquets appears to meet these criteria (Hawkey, 1979; Zuber, 1980).

According to Sharp (1978b), squash is a very high energy expending sport (15 kcal/min or 63 kJ). Montpetit et al.(1977) state that a squash player expends approximately 12.25 kcal/min (51 kJ). Both studies provide a high value in terms of energy expenditure per unit of time. According to McArdle et al. (1981) squash is classified as an activity involving "unduly heavy" energy expenditure.

The relationship between playing ability and the physical demands of a squash workout has been studied by several investigators. Montpetit et al. (1977) emphasized the importance of matching players of equal ability if both participants are to obtain a good cardiovascular workout.

Docherty and Howe (1978) also investigated the heart rate response of squash players during a 30 minute game against an opponent of equal ability. Thirty male subjects were divided into three groups according to skill level: highly skilled ('A' level tournament players), medium skilled ('C' level tournament players) and low skilled (players with no tournament experience). They concluded that the physical demands of playing squash were independent of the skill level of the participants. The similarity in the physical demands of 30 minutes of squash play between the different skill groups suggested that the high skilled and medium skilled groups have developed efficient stroke production, better court coverage and superior anticipation over that of the less skilled players (Docherty and Howe, 1978). Since squash is played within a walled court in which there is considerable margin for error, a stroke can be poorly executed but still remain in-play. The error margin coupled with poor anticipation and the inefficient movements of beginner players may be responsible for the similarity in the stress levels of the low skilled group when compared to the medium and high skilled groups (Docherty and Howe, 1978).

While a winning performance may have numerous components (such as those cited previously), Broadhead (1967) claims that two variables outweigh all others when determining the outcome of a squash match. These variables are, the ability of the player to keep the ball in-play by being able to reproduce a range of accurate strokes and, the ability of the player to complete the match through superior physical condition.

In his study, Broadhead used 39 successful American players. The subjects were grouped by rankings: 1) nationally seeded players, 2) nationally ranked but unseeded players, and 3) nationally unranked players. He measured their scores on the Broadhead rebound test and a step test. Stroking ability was defined in terms of grip, backswing, preparation, contact of the ball and body position. A step test was used to assess fitness since the ability to recover after a bout of exercise seemed particularly important. It was concluded that the reproduction of a range of accurate strokes and superior physical condition accounted for a large proportion of the variance. Furthermore, both tests discriminated between the different levels of players.

From these two variables stems Broadhead's classification of squash players as "good strokers" and/or "retrievers". The "retrievers" rely on their ability to move very efficiently on a continuous basis, while the "good strokers" rely on their ability to produce a variety of precision strokes with great consistency. This no doubt accounts in part for the variability among squash champions in terms of style as well as age. For example, Hashim Khan dominated the British game of squash racquets from 1950 to 1962 and in 1963, at age 54, won all the major U.S championships. Experts refer to him as the "master" of strokes. On the other hand, Jonah Barrington, a contender for the British Open crown several times, has been described as a "retriever" since his greatest asset was his ability to get to almost any ball hit by his opponent.

Racquet sports in general have alternating periods of high and low work intensity. In squash, the exercise is broken up by an approximate 10 second gap between rallies (Sharp,1979). In order to comprehend the nature of the game of squash, particularly as a form of intermittent exercise, various investigators have performed time-motion analyses by which the game is broken down into various components.

The CSRA (1982) conducted time-motion studies on a number of national level male and female players. These studies indicated average rally lengths ranging from 10 seconds to 25 seconds among players of international calibre. An approximate 1:1 work to recovery ratio was found to exist. As a result of this finding the six-point test was developed (A.Reed, personal communication, September 17, 1984).

Montpetit et al. (1977) investigated task analysis during 41 games of racquetball and squash involving beginner, intermediate, and advanced players. They measured: 1) duration of a game, 2) number of hits by one player during a game, 3) number of hits per minute, and 4) percentage of active time. For squash, the average game duration was 6.5 minutes with the players involved in rallies 65.6% of the game. The players averaged 9.2 hits per minute or 57 hits per game.

Docherty and Howe (1978) reported their time-motion analysis data according to skill levels. They found mean rally times of 8.8, 8.4 and 5.4 seconds for highly skilled, medium skilled and low skilled players, respectively.

In another study (Beauchamp, 1980) in which physiological measurements were taken during racquetball and squash matches, time analyses were also performed. A mean rally time of 4.9 seconds was found for the game of squash. The actual time that the ball was in-play represented 43.7% of total time. The subjects in the study were male players of "C" level calibre.

Montgomery et al. (1981) also examined time analysis during squash play. They compared the heart rate response of 45 minutes of running with 45 minutes of squash play. Ten recreational squash players served as subjects. It was reported that the squash ball was in-play 52% of the total game time, and the mean duration of a rally was 7.7 seconds. In this study a 1:1 work to recovery ratio was observed.

A pilot study was recently conducted during the Quebec Open Squash Championships held in Montreal (Constantinides, 1984). Matches involving women's A, B and C level players were recorded and measurements taken in order to assess the duration of the rallies (work periods) and the time between rallies (recovery periods). Whereas work periods as long as 34 seconds were recorded, the average work values for A, B, and C levels were: 6.5, 7.1 and 5.9 seconds, respectively. The mean values for the recovery periods for the same levels were: 6.4, 7.2 and 6.3 seconds, respectively.

With the exception of the findings by the CSRA, all the aforementioned studies have found an average rally to be less than 10 seconds in duration. The importance of the duration of the work and recovery periods is discussed in a later section of this review of literature.

2.2 Energy System Utilization

In any kind of physical activity, chemical energy must be supplied to the tissues in order to observe some form of biologic work (McArdle et al., 1981). There are three energy systems which provide adenosine triphosphate (ATP). Adenosine triphosphate is the energy currency of the body. The first two, ATP-CP and lactic acid (LA), are considered anaerobic. The third, the oxygen system (O), is referred to as aerobic. The ATP-CP system (or the phosphagen system) is extremely limited in its ability to produce large amounts of ATP (Fox 1979; Fox and Mathews 1981; Green, 1982). The quantity of available ATP within the muscle has been found to increase with conditioning, while the CP values remain the same after training (Karlsson et al., 1972). After the first few seconds of intense exercise other metabolic pathways must predominate if ATP levels are to remain high. The usefulness of the ATP-CP system lies in the rapid availability of energy rather than in the quantity. Lactic acid accumulates when there is an inadequate amount of oxygen available at the cellular level. When the ATP-CP system is substantially depleted, ATP is produced through the breakdown of glucose and glycogen into lactic acid (Fox and Mathews, 1981).

Fox and Mathews (1981) have compared the percentage of ATP contributed by the three energy systems in relation to performance time or power output. In activities in which the LA system is important, at least one of the other two systems also is a significant contributor of ATP supply. It is important to note that the three energy systems cannot be thought of as isolated processes which operate independently during exercise; all three systems contribute concurrently (Green, 1982).

A number of investigators have attempted to classify activities according to the proportion of the energy system utilization. Thoden et al.(1982) have partitioned work time according to the relative contribution to the ATP supply of each of the three energy systems(Table 2.1).

Table 2.1: Work time partitioned to percentage aerobic/ anaerobic contribution

Maximum effort of work (time)	ATP-CP (%)	LA (%)	O2 (%)
5 s	85	10	5
10 s	50	35	15
30 s	15	65	20
1 min	8	62	30
2 min	4	46	50
4 min	2	28	70
10 min	1	9	90
30 min	1	5	95
1 hr	1	2	98
2 hr	1	1	99

Thoden et al., 1982.

Fox and Mathews (1981) state that the ATP-CP system dominates in activities less than 30 seconds in length while the oxygen system is predominant in events exceeding three minutes. Between 30 seconds and three minutes, the lactate system combines with the ATP-CP system and/or the oxygen system to provide the energy to perform the activity.

Several investigators have examined the energy systems utilized in the game of squash (Blanksby et al., 1973; Beaudin et al., 1978; Sharp, 1978a, 1979; Montgomery et al., 1981; CSRA, 1982; Northcote et al., 1983). In the CSRA manual (1982), it was stated that squash is an anaerobic sport involving repeated, lengthy bursts of play with the majority of the rallies longer than 10 seconds. The manual states that "high level players can tolerate these rallies quickly removing lactic acid and demonstrating rapid heart rate recovery. This fact indicates the involvement of the aerobic energy system in the recovery periods" (CSRA, 1982).

Aerobic fitness appears to be an essential aspect of fitness specific to squash. It is critical when performing relatively high intensity work for as long as possible as well as for rapid recovery necessary between repeated bouts of high levels of power output.

Wenger (1981) points out that aerobic fitness is not a simple, unidimensional characteristic. He presents a model in which aerobic fitness consists of many facets (Appendix A). As a result, an individual's aerobic fitness will have different components developed to varying levels. Of Wenger's seven components of aerobic fitness, the ability to recover from high intensity exercise is of critical importance in squash since the aerobic energy system is crucial for the replacement of high-energy substances following short bursts (5-30 s) of activity.

Sharp (1978a, 1979) states that the squash pattern, that is, exercise being broken by the ending of the rallies, enables one to describe squash as an aerobic activity but with frequent forays into anaerobic territory. Hence there is a need for both anaerobic and aerobic fitness in squash.

Beaudin et al. (1978) conducted a study in which the purpose was to measure blood lactate levels after exercise, and to determine whether the activity of playing squash is sufficiently intense to promote and/or maintain aerobic fitness. Ten male subjects of intermediate squash ability were used. Aerobic power and lactate measurements were recorded. Heart rates were monitored by telemetry throughout the squash match and used to determine exercise intensity. The average heart rate intensity was 77% of maximum with the range being 71-90% of maximum. The mean lactate value after a game of squash was 24 mg% (2.6 mmol/l) with a standard deviation of 13.8 mg% (1.5 mmol/l). In most cases, the amount of lactate produced after 45 minutes of squash play was minimal despite relatively high intensities. The authors concluded that the lactic acid system did not play a major role in the game of squash.

The involvement of the aerobic system in squash is not readily apparent because of the nature of the game. Squash is an activity with periods of high and low work intensity. For discontinuous exercise to be considered as an aerobic activity capable of effectively improving aerobic power, the high intensity workloads must be long enough to bring the average intensity up to 70% of maximum heart rate (American College of Sports Medicine,1981).

The aerobic component of the game has also been examined by Blanksby et al. (1973). They studied heart rate responses of middle aged sedentary, middle aged active and 'A' grade male squash players using 25 subjects in each category. The maximum heart rates attained during the activity were 170 beats min for the sedentary group, 153 beats min for the active group and 163 beats min for the 'A' level players. It was concluded that squash is an activity providing prolonged and severe workloads.

Montgomery et al. (1981) compared the heart rate response of running and squash. The subjects were asked to run 45 minutes at a self-selected pace and to play 45 minutes of squash with a partner of equal ability. Heart rate was monitored by telemetry. The exercise intensity for running was 84% as compared to 80% for squash. The authors concluded that squash provides the same aerobic benefits as a continuous activity such as running.

The heart rate intensities during squash play were also examined by Northcote et al.(1983). The authors were interested in finding out if there was any relationship between the cardiovascular system and the cause of sudden death during or shortly after squash. Twenty one male players from Scotland of similar average ability were monitored 45 minutes prior to the onset of the activity and for 45 minutes during the actual squash match. The maximum heart rate during play was 170 ± 16 beats $\cdot$ min^{-1} with a range from 144 to 197 beats$\cdot$$min^{-1}$. When expressed as a percentage of predicted maximum heart rate, as defined by Astrand and Rodahl (1981), this represented a mean of 90 percent. The mean heart rate during play (calculated every minute) was 149 ± 18 beats $\cdot$ min^{-1} (range= 120 - 182 beats$\cdot$$min^{-1}$) which represented 80% ± 10% of predicted maximum heart rate. It was concluded by the authors that squash was an extremely strenuous activity.

2.3 Racquetball, Similarities and Differences

Racquetball is a game of very recent origin having been developed by Sobrek in Connecticut in 1958 (Reznik et al., 1972). Like squash it has gained much popularity in recent years. Both activities are played indoors, within four walls and both activities require the use of a racquet. A standard size racquetball court is 20 ft (6.10 m) wide, 40 ft (12.20 m) long, with a 20 ft (6.10 m) ceiling and 12 ft (3.66 m) high back wall. This is considerably larger than an international or an American squash court. In addition, the ball and the racquet used in the game of racquetball vary considerably from those used in squash. Since many individuals are turning to racquetball and squash as alternative forms of exercise for developing or maintaining a degree of physical fitness, several investigators have performed studies which deal with task analysis and the assessment of various physiological variables related to racquet games (Docherty, 1982).

Montpetit et al. (1977) describe racquetball as a high energy expending sport. They state that a racquetball player expends 12.25 kcal/min (51 kJ); a value which is equal to that of a squash player. The authors performed task analysis in order to gain information on the components of the game. They determined that there were 140 hits per game, or nine hits per minute, with the ball in-play 65% of the total playing time.

A study conducted by Montgomery (1981) used nine male racquetball players classified as "A", "B", or "C" level according to their performance in previous tournaments. The investigator observed 12 matches of "equal" competition (A against A, B against B and C against C). Twelve matches were observed in which the observed player was "weaker" than the opponent, and another twelve matches were played in which the observed player was "stronger" than the opponent. It was found that in the matches in which the opponents were of equal ability, 81% of the rallies were 10 seconds or less, 16% were between 11 and 20 seconds, and only 3% of the rallies were greater than 20 seconds in duration. In the matches in which the opponents were of unequal ability, 85% of the rallies were 10 seconds or less, 13% were between 11 and 20 seconds, and 2% were greater than 20 seconds in duration. It was concluded that racquetball matches are longest when the players are of equal ability. Table 2.2 provides detailed description of the results of the task analysis in this study.

Table 2.2: Rally duration and length as a percentage of total number of rallies

Ball Position	Time (s)	Equal matches	Unequal matches
In-play	1-10	81	85
	11-20	16	13
	> 20	3	2
In-play	Total (%)	44	44
	Average (s)	7.4	6.7
Out-of-play	Total (%)	56	56
	Average (s)	9.4	8.5

Montgomery, 1981.

Time analysis was recently conducted during singles and doubles competition in racquetball by Morgans et al.(1984). The duration of the rallies for singles competition was 8.6 seconds while for doubles competition it was 8.3 seconds. The ball was out-of-play 9.6 seconds and 10.3 seconds for singles and doubles respectively. The ball was in-play 47% of total time in the singles matches, and 45% of total time during the doubles matches. These results re-confirmed the findings of Montgomery (1981).

In an attempt to determine the intensity and caloric cost of playing racquetball, Faria and Lewis (1982) reported descriptions of a game of racquetball. They stated that the ball was in-play 32% of total game time, considerably lower than the times reported in the previous two studies, and that 90% of the rallies were shorter than 10 seconds. There was no reference to the level of competence of the players.

Investigators have also attempted to assess physiological responses during racquetball activity. Montgomery (1981) assessed the heart rate response of racquetball players. The subjects (n=9) were monitored during matches between players of equal ability, one player stronger than the opponent and vice versa. Only one player was monitored at a time. When the monitored player was stronger, the heart rate intensity was 70%, whereas, when the monitored player was weaker than the opponent, the heart rate intensity was 90 percent. When the two players were of equal ability the heart rate intensity was 87 percent. The author concluded that even though the heart rate response of racquetball players was high, the exercise intensity estimated from this variable may be an overestimation of the actual intensity. Racquetball involves greater arm work due to the shorter racquet which causes an increase in the heart rate response over and above exercise just involving the legs (Montgomery, 1981). The same author was involved in a study in which heart rate responses during squash play were assessed (Beaudin et al., 1978). They reported heart rate intensity values of 77 percent. The authors attributed the slightly higher heart rate values obtained during racquetball to the larger court size and the more vigorous upper body movements in racquetball as compared to squash.

In an attempt to provide a physiological profile of 10 professional racquetball players, Pipes (1979) described the racquetball professional with respect to physique, body composition, muscular strength, flexibility and cardiovascular endurance. The VO_2 max was found to be 58.3 ml/kg min, while the heart rate intensity range during actual playing time, was between 78% and 92% of the maximum.

Faria and Lewis (1982) assessed the aerobic power of racquetball players by comparing values obtained during actual racquetball play with VO_2 max during a treadmill test. They reported a mean oxygen consumption value of 96% of VO_2 max during play. They concluded that the metabolic responses during racquetball play were consistent with the physiologic responses to high intensity, short term work.

Morgans et al. (1984) monitored heart rates of 15 racquetball players in singles and doubles competition. During one hour singles matches, subjects attained an average of 83% of their maximum heart rate reserve (MHRR) and played above 60% of their MHRR for 56 continuous minutes. During the doubles matches, the players averaged 67% of their MHRR and played above 60% of their MHRR for 29 continuous minutes. The authors concluded that, although doubles competition is not as strenuous as singles competition, both forms of exercise develop and maintain cardiorespiratory fitness.

A number of comparative studies have also been conducted among the various racquet sports (Montpetit et al., 1977; Beauchamp, 1980; Docherty, 1982). Montpetit et al. (1977) have compared racquetball and squash to tennis. They state that a tennis player expends approximately 7.5

kcal/min (31 kJ) as compared to 12.25 kcal/min (51 kJ) during racquetball and squash. They report oxygen consumption values of 27 ml/kg·min for tennis as opposed to 35 ml/kg·min for racquetball and squash. The authors also compared task analyses between racquetball and squash. They filmed 41 racquetball and squash matches involving players of beginning, intermediate and advanced ability. The duration of a squash match was significantly shorter than a racquetball match (6:30 versus 15:30 minutes, respectively). Two reasons could account for the above finding. First, a squash match ends after 15 points (American game) while a racquetball match is played to 21 points. Secondly, in racquetball, only the server receives points while, in squash, points are gained even when service is won. Heart rates were also assessed using telemetry. During squash the mean heart rate was 167 beats·min^{-1} and 171 beats min^{-1} for racquetball as compared to 143 beats·min^{-1} in tennis.

The physiological responses during racquetball and squash were simultaneously observed during a study involving 16 racquetball and 16 squash players of "C" ability (Beauchamp,1980). Oxygen consumption was measured by indirect respiratory calorimetry. Time-motion analysis was also performed. For racquetball, the mean rally time was 5.8 seconds as compared to 4.9 seconds for squash. During racquetball the ball was in-play 49.6% of the total time and 43.7% for squash. The oxygen consumption during two matches of racquetball was 28 and 27 ml/kg·min (52% and 50% $\dot{V}O_2$

max) whereas, for squash, the oxygen consumption value was 31 ml/kg·min for two games (57% $\dot{V}O_2$ max). This difference in oxygen consumption between squash and racquetball was found to be significant. Heart rate intensities during two games of racquetball were 154 and 149 beats·min^{-1} and the respective intensities for squash were 150 and 144 beats·min^{-1}. Lactic acid concentrations were also measured before and after the games. Following the racquetball matches the lactic acid value was 11.7 mg% (1.2 mmol/l) while the squash value was 11.0 mg% (1.1 mmol/l). Both values were found to be low.

The following tables summarize the squash and racquetball studies reviewed in this section.

Table 2.3: Summary of physiological variables for squash and racquetball

Reference	Sport	n	Calibre	H.R. (beats min^{-1})	H.R. Intensity (%)	VO_2 (ml/kg min)	VO_2 max (%)	Lactate (mg%)
Blanksby et al., 1973	SQ	25	Sedentary	170	97	-	-	-
		25	Recreational	153	86			
		25	'A' Level	163	84			
Montpetit et al., 1977	SQ	-	Beg., Int., Adv.	167	-	35	-	-
	RB			171	-	35	-	-
Beaudin et al., 1978	SQ	10	Above average	155	77	-	-	24.5
Docherty and Howe, 1978	SQ	30	High	-	80	-	-	-
			Medium	-	85	-	-	-
			Low Skilled	-	80	-	-	-
Pipes, 1979	RB	10	Professional	-	78-92	-	-	-
Beauchamp, 1980	SQ	2	'C' Level	147	-	31	57	11.0
	RB	2	'C' Level	151.5	-	27.5	51	11.7
Montgomery et al., 1981	SQ	10	Recreational	167	80	-	-	-
Montgomery, 1981	RB	9	A, B, C					
			- Equal	173	87	-	-	-
			- Stronger	146	70	-	-	-
			- Weaker	181	90	-	-	-
Faria and Lewis, 1982	RB	20	-	-	-	38	96	-
Northcote et al., 1983	SQ	21	Average	170	80	-	-	-
Morgans et al., 1984	RB	15	Open, B, C					
			- Singles	161	83	-	-	-
			- Doubles	145	67	-	-	-

Table 2.4: Summary of time-motion studies of squash and racquetball

Reference	Sport	n	Calibre	Rally length (s)	In-Play (%)
Montpetit et al., 1977	SQ	-	Beg., Int., Adv.	-	65.6
	RB			-	65
Docherty and Howe, 1978	SQ	30	High,	8.8	50
			Medium,	8.4	50
			Low Skilled	5.4	50
Beauchamp, 1980	SQ	16	'C' Level	4.9	43.7
	RB	16	'C' Level	5.8	49.6
Montgomery et al., 1981	SQ	10	Recreational	7.7	52
Montgomery, 1981	RB	9	A, B, C		
			- Equal	7.4	44
			- Unequal	6.7	44
CSRA, 1982	SQ	-	Elite	10-25	-
Faria and Lewis, 1982	RB	20	-	10	32
Constantinides, 1984	SQ	16	A	6.5	-
			B	7.1	-
			C	5.9	-
Morgans et al., 1984	RB	15	Open, B, C		
			- Singles	8.6	47
			- Doubles	8.3	45

2.4 Physiology of Intermittent Exercise

Intermittent exercise is characterized by repeated periods of work interrupted by periods of active or passive recovery. This pattern of activity requires a unique series of physiological adaptations and allows a frequent repetition of high intensity exercise stimuli which would not be possible in other forms of exertion (Keul and Doll, 1973). Many investigators have examined the underlying mechanism of interval training since this particular training regime is based on the physiological adaptation to intermittent exercise.

The adaptations vary depending on work to recovery ratio as well as the duration of each of these two components. The physiological adaptations to intermittent exercise manifest themselves in terms of energy system utilization. In the literature on intermittent exercise, attempts have been made to quantify the contribution of each of these systems. In addition, the importance of muscle myoglobin as an energy source has been mentioned.

A study by Christensen et al. (1960), examined various physiological measures during continuous and intermittent work. Two well trained male subjects ran on the treadmill with zero percent grade at a speed of 20 km/hr. Work periods of 5, 10 and 15 seconds were used with recovery periods varying from 5 to 45 seconds. Blood samples were taken every five minutes and analyzed for lactic acid concentration. There was a marked tendency toward increased lactic acid concentrations when the work periods were 15 seconds compared to five or ten seconds. The importance of the recovery period as well as the work:rest ratio was clearly evident.

Astrand et al. (1960a,b) examined the effects of altering the exercise and recovery intervals on several physiological variables. When the exercise and recovery periods were short (30 s) and equal in duration, the work was perceived to be "relatively light" with no fatigue after one hour. In the initial study (1960a), the authors were unable to determine whether the favorable response was due to the short exercise periods or the short recovery periods. As a result, a follow-up study used exercise periods of 10, 15, 30 and 60 seconds and recovery periods from 20 to 240 seconds. When the total amount of exercise was the same, the length of the exercise period was the most distinguishing factor influencing the physiological response. The duration of the exercise period has been associated with accumulation of lactic acid while the duration of the recovery period has been linked with the replenishment of energy stores (Astrand et al., 1960b; Saltin et al., 1977).

The accumulation of lactic acid after continuous and intermittent exercise was studied by Astrand et al.(1960a). After nine minutes of continuous work, the blood lactate concentration was 150 mg% or 16.6 mmol/l. Following intermittent exercise of the same total volume of work, with equal work and rest intervals (30 s), the mean lactate value was 20 mg% or 2.2 mmol/l. However, when the intervals were lengthened (3 min work: 3 min recovery), the mean lactate concentration was significantly higher (120 mg% or 13.3 mmol/l). In the follow-up study (1960b), the duration of the work and rest intervals was manipulated. With short work periods of 10 seconds followed by pauses of 20 seconds, the blood lactic acid concentration was about 20 mg% (2.2 mmol/l), while in the experiment with 40 second pauses, it was 15 mg% (1.6 mmol/l). When the work periods were lengthened to 30 seconds and the recovery periods to 60 seconds, there was a significant increase in the blood lactic acid concentration.

The energy utilization patterns in intermittent exercise of supramaximal intensity was investigated by Margaria et al. (1969). The authors assumed that lactic acid was not produced until 10-15 seconds after the beginning of exercise, presumably when the phosphate stores were diminished. They postulated that if the exercise was less than 10 seconds, only an alactic oxygen debt would be observed. The alactic oxygen debt was defined by this research team as an anaerobic process responsible for the splitting of ATP and CP. Therefore, a very short period of recovery would be sufficient to replenish the phosphagen stores and re-saturate the hemoglobin and myoglobin stores thereby permitting the subject to perform the exercise again on the same energy source with no appreciable lactic acid accumulation. The study involved three subjects performing a series of experiments on a treadmill. The experimental conditions consisted of running at 18 km/hr on a 15% grade with work periods of 10 seconds alternated with rest periods of 10, 20 or 30 seconds. During the first session they reached exhaustion after 30-40 seconds with maximum blood lactate concentrations of 50-60 mg% (5.5-6.0 mmol/l). The results revealed that no lactic acid accumulated if the period of recovery was 30 seconds. Also the increase in blood lactic acid concentration, due to 10 seconds of running, increased when the recovery period was decreased from 20 to 10 seconds. In addition, the blood lactic acid concentration was dependent on the number of runs.

Edwards et al. (1971) compared blood lactate concentrations during continuous and intermittent exercise with the same average power output. Three male subjects exercised on a bicycle ergometer. The intermittent pattern consisted of 10, 30 and 120 second work bouts alternated with 30 seconds of rest. Blood lactate concentration rose progressively during the six minutes of continuous exercise but, with intermittent exercise, the increase was noticeably less. When the work periods were only 10 seconds long there was no increase in blood lactate. However, the average power output was markedly reduced from 1000 kp m/min (164 Watts) to 250 kp m/min (41 Watts) with the shortest work periods.

The importance of the recovery periods in an intermittent activity, with relatively short work periods, has been linked to the process of phosphagen resynthesis. In their text book, Fox and Mathews (1981) relate the duration of the relief interval to the percentage of ATP and CP resynthesized (Table 2.5).

Table 2.5: Duration of relief interval and ATP-CP resynthesis.

Relief Interval (s)	% ATP-CP restored
less than 10	very little
30	50
60	75
90	88
120	94
more than 120	100

Fox and Mathews, 1981.

The significance of phosphagen replenishment has been questioned by several investigators. Saltin and Essen (1971) had three subjects perform intermittent exercise for 30 minutes at supramaximal load of 2400 kp·m/min (392 Watts). The work and recovery periods were 10 s:20 s, 20 s:40 s, 30 s:60 s and 60 s:120 s. The ATP-CP depletion was most marked with the longer work periods. When the recovery periods lasted more than 20 seconds, a significant increase in the ATP-CP was observed in the muscle. It was concluded that, during recovery periods of less than 20 seconds, the reloading of ATP-CP had an insignificant role in energy supply during intermittent exercise. Re-synthesis of phosphagen stores during repeated bouts of exercise plays a major role in meeting energy requirements only when the recovery period is at least 60 seconds in duration (Saltin, 1973). In a later study, Saltin et al. (1977) reported that the energy available from ATP and CP concentrations of 5 and 20 mmol/kg of wet skeletal muscle, respectively, could provide the energy for high intensity exercise of 5-15 seconds duration provided that the phosphagen stores were fully resynthesized to normal levels during the recovery periods.

Fox et al. (1969) compared continuous and interval running in terms of metabolic energy source utilization. The subjects ran continuously to exhaustion at a constant speed and grade on a treadmill. On another day, they performed the same total amount of work in intervals ranging from 10 to 60 seconds in duration alternated with relief intervals of 20 to 150 seconds. The metabolic energy production, as determined by summing the energy delivered from the components, was found to be virtually the same for continuous and interval runs of comparable work output.

Although the energy supplied, via the aerobic mechanism, during interval running is only slightly altered, the proportions of energy delivered from the phosphagen stores and the LA system are quite different from those during continuous running. For example, in a continuous run requiring 30 kcal/kg hr (126 Joules), approximately 37.5% of the total energy is delivered by the aerobic mechanism, 35% by the LA system, and 27.5% by the phosphagen system. In contrast, during interval running requiring the same total energy and supplying the same energy aerobically, the energy delivered by the LA system is reduced to 15% and that by the phosphagen system increased to 47.5% of the total (Fox et al., 1969).

The contribution of the energy systems in terms of total ATP required during exercise has been investigated by Essen et al.(1977). The exercise regime consisted of one hour of cycling with 15 second work intervals and 15 second recovery intervals. Of the total of 0.19 moles of required ATP, the oxygen system contributed 0.09 moles (47.4%) and the myoglobin stores 0.05 moles (26.4%). The phosphagen stores and the LA system provided 0.03 and 0.02 moles (15.8% and 10.5%), respectively.

The contribution of myoglobin to intermittent exercise has been examined by many investigators. Myoglobin is a protein found in skeletal muscle which binds oxygen and facilitates the transport of oxygen within the muscle cell. The amount of oxygen stored by myoglobin is about 11 ml/kg of muscle tissue. For athletes, it would be approximately half a liter of oxygen (Fox, 1979). While this quantity of oxygen does not appear to be significant, the oxygen myoglobin stores play an important role during continuous exercise and are particularly significant during intermittent exercise of short duration (Astrand et al., 1960b; Christensen et al., 1960; Saltin and Essen, 1971).

The oxygen myoglobin stores provide a very rapid oxygen source for the muscle. During the initial phases of exercise, before the oxygen transport system can supply additional oxygen, the oxygen bound to myoglobin is consumed. This supply of oxygen helps to delay the accumulation of lactic acid in the muscles and blood. Like the phosphagen stores, the oxygen myoglobin stores are replenished very rapidly during the recovery period (Fox, 1979).

Astrand et al. (1960a) hypothesized that, since the formation of lactic acid during short work periods is minimal, the initial phase of the work could be handled by the aerobic system depending upon the amount of oxygen used by the muscles when the work is started. The oxygen bound to myoglobin and to hemoglobin is the source of this aerobic work. During the recovery period, even if it is only half a minute long, myoglobin must be reloaded with oxygen before the next work period begins.

2.5 Field Tests in Squash

Since the development of physical education programs should be based on accurate research evidence, it is important to scientifically construct valid, reliable and objective tests in sporting activities (Johnson and Nelson, 1979). In the past, research on physiology of sport has been concerned with the assessment of physiological components in a controlled laboratory environment. However, it is possible to obtain objective and reliable measures in competitive situations through field tests (Reed, 1982). A field test is one conducted in an environment which attempts to simulate the actual competitive situation (Reed, 1982).

A review of the literature concerning skills tests for squash racquets revealed three tests. Edgreen and Robinson (as cited in Cahill, 1977) suggested a battery of five squash items, including a speed test, a volley control test, an overhead serve test, an underhand lob test and an accuracy test. Reliability and validity were not reported.

Broadhead (1967) designed a rebound test that discriminated the stroking ability between different levels of players. He examined the grip, backswing, preparation, control of the ball and body position.

Cahill (1977), developed a squash racquets skill test battery to serve as an evaluation tool and classification device for beginning level squash players. He also investigated the discrimination powers of the test and developed its validity, reliability and objectivity using 199 undergraduate students. The battery originally consisted of 10 items: 1) 30 second rally, 2) lob serving to the right, 3) lob serving to the left, 4) forehand alley, 5) backhand alley, 6) forehand crosscourt, 7) backhand crosscourt, 8) volley test, 9) power and 10) agility. After statistical analysis of these 10 items, the final testing battery was reduced to: a 30 second rally test, a forehand crosscourt test and a volley test.

The only existing field test measuring physiological parameters specific to squash play has been developed by Reed for the CSRA (1982). The test is based on time-motion studies conducted at several levels of squash play for both men and women. This test was originally designed for elite squash players although it has been suggested that its use can be applied to all levels of players.

CHAPTER III

METHODS

Included in this chapter are the following sections:

3.1 Subjects

3.2 Laboratory and Field Tests

3.3 Instrumentation

3.4 Statistical Analyses

3.1 Subjects

The subjects for this study consisted of 30 female competitive squash players residing in the Montreal area. The age range of the subjects was from 19 to 42 years. The subjects were acquired on a volunteer basis and were divided into three groups representing "A" level, "B" level and "C" level calibre of play. The criterion for forming the groups was based on the subjects' squash ability, as defined by tournament performance over a period of years. The sample included the 10 top ranked players in Quebec, three of whom represented the province in the 1984 national championships. Informed consent was obtained from all subjects prior to testing.

3.2 Laboratory and Field tests.

All subjects participated in five testing sessions consisting of two laboratory tests and three field tests.

The testing sessions included: 1) An Aerobic Power Test, 2) An Anaerobic Endurance Test, 3) The CSRA Six-Point Fitness Test, 4) The Modified Test of Squash Fitness and 5)The Modified Test of Squash Fitness for a second time to establish its reliability by the test-retest method.

The treadmill is a commonly used dynamic testing modality in many laboratories (Froelicher, 1983). In the present investigation the treadmill was selected because it involves a skill with which subjects are familiar, that is, walking and running and requires more large muscle activity than other test modalities since the arms and shoulders aid the motion. Because squash requires the player to run from one corner of the court to the other, running on the treadmill was considered the most appropriate motor pattern to evaluate the squash player's aerobic and anaerobic fitness.

Tests were completed within a two week period. All five tests were administered on separate days. The test order was randomly assigned to each subject.

Subjects were asked to refrain from eating, drinking (except water), or smoking for two hours prior to testing. The subjects reported in appropriate attire for all tests. For the field tests, they were encouraged to report in squash costume including court shoes that were in good condition. Due to the constant change of direction in squash, good grip is essential for efficient movement in the court (Zuber, 1980). It was therefore considered important to minimize any factors, such as sliding on the court, that might have impeded a subject from attaining her best performance. For the laboratory test, the subjects were encouraged to use quality running shoes.

Prior to each session the subjects were familiarized with the testing procedures. Verbal explanation was given by the investigators prior to and during the field and laboratory tests. Each subject was encouraged to perform a warm-up prior to all tests.

Aerobic Power Test

All subjects underwent an exercise test to exhaustion on a motor driven treadmill to determine maximal oxygen power. The subjects were familiarized with the treadmill before the test was administered.

The protocol began with the speed of the treadmill set at 6.4 km/hr (4 mph) and the grade set at zero percent. The work load changed every minute. In the first four increments the grade of the treadmill was increased by 2.5% every minute. Once the treadmill grade was at 10%, further increments occured by increasing the speed by 0.8 km/hr (0.5 mph) every minute.

The subjects were verbally encouraged to continue running until exhaustion by the investigators, who used standard statements for all subjects. A 10 second post-exercise heart rate count was taken with a stethoscope. The one mimute maximum heart rate value was then calculated. The subjects continued to run/walk at a slow speed in order to aid the recovery process. During the three minutes of recovery, 30 second heart rate measurements were taken with a stethoscope.

To determine the maximal oxygen consumption values of the subjects, any two of the following criteria had to be achieved: 1) the attainment of an oxygen consumption plateau with increasing workloads (as indicated by a change of less than 100 ml/min), 2) achievement of near maximal heart rate (within 10 beats from the age-predicted maximum heart rate) and 3) a respiratory exchange ratio in excess of 1.00 (McArdle et al., 1981).

Anaerobic Endurance Test.

This test involved a run to exhaustion on a motor driven treadmill to determine anaerobic endurance. The test procedure was a modification of that used by Cunningham and Faulkner (1969). Subjects were required to run on the treadmill for as long as possible at a velocity of 188 m/s (7.0 mph) and with a grade of 20 percent. All subjects were familiarized with the high speed and grade used in the protocol prior to the testing. Again, the subjects were given verbal encouragement by the investigators in order to elicit maximal performance. Subjects were asked to remain on the treadmill until exhaustion. A stopwatch was activated when the subjects started running on the treadmill and was stopped when the subjects grabbed the side rails for assistance. Running time in seconds was reported for each subject.

CSRA Six-Point Fitness Test.

The pattern established in the CSRA test consists of placing six targets on the walls of the squash court. The player runs and taps the head of her racquet against the six targets six points in a predetermined sequence. The subjects were asked to run the pattern as fast as possible. Pacing was discouraged. The pattern began and ended at the "T" spot. The subject stood inside the "T" spot with both feet. On the word 'Go' she ran to the right side and touched the target on the wall with the racquet head and then returned to the "T" spot where it was necessary to place one foot inside the box. The next movement consisted of going to the right front corner and again returning to the "T" spot. The subject then ran to the right side wall target and back to the 'T' three times before continuing to the next target. The right back corner was the last target to be touched before moving to the left side. The same pattern was followed for the left side. The test ended when one foot touched inside the box at the "T". The complete pattern is presented in figure 3.1.

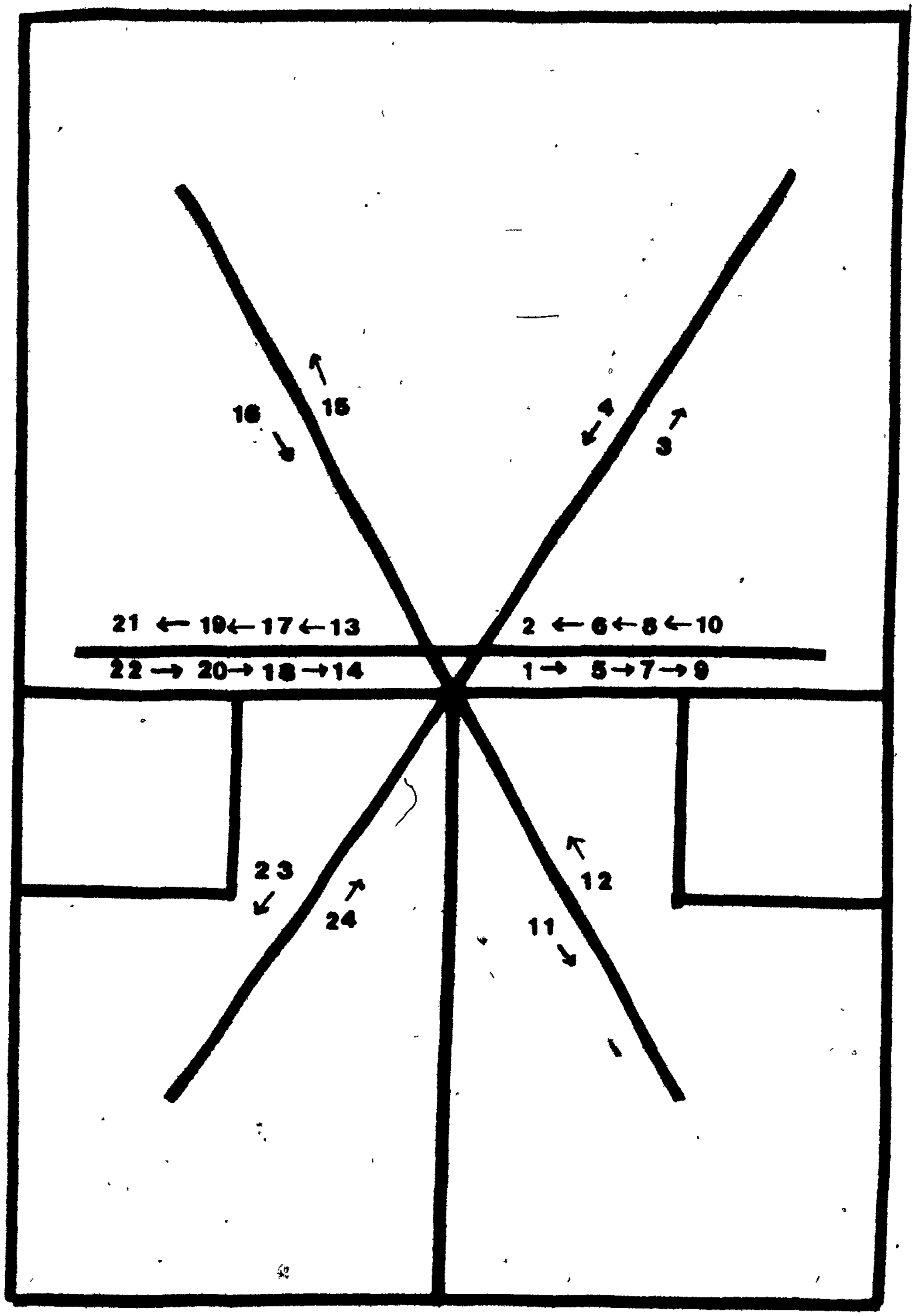

Figure 3.1: The six-point fitness test pattern (CSRA, 1982)

The numbers represent the sequence of movements. The procedure which was followed to provide consistent instructions to each individual is presented in Appendix C. This movement pattern was based on a 20 second work interval and was repeated six times. Each repeat began 40 seconds after the start of the one before it. The purpose of the six repeats was to force the players to initially draw upon the phosphagen stores and then tax the lactic system. The test is designed to measure the drop in speed associated with lactic acid accumulation and fatigue (A.Reed, personal communication, September, 17, 1984). The dependent variable is performance time for each repetition. The difference between the fastest and slowest times was recorded as the drop-off index. Total repetition time was calculated by adding the times of the six repetitions. At the end of the six repetitions, recovery measurements were taken in order to observe the relationship between aerobic fitness and heart rate recovery (A.Reed, personal communication, September, 17, 1984). Heart rate measurements were taken at 30 second intervals for three minutes, starting immediately after finishing the sixth repetition. The subjects' maximum heart rate intensity was calculated by the Karvonen(1957) formula:

$$\text{Peak H.R. intensity} = \frac{\text{Post-exercise H.R.} - \text{Resting H.R.}}{\text{Maximum H.R.} - \text{Resting H.R.}} \times 100$$

Post-exercise heart rate was attained at the end of the last repetition. Maximum heart rate was determined at the end of the exhaustive run in the aerobic power test while the resting heart rate was established by each subject prior to getting out of bed in the morning. Each subject was given instructions on the technique of self-palpation of the carotid artery. The subjects' heart rate recovery was also calculated for the three minute post-exercise time period. Recovery heart rate was expressed as an intensity using the following equation:

$$\text{Recovery H.R. Intensity} = \frac{\text{Post-exercise H.R.} - \text{3 min recovery H.R.}}{\text{Maximum H.R.} - \text{Resting H.R.}} \times 100$$

The post-exercise H.R. was attained at the end of the last repetition and the 3 min recovery H.R. was attained following three minutes of recovery. A sample data sheet is presented in Appendix D.

Modified Test of Squash Fitness

This test was administered twice in order to establish its reliability. According to Baumgartner (1969) and Baumgartner and Jackson (1975), objectivity, or rater reliability is a very important attribute of a test. The determination of the objectivity of a test is essential as stated also by the CASS in the Physiological Testing of the Elite Athlete manual (refer to appendix B). If a test is objective, there will be close agreement between the scores assigned to each subject by different investigators. The objectivity of the modified test was determined by comparing the performance scores of two investigators. Both scorers were located in the squash court. The first scorer was placed in the forecourt area while the second scorer was placed in the backcourt area. Both scorers were familiarized with the testing procedures prior to the testing sessions.

The modified test was based on the most frequently used patterns in the CSRA six-point fitness test. However, since the work and rest intervals were much shorter in duration than the CSRA intervals, the modified test used only four points and was therefore much shorter. The test began and ended at the "T" spot with the player tapping each of the points on the wall with her racquet head. The first repetition began by going from the "T" spot to the right side wall and back. The right forecourt spot was next (always returning to the "T" spot) followed by the left side wall. The left backcourt was the last movement performed to complete the first repetition. The second repetition began by going from the "T" spot to the left side wall and back. The left forecourt was next, followed by the right side wall. The repetition ended by running to the right backcourt spot. Each movement to a particular target point was followed by returning to the marked "T" spot. The third, fifth, seventh and ninth repetitions followed the same pattern as the first repetition, while the fourth, sixth, eighth and tenth repetitions were the same as the second repetition. This alternation was introduced in order to eliminate any possible right hand or left hand bias among subjects. The full pattern is found in figures 3.2a and 3.2b.

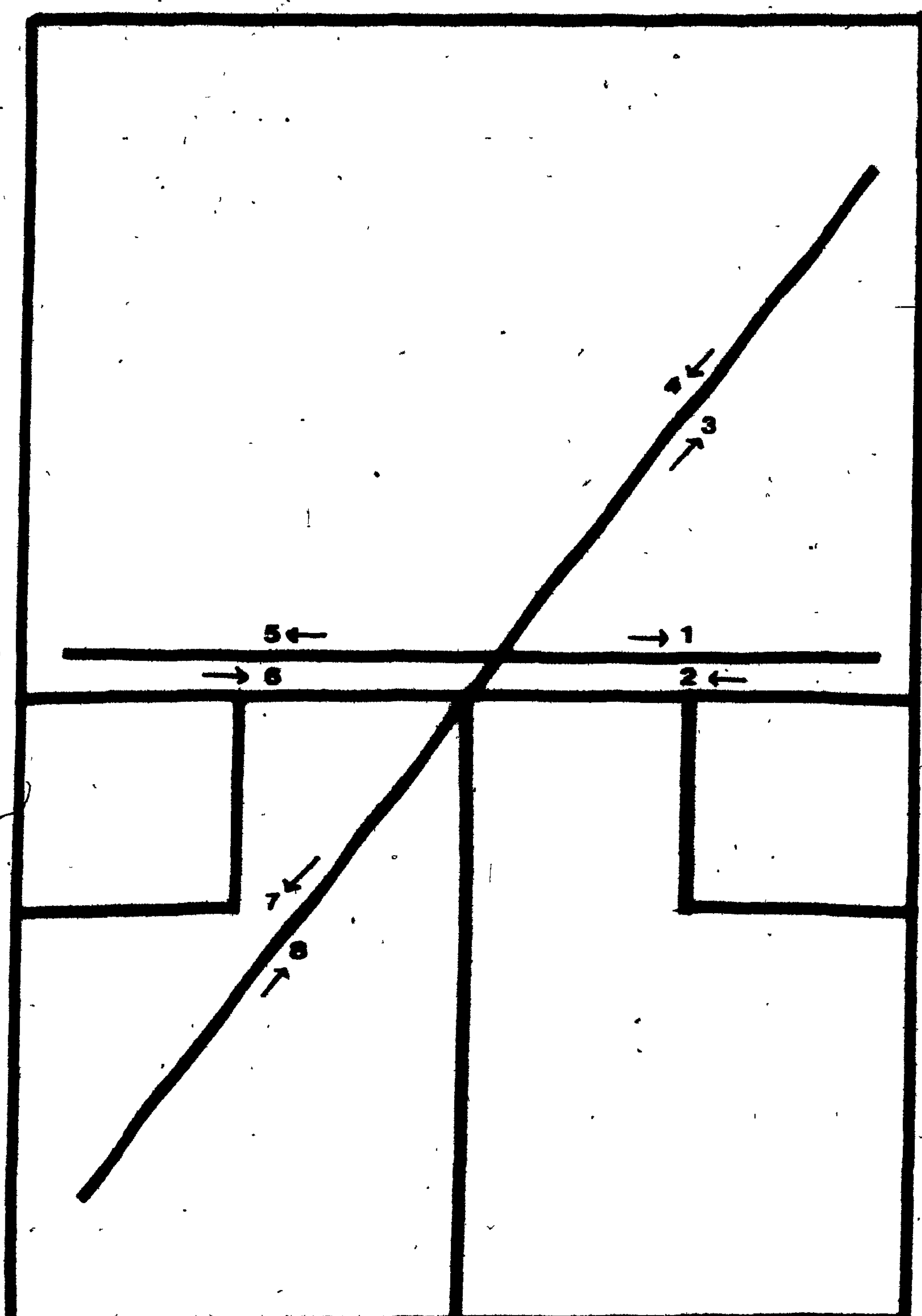

Figure 3.2a: The modified test of squash fitness pattern

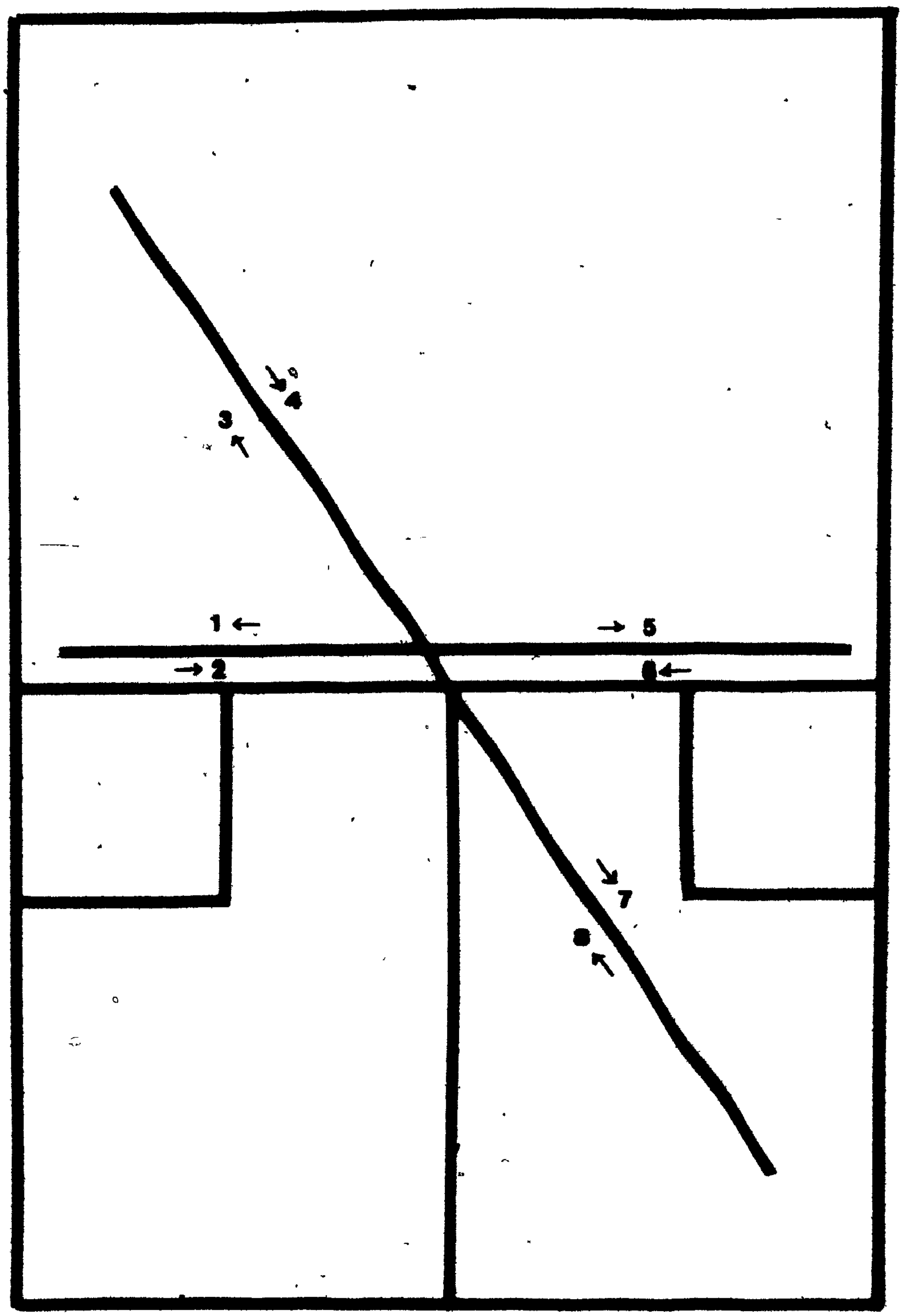

Figure 3.2b: The modified test of squash fitness pattern

The pattern has been numbered according to the sequence of movements. The complete pattern was based on 10 second exercise intervals. It was repeated 10 times. Each repetition began 20 seconds after the start of the previous one. Once again, the players were instructed to perform at maximum effort for the 10 repetitions. The procedure for providing consistent instructions to each individual is presented in Appendix C. The performance variable was the time to complete each repetition. The fastest and slowest times were recorded and the difference between the two times was termed the drop-off index. The total repetition time was calculated by adding the times of the 10 repetitions. At the end of the 10 repeats, maximum and recovery heart rates were measured at 30 second intervals for three minutes starting immediately after completion of the 10th repetition. The subjects' maximum heart rate intensity and recovery heart rate intensity were calculated using the two formulas described in the previous section. A sample data sheet is presented in Appendix D.

3.3 Instrumentation

The aerobic power test was performed on a Collins motor driven treadmill (Model number 07203). Metabolic measurements were made using a Roxon computerized exercise system. The mouthpiece was suspended from an adjustable bar on the treadmill in order to allow free movement by the subject. Inspired air was collected and passed through a turbine. The sample of inspired air was analyzed by a Morgan ventilometer (Mark 2) providing measurement of inspired ventilation in liters per minute. Once the mouthpiece was attached to the subject, expired air was collected in a mixing chamber. A flow control (model R-1) was used in order to regulate the volume of sample gas. Expired oxygen and carbon dioxide measurements were made using an Applied Electrochemistry Oxygen Analyzer (S-3A/I) and an Applied Electrochemistry Carbon Dioxide Analyzer (CD-3A). The maximum heart rate was measured at the end of the test using a stethoscope.

Measurements were taken throughout the test and for three minutes into recovery. Thirty second values were displayed on-line using an Apple IIe computer and Okidata micro-82A printer. Calculated measurements included $\dot{V}E$, $\dot{V}O2$, R, Mets, and $\dot{V}E/\dot{V}O_2$. The computerized system approach for the collection and analysis of respiratory and metabolic data, is illustrated on a flow chart in Appendix E.

Prior to the exercise testing, the oxygen and carbon dioxide analyzers and the ventilometer were calibrated. In addition, subject name, age, height and weight were entered in the computer. Environmental conditions such as, barometric pressure, humidity and temperature were also entered to correct the measurements to STPD conditions.

The anaerobic threshold (A.T) was determined from a graph plotting the ventilatory equivalent ($\dot{V}E/\dot{V}O_2$) versus time and treadmill speed. The anaerobic threshold was determined from the intersection of two linear lines. $\dot{V}O_2$ and $\dot{V}O_2$ as a percentage of $\dot{V}O_2$ max were recorded at the anaerobic threshold. An example of the determination of anaerobic threshold is included in Appendix F. The graph was plotted by the computerized system.

The anaerobic endurance laboratory test was also performed on a Collins motor driven treadmill (Model number 07203). Running time in seconds was recorded for each subject. Measurements were made to the nearest hundredth of a second.

Both the CSRA field test and the modified test of squash fitness were administered on international courts. Each subject was tested at her own club (Montreal Badminton and Squash Club, Mirabel Racquet Club, West Island Tennis Club, Old Montreal Squash Club, Montreal Amateur Athletic Association, Rockland Racquet Club, and St. Eustache Racquet Club). A number of subjects did not belong to a particular club and the Old Montreal Squash Club and the Montreal Amateur Athletic Association international courts were used for them. An effort was made to control court temperatures as well as the lighting throughout all testing sessions. In addition, random assignment of the subjects was made to the different courts in order to eliminate any possible bias due to environmental conditions.

For the administration of the two field tests specific court markings were required. For the CSRA field test and the modified field test, touch targets were placed on the walls at prescribed locations. These points were accentuated by using red colored rectangular pieces of cardboard 28 cm by 23 cm. A white colored square, 40 cm by 40 cm was taped to the floor at the "T" spot to mark the start, return and finish point. The court markings for both field tests are illustrated in Appendix G.

During the administration of both field tests, performance times were recorded to the nearest hundredth of a second using digital stopwatches.

3.4 Statistical Analyses

Means and standard deviations were computed for the descriptive characteristics of the subjects. These included age, height and weight. The subjects were divided into three groups based on squash ability. Means and standard deviations were also computed for data collected during the laboratory tests and field tests. Differences among the three squash groups for the laboratory test variables were determined with analysis of variance procedures.

To establish criterion related validity, Pearson product-moment correlation coefficients were determined. A correlation matrix was computed which included three variables from the CSRA and modified squash tests (total repetition time, drop-off index and recovery H.R.) and two variables from the laboratory tests ($\dot{V}O_2$ max in ml/kg·min and anaerobic endurance performance time).

The discrimination powers of the modified field test of squash fitness were examined by the multiple discriminant function analysis (construct validity). Multiple discriminant function analysis was also performed for the CSRA field test. The discrimination powers of the CSRA field test and the modified field test were compared using drop-off index and total repetition time as predictors.

The reliability of the modified field test of squash fitness was determined by the intraclass correlation coefficient (R). A univariate statistic was used since subjects were tested more than once on the same test (repeated measures). The objectivity of the test was also determined using analysis of variance and the intraclass correlation coefficient. Objectivity was established by comparison of each repetition score from the two investigators on day one and day two.

CHAPTER IV

RESULTS

This chapter is divided into the following five sections:

4.1 Descriptive Data

4.2 Field Tests

4.3 Validity Results

4.4 Reliability Results

4.5 Objectivity Results

4.1 Descriptive Data

Means and standard deviations for age, height, and weight of the three levels of squash players are presented in table 4.1.

The level C players were younger (27 yrs) than both level B and A players (30 yrs). The level B players were taller (168.3 cm) than the C players (165.3 cm) who, in turn, were taller than the A players (163.2 cm). The A players were the heaviest (62.8 kg) followed by the B players (60.7 kg) and by the C players (57.6 kg). These differences were not significant among the three squash levels.

Table 4.1: Descriptive data ($\bar{X}$ ± S.D) of subjects (n=30)

Level	n	Age (yrs)	Height (cm)	Weight (kg)
A	10	30.0 ± 4.5	163.2 ± 11.9	62.8 ± 11.8
B	10	30.0 ± 5.0	168.3 ± 4.5	60.7 ± 4.9
C	10	27.0 ± 6.0	165.3 ± 7.6	57.6 ± 7.1
Total	30	29.0 ± 5.0	165.6 ± 5.0	60.4 ± 8.4

The results of the maximal aerobic power test and the anaerobic endurance test are presented in table 4.2. Both tests were performed on the treadmill.

Table 4.2: Physiological variables ($\bar{X}$ ± S.D)

Variable	Level A n=10	Level B n=10	Level C n=10	Total n=30
Aerobic Test				
H.R. max (beats·min^{-1})	193.0±14.0	189.0±13.0	194.0±12.0	192.0±13.0
$\dot{V}E$ max (l/min)	97.1±17.7	89.0±18.4	93.0±12.1	93.0±16.7
$\dot{V}O_2$ max (ml/kg·min)	44.5± 8.0	46.5± 4.0	46.4± 4.7	45.8± 5.7
A.T (% $\dot{V}O_2$)	78.7± 8.9	77.2± 6.6	75.3± 8.2	77.1± 7.8
Anaerobic Test				
An. End.(s)	31.1±17.2	40.8± 9.3	33.6±11.3	35.2±13.0

The entire sample had a mean maximum heart rate of 192 beats·min^{-1} which is approximately what would be predicted from the formula 220 - Age or 220 - 29 = 191 beats·min^{-1}. The maximum oxygen uptake averaged 45.8 ml/kg·min or 2.77 l/min with a $\dot{V}E$ max of 93.0 l/min. The maximal oxygen uptake value for the A players was 44.5 ml/kg·min as compared to 46.5 ml/kg·min and 46.4 ml/kg·min for the B and C players, respectively. The differences were found to be nonsignificant. The overall $\dot{V}O_2$ max mean value was 45.8

ml/kg·min. When the peak ventilatory equivalent of oxygen ($\dot{V}E/\dot{V}O_2$) was calculated, the group mean was 33.6 liters of air per liter of oxygen which suggests that the treadmill test was maximal for the groups. When the anaerobic threshold was calculated from a plot of ventilatory equivalent of oxygen versus time, a mean value of 35.3 ml/kg·min or 77.1% of $\dot{V}O_2$ max was found. When the anaerobic threshold was expressed relative to the maximum oxygen uptake, the results suggest that the females were trained subjects.

The anaerobic capacity test produced variability in scores among the three levels of squash players, however, the differences were not significant. The B players averaged 40.8 s compared to 33.6 s for the C players and 31.1 s for the A players.

4.2 Field Tests

The CSRA six-point fitness test and the modified test of squash fitness were administered on separate days. Table 4.3 provides the mean repetition times of all 30 subjects for the CSRA six-point fitness test. The modified test of squash fitness was administered twice in order to establish its reliability. Tables 4.4 and 4.5 summarize the variables measured during the tests, as well as the data calculated at the end of the tests.

Table 4.3: CSRA test repetition times ($\bar{X}$ ± S.D)

Repetition	Time(s)
1	29.40 ± 2.50
2	30.43 ± 2.52
3	31.22 ± 2.61
4	31.63 ± 2.55
5	31.40 ± 2.88
6	31.74 ± 2.81
Total	185.78 ± 14.92

Table 4.4: CSRA six-point fitness test (n=30)

Variable	$\bar{X}$ ± S.D
Sum of six reps (s)	185.78 ± 14.92
Fastest repetititon (s)	29.22 ± 2.46
Drop-off index (s)	3.01 ± 1.73
Post-exercise H.R.(beats·min^{-1})	178 ± 13
H.R. intensity (%-H.R. max)	92 ± 9
Rec H.R. - 3 min (beats·min^{-1})	95 ± 17
Rec H.R. - 3 min (%)	27 ± 11

There appears to be a discrepancy between the variables presented in table 4.4 and table 4.3. The mean value of the first repetition of the CSRA test (table 4.3) is 29.40 seconds, whereas, the fastest repetition mean value (table 4.4) is 29.22 seconds. In the first case, the mean was computed across the first repetition scores of all subjects while, in the second case, the mean was computed across the fastest repetition times of all subjects which was not necessarily the first repetition.

Table 4.5: Modified test of squash fitness (n=30)

Variable	Day 1 ($\bar{X}$ ± S.D)	Day 2 ($\bar{X}$ ± S.D)
Sum of 10 reps (s)	105.67 ± 0.76	102.67 ± 6.79
Fastest repetition (s)	10.06 ± 0.67	9.82 ± 0.66
Drop-off index (s)	1.07 ± 0.42	0.99 ± 0.38
Post-exercise H.R. (beats·min^{-1})	178 ± 12	174 ± 12
H.R. intensity (% H.R. max)	91 ± 8	88 ± 9
Rec H.R. - 3 min (beats·min^{-1})	92 ± 20	90 ± 21
Rec H.R. - 3 min (%)	25 ± 14	23 ± 13

4.3 Validity Results

One of the purposes of this investigation was to establish two kinds of validity: criterion related validity and construct validity. Pearson-product moment correlation coefficients were determined between two laboratory variables and a number of field test variables. The laboratory variables were the $\dot{V}O_2$ max in ml/kg • min (a measure of aerobic fitness) and performance time from an anaerobic endurance test. Both tests were performed on a treadmill and were considered to be appropriate motor patterns for squash players. The statistical analysis to examine the validity of the modified test of squash fitness is presented in the next table.

Table 4.6: Correlation coefficients (n=30)

	----CSRA field test----			--Modified field test--		
Laboratory Variable	**Sum of 6 Reps**	**Drop-off**	**Rec H.R.**	**Sum of 10 Reps**	**Drop-off**	**Rec H.R.**
$\dot{V}O_2$ max (ml/kg·min)	-0.51**	-0.44*	0.11	-0.52**	-0.27	0.38*
An. End. (s)	-0.58**	-0.16	-0.14	-0.63**	-0.24	-0.11

* $P < 0.05$ ** $P < 0.01$

Maximum oxygen uptake correlated significantly with the total repetition times of both field tests, the CSRA drop-off index and the modified test recovery heart rate. Anaerobic endurance correlated significantly with the total repetition time of both field tests.

Construct validity was tested by examining the discriminant powers of both field tests using the drop-off index and the total repetition time. The nominal variable consisted of three groups: levels A, B, and C players. The discriminant function analyses for the CSRA and the modified field tests were found to be nonsignificant. Tables 4.7 to 4.10 present the discriminant function analysis for the CSRA test while tables 4.11 to 4.14 present the analysis for the modified test.

Table 4.7: Canonical discriminant functions (CSRA)

Function	% Var.	Chi-squared	df	Sig.
1	98.1	3.36	4	0.5
2	1.9	0.68	1	0.8

Table 4.8: Standardized canonical discriminant function coefficients (CSRA)

	Function 1	Function 2
Drop-off index	0.98	0.35
Sum of 6 reps	-0.61	0.84

Table 4.9: Canonical discriminant functions evaluated at group means - group centroids (CSRA)

Level	Function 1	Function 2
A	0.30	0.05
B	0.19	-0.06
C	-0.48	0.01

Table 4.10: Classification results (CSRA)

Level	No. of cases	Predicted group membership A	B	C
A	10	3	4	3
B	10	4	3	3
C	10	3	0	7

Percent of "grouped" cases correctly classified = 43.3 %

Table 4.11: Canonical discriminant functions (modified)

Function	% Var.	Chi-Squared	df	Sig.
1	70.7	2.12	4	0.7
2	29.3	0.63	1	0.4

Table 4.12: Standardized canonical discriminant function coefficients (modified)

	Function 1	Function 2
Drop-off index	0.14	1.05
Sum of 10 reps.	0.95	-0.48

Table 4.13: Canonical discriminant functions evaluated at group means - group centroids (modified)

Level	Function 1	Function 2
A	0.27	0.12
B	-0.29	0.09
C	-0.02	-0.21

Table 4.14: Classification results (modified)

Level	No. of cases	Predicted Group Membership A	B	C
A	10	3	4	3
B	10	3	4	3
C	10	2	3	5

Percent of "grouped" cases correctly classified = 40.0%

For the CSRA field test the first function accounted for 98.1% of the total variance while the second function accounted for only 1.9% of total variance. These results were not significant. In terms of the two predictors used, the first function had a higher weighting on the drop-off index. For the modified test of squash fitness the first function was responsible for 70.7% of total variance and the second function accounted for 29.3% of the total variance. Again, these results were not significant. Contrary to the CSRA discriminant function analysis, the first function had a higher weighting on total repetition time as opposed to drop-off index.

The classification results of the CSRA test showed that only 43.3% of the cases were correctly classified. The classification results of the modified test revealed that only 40% of the cases were correctly classified. Neither of the two field tests demonstrated any discrimination powers when using drop-off index and total repetition time as predictors.

4.4 Reliability Results

The mean repetition times recorded by the two scorers for each day were used to determine the test-retest reliability of the field test. Table 4.15 lists the 10 repetition times for both days. The intraclass correlation coefficient (R), as determined by the analysis of variance approach, was 0.89.

4.5 Objectivity Results

In order to determine the objectivity of the modified test of squash fitness, two scorers were always present during the administration of the tests. For each of the 10 repetitions, performance time, in seconds, was recorded by the two scorers simultaneously. The above procedure was carried out for both day one and day two. The modified test repetition times for day one and day two are seen in table 4.16. The intraclass correlation coefficients (R), derived from analysis of variance procedures, for days one and two were 0.95 and 0.94, respectively.

Table 4.15: Repetition times for the modified test of squash fitness (n=30)

Repetition(s)	Day 1 ($\bar{X}$ ± S.D)	Day 2 ($\bar{X}$ ± S.D)
1	10.47 ± 0.72	10.08 ± 0.77
2	10.66 ± 0.77	10.25 ± 0.71
3	10.46 ± 0.83	10.31 ± 0.71
4	10.69 ± 0.84	10.34 ± 0.62
5	10.60 ± 0.99	10.20 ± 0.80
6	10.64 ± 0.83	10.37 ± 0.75
7	10.60 ± 0.94	10.23 ± 0.79
8	10.51 ± 0.79	10.35 ± 0.75
9	10.53 ± 0.91	10.27 ± 0.68
10	10.51 ± 0.90	10.31 ± 0.82
Total	105.67 ± 7.76	102.67 ± 6.79

Table 4.16: Modified test of squash fitness ($\bar{X}$ ± S.D) for days one and two for two scorers (n=30)

Rep	Day 1		Day 2	
	Scorer 1	Scorer 2	Scorer 1	Scorer 2
1	10.50 ± 0.71	10.43 ± 0.73	10.09 ± 0.78	10.06 ± 0.78
2	10.75 ± 0.81	10.57 ± 0.72	10.38 ± 0.78	10.11 ± 0.70
3	10.50 ± 0.86	10.43 ± 0.92	10.38 ± 0.76	10.24 ± 0.71
4	10.74 ± 0.81	10.64 ± 0.87	10.43 ± 0.64	10.24 ± 0.63
5	10.66 ± 1.06	10.54 ± 0.97	10.26 ± 0.79	10.14 ± 0.83
6	10.67 ± 0.86	10.60 ± 0.83	10.45 ± 0.81	10.28 ± 0.72
7	10.65 ± 0.94	10.55 ± 0.97	10.32 ± 0.78	10.16 ± 0.79
8	10.56 ± 0.81	10.46 ± 0.81	10.46 ± 0.79	10.23 ± 0.74
9	10.62 ± 0.96	10.43 ± 0.90	10.35 ± 0.71	10.19 ± 0.68
10	10.57 ± 0.92	10.46 ± 0.90	10.39 ± 0.80	10.19 ± 0.83
Total	106.23 ± 7.87	105.12 ± 7.70	103.51 ± 6.90	101.84 ± 6.69

CHAPTER V

DISCUSSION

The following sections are included in this chapter:

5.1 Laboratory Findings

5.2 Field Tests

5.3 Validity Results

5.4 Reliability and Objectivity Results

5.1 Laboratory Findings

The mean maximal oxygen uptake value for the group of squash players was 45.8 ml/kg·min. When compared with Canadian women of similar age, the group mean ranks in the 95th percentile (Standardized Test of Fitness, 1981). This mean score characterizes these squash players as having "excellent" aerobic fitness when compared with the Canadian female population. However, when contrasted with $\dot{V}O_2$ max values for other groups of female athletes the results are equivocal.

Sinning (1973) reported a $\dot{V}O_2$ max value of 42.9 ml/kg·min for female basketball players with a mean age of 19 years. Maksud et al. (1976) assessed the $\dot{V}O_2$ max values of female field hockey players and basketball players and reported values of 42.9 ml/kg·min for hockey players and 40.8 ml/kg·min for basketball players.

The maximal oxygen uptake values of female cross-country skiers have been reported by Saltin and

Astrand (1967) and Rusco et al. (1978). The latter reported a mean $\dot{V}O_2$ max value of 68.2 ml/kg • min with the highest individual value being 75 ml/kg·min. Saltin and Astrand reported a lower value of 63 ml/kg•min for cross-country skiers; nevertheless, it is considerably higher than the values in the present investigation. Wilmore and Brown (1974) investigated the physiological profile (including maximal oxygen uptake) of national and world class women distance runners. They reported a value of 59.1 ml/kg•min. Krahenbull et al. (1978) examined the characteristics of national and world class female pentathletes. Their sample included nine athletes with a mean $\dot{V}O_2$ max of 45.9 ml/kg• min. In a recent study, Riezebos et al. (1983) assessed various physiological parameters of 21 female provincial basketball players aged 18 to 28 years. Their $\dot{V}O_2$ max value of 50.1 ml/kg • min is considerably higher than the previous studies reporting maximal oxygen uptake values for basketball players.

It must be noted that the highest $\dot{V}O_2$ max values reported have been measured for activities requiring continuous exercise of an aerobic nature. In intermittent activities, such as field hockey and basketball, the $\dot{V}O_2$ max values are similar to the values of the squash players in this investigation.

The mean maximum heart rate value, for all subjects in the present study, was 192 beats•min^{-1}. Since the purpose of the aerobic test was to tax the cardiovascular system to the maximum, lack of motivation sometimes poses problems in tests of this nature. However, the maximum heart rate attained at the end of the aerobic test in this study suggests that the treadmill run was indeed an exhaustive run. The value of 192 beats·min^{-1} is approximately what would be predicted from the formula 220 - Age. Using the mean age of 29 years for the sample in the present study translates to: 220 - 29 = 191 beats.min^{-1}.

The anaerobic threshold value for the 30 subjects was 77.1% when expressed as a percentage of maximum oxygen uptake. This value suggests that the women in this study were well trained athletes. Nagle et al. (1970) have reported an anaerobic threshold value of 75% of $\dot{V}O_2$ max in physically active non-endurance athletes. MacDougall (1977) investigated the concept of anaerobic threshold and its significance for the endurance athlete in which his sample included ten elite non-endurance athletes and nine elite endurance athletes. The anaerobic threshold for the former group was 70% of $\dot{V}O_2$ max while, for the latter group was 86% of $\dot{V}O_2$ max. In a recent study, Boulay et al. (1984) described a test procedure for the quantification of maximal aerobic capacity. Their sample included 14 females and 16 males. They found a $\dot{V}O_2$ max value of 42.9 ml/kg·min for the females and an anaerobic threshold value of 36.3 ml/kg·min corresponding to 85% $\dot{V}O_2$ max for the females. They concluded that the subjects in their study had a higher than average level of physical fitness.

According to Bouchard et al. (1982), anaerobic endurance is defined ~~as~~ the total amount of energy available to perform short term intense exercise. A number of different protocols measuring anaerobic endurance exist in the literature. In the present investigation, a modification of the protocol introduced by Cunningham and Faulkner (1969) was used. Among the three levels of squash players, the results of the anaerobic endurance test produced greater variability than the maximal oxygen uptake results. Even though the "B" level squash players had a higher value than the two other groups the differences were not significant.

There are relatively few studies in the literature reporting anaerobic endurance values of female subjects using the Cunningham and Faulkner (1969) protocol. Most findings have monitored male subjects and report values of 52 seconds and higher. One recent study of female basketball players by Riezebos et al.(1983) assessed various physiological parameters. For the assessment of anaerobic endurance the authors used the same protocol as in the present investigation. They reported a mean value of 38.6 seconds which is slightly higher than the mean group value of 35.2 seconds in this study.

5.2 Field Tests

Both field tests utilized similar court patterns. The major difference is found in the duration of the work and recovery intervals. Since the CSRA test consisted of running six repetitions as compared to 10 repetitions for the modified test, it is not possible to make direct comparisons between the two. However, one can perhaps draw some tentative conclusions regarding the general trends of the tests.

In the CSRA test, an increase in mean repetition times was evident towards the end of the test. When examining the repetition times of the modified test, there is no systematic variation in the times from beginning to end. The mean total repetition time of the CSRA test was 185.78 seconds as compared to 105.67 and 102.67 seconds for the modified test (days one and two). Despite the significant difference in total work time, the post-exercise heart rate values obtained at the end of the field tests indicated that the cardiovascular system was taxed just as heavily during the modified test. When heart rate intensities were calculated as a percentage of H.R. max the mean value during the CSRA test was 92% as compared to 91% and 88% for the modified test on days one and two. These differences were not significant.

The heart rate recovery pattern also showed a similar trend during both field tests. In the CSRA test, following a three minute recovery period, a heart rate of 95 beats$\cdot$min^{-1}

was reported whereas, in the modified test, the figures were 92 beats·min^{-1} and 90 beats·min^{-1} for days one and two, respectively. When the recovery heart rates were expressed as a percentage of H.R. max, the value for the CSRA test was 27%, while those for the modified test were 25% and 23%, respectively.

In both field tests there was a drop-off time between the fastest and slowest repetitions. In the CSRA field test, the mean drop-off index was 3.01 seconds and the respective values for the modified test were 1.07 and 0.99 seconds. It appears that the CSRA test value is significantly higher than the modified test value, however, the absolute values are directly related to the duration of the initial work periods. The difference between the drop-off indices is masked when they are expressed in relation to the fastest repetition. There was a 10.3% drop-off index for the CSRA, and a 10.6% and 10.1% drop-off index for days one and two of the modified field test.

The interpretation of the drop-off index is a difficult one to make. In the CSRA manual (1982), Reed states that the drop-off index is related to anaerobic endurance and the need for anaerobic training. However, it is possible to describe two hypothetical situations in which Reed's statement may be questioned. An individual with a high anaerobic endurance may have a high drop-off index if the aerobic fitness of the individual is not developed. In other words, it is possible for an individual to have a very fast first repetition but, because of the inability to recover between repetitions, the individual performs the last repetition in a very slow time. As a result, a high drop-off index will be reported. In another situation, an individual may have a low anaerobic endurance and a high aerobic fitness thus resulting in a low drop-off score. In this case, the first repetition may not be a very fast one, as compared to a person with high anaerobic speed, but because the individual has the ability to recover between work bouts, the remaining repetitions will be performed at similar speeds, thus resulting in a low drop-off score.

The results of the present investigation provide reason for further questioning of the significance of the drop-off index. These are discussed in the following section.

5.3 Validity Results

Validation of performance tests and various field tests is usually determined by correlating field test results with already established laboratory tests. For example, Cooper (1968) attempted to validate a 12 minute running performance test by comparison with a treadmill maximal oxygen consumption test. The correlation between the two variables was 0.897. The author concluded that the 12 minute field performance test was a valid measure of physical fitness reflecting the cardiovascular status of the individual. Doolittle and Bigbee (1968) investigated the relationship between the 600 yard run-walk performance test and the 12 minute performance test. These investigators performed correlational analysis between a maximum oxygen consumption test and each of the performance tests. The 12 minute performance test was a better indicator of cardiorespiratory fitness (r=0.90) than the 600 yard run-walk test (r=0.62). Burke (1976) investigated the validity of selected laboratory and field tests of physical working capacity. Again, correlational analyses were used and significant correlation coefficients were found between $\dot{V}O_2$ max (expressed in ml/kg · min) and a number of laboratory and field tests.

In a recent study, Leger and Boucher (1980) developed a continuous running multistage field test in order to be used as an alternative to the all-out 12 minute Cooper test. Maximum oxygen uptake predicted with the Universite de Montreal Track Test (UM-TT) was compared to $\dot{V}O_2$ max measured directly on the treadmill using horizontal and inclined running protocols. Results revealed r values of 0.96 between the UM-TT and horizontal treadmill running and 0.89 between the UM-TT and inclined treadmill running. It was concluded that the UM-TT is accurate, valid, reliable and safe for young and middle aged adults, males and females, whether they are trained or not. Leger and Lambert (1982) developed a multistage 20 meter shuttle run test to predict $\dot{V}O_2$ max. To establish validity of the test, maximum oxygen consumption measured directly from a treadmill test was used as a criterion. The authors concluded that the 20 meter shuttle run test is a valid and reliable test for male and female adults, individually or in groups, on most gymnasium surfaces.

In the present investigation correlational analysis was used in order to establish the criterion related validity of the modified test of squash fitness. The Pearson-product moment correlation coefficient was determined between field performance variables and two laboratory variables, namely, maximum oxygen uptake and anaerobic endurance performance time.

Maximum oxygen uptake is generally considered the best indicator of aerobic fitness (Mitchell et al., 1958). Since aerobic fitness is important during intermittent exercise (Wenger, 1981; Thoden et al., 1982) and particularly in squash (Sharp, 1978a, 1979; Blanksby et al., 1973; Beaudin et al., 1978; CSRA, 1982; Montgomery et al., 1981; Northcote et al., 1983) it was considered appropriate to use $\dot{V}O_2$ max as a validity criterion. The second criterion used in the analysis was anaerobic endurance. This value was attained by a treadmill sprint, an activity which closely relates to squash play.

For the modified test, there was a significant negative correlation (0.01 level) between the $\dot{V}O_2$ max and the total repetition time ($r = -0.52$), implying that a high $\dot{V}O_2$ max value is associated with a low total repetition time. The $\dot{V}O_2$ max also correlated significantly ($r = 0.38$) with recovery heart rate. An association between recovery heart rate and maximal oxygen consumption is reported in the literature. For example, the recovery heart rate from a bench stepping exercise has been shown to be an effective means of classifying people in terms of aerobic fitness (McArdle et al., 1972; Fox, 1973). In the modified test, the total repetition time also correlated with the anaerobic endurance performance time ($r = -0.63$, $P < 0.01$). Again, the r value was negative implying that a low total repetition time was associated with longer performance times on the treadmill. Reviewing the r values between total repetition time and the two laboratory tests, it is believed by the present investigator that total repetition time is a better indicator of anaerobic endurance than of aerobic fitness. No significant correlations were found between the drop-off index of the modified test and any of the laboratory variables.

For the CSRA test, there was a significant correlation between the total repetition time and $\dot{V}O_2$ max ($r = -0.51$, $P < 0.01$). This value is similar to the value for the modified test. The total repetition time also correlated significantly ($r = -0.58$) with the anaerobic endurance test. Contrary to recovery heart rate from the modified test of squash fitness, the recovery heart rate following the CSRA test did not correlate significantly with the maximal oxygen uptake value.

A major finding in the correlational analyses was the significance found between the CSRA drop-off index and the

$\dot{V}O_2$ max ($r = -0.44$; $P < 0.05$). In the training manual of the CSRA (1982) Reed associates the drop-off index with anaerobic endurance. The same investigator has also been involved in the development of fitness tests for ice hockey and badminton. In the manual published by the Canadian Badminton Association (1981), Reed designed the four-corner badminton fitness test. He used the same rationale for the six-point squash fitness test and, again, associated the drop-off index with the need for short interval anaerobic training. In an attempt to develop and validate an on-ice hockey fitness test (Reed, 1978; Reed et al., 1979) he related the drop-off index to anaerobic endurance. There was no mention, in any of the three fitness tests, of a possible relationship between the drop-off index and aerobic fitness.

The association between the CSRA drop-off index and the maximal oxygen uptake found in this investigation suggests that the magnitude of the drop-off index is dependent on the aerobic fitness and not the anaerobic endurance of the individual. Since aerobic fitness is crucial for the replacement of high energy substances following short bursts of 5-30 seconds duration (Wenger, 1981), it would appear that the higher level of aerobic fitness of an individual would manifest itself in a lower drop-off index value. Further studies are needed to confirm the above finding.

Construct validity is concerned with the extent to which a particular measure relates to other measures consistent with theoretically derived hypotheses concerning the concepts that are being measured (Carmines and Zeller, 1983). The constructs used in this study were the three ability levels of squash players. The predictors used for both field tests were the drop-off index and total repetition time. These predictors were chosen based on their significance in previous studies of squash players.

Discriminant function analyses for both the CSRA and the modified field tests revealed that the tests did not have any discriminant powers. In the CSRA test, only 43.3% of the cases were correctly classified, while in the modified test, only 40.0% of the cases were correctly classified.

At the onset of this investigation, based on existing literature, the assumption was made that the A players would probably have better aerobic and anaeobic fitness than the B players who, in turn, would be fitter than the C players. Previous investigators have elaborated on the importance of fitness for successfull play in squash. Broadhead (1967) conducted a study in which subjects were grouped by rankings. He measured their scores on the Broadhead rebound test and a step test. He concluded that the reproduction of a range of strokes and superior physical condition accounted for a large proportion of the variance in scores. Furthermore, both tests discriminated between the different levels of players.

It was therefore assumed, in the present study, that the subjects' fitness levels would match their rank levels. In this study this was not the case. The $\dot{V}O_2$ max values for the three levels of squash ability were similar. Despite the greater variability found in the anaerobic endurance scores among the three levels, there were no significant differences reported. It may therefore be possible that the skill level of the players determined their rankings. Perhaps in the province of Quebec the competition is such that the "A" players rely more heavily on their ability to reproduce a range of strokes as well as on their tactical abilities. Quebec women may thus be capable of success without high levels of aerobic and anaerobic fitness compared to other sports. When they compete outside of the province of Quebec, such as in Ontario tournaments and in national championships, they are no longer among the top performers. There are no Quebec players included in the 1984 national rankings of the top 20 squash players. In addition, in the 1984 Canadian women's soft ball championships, the two players from Quebec failed to advance to the second round of play in a six round tournament (Canadian Squash, 1984).

The question therefore arises as to whether it is possible that the modified test of squash fitness would have discriminated between different levels of squash players if a larger sample representing players from several provinces had been used. The results of this study may suggest that, within the sample, fitness was not the primary factor determining success in competition. It may be that A level players, who had no better level of aerobic and anaerobic fitness than B and C level players, had greater success because of superior technical squash ability.

5.4 Reliability and Objectivity Results

The three important characteristics of a good field test are validity, reliability and objectivity (Baumgartner and Johnson, 1975). If any of these factors are lacking the test cannot be considered to have scientific construction and is of little worth.

The concept of reliability has been present since the early part of the century (Safrit, 1976). According to Carmines and Zeller (1983) reliability can be defined as the extent to which an experiment, test or any measuring procedure, yields the same results on repeated trials. Synonyms for reliability are: dependability, stability, consistency, predictability and accuracy (Kerlinger, 1964). A correlation coefficient is used to determine the degree of agreement between the trials.

Objectivity is a concept closely related to reliability. It is defined as rater reliability (Baumgartner and Jackson, 1975; Safrit, 1976). If a test is objective there will be close agreement between the scores assigned to each subject by two or more judges. A correlation coefficient is calculated which indicates the degree of agreement between the scorers.

In the present investigation the modified test of squash fitness was administered on two separate days in order to establish its reliability. For each testing session there were two scorers present to time the subjects during the tests. The results were then analyzed to determine reliability and objectivity.

In the past, the commonly accepted practice for estimating test reliability involved the product-moment correlation coefficient or some variation of it (Feldt and McKee, 1958; Liba, 1962; Kroll, 1962). However, an important limitation of this estimation method is that it is a bivariate statistic and should be used to determine the relationship between two different variables. When subjects are tested twice on the same test or two judges rate the performance of each subject, only one variable is measured, and a univariate statistic should be used (Safrit, 1976).

In the present investigation, the estimation of reliability and objectivity was determined by the intraclass correlation coefficient through the analysis of variance approach, a univariate statistic. The intraclass correlation coefficient for reliability was found to be 0.89. The correlation coefficients for objectivity were 0.95 and 0.94 for days one and two. These values provide strong evidence for the establishment of reliability and objectivity of the modified test of squash fitness.

CHAPTER VI

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

The purpose of this investigation was to establish the validity, reliability and objectivity of a field test of squash fitness. The existing field test for squash, developed by the CSRA (1982), was based on work periods of 10-25 seconds. Its application as a training device is suggested for all levels of players. The modified field test of squash fitness used similar court patterns to the previous test, however differs in the duration of the work and recovery intervals. This modification was based on prior studies of time analysis during squash play in which rally times were found to be less than 10 seconds. It was believed that the modified field test of squash fitness would be more representative of a typical rally during squash play and could be applied to a greater range of squash players.

A total of 30 female squash players from the Montreal area, representing three levels of play (A, B, C), were used in the study. The subjects performed two laboratory tests; an aerobic power test and an anaerobic endurance test, and three field tests. The field tests consisted of the CSRA test and the modified test which was administered twice in order to establish its reliability. The aerobic power of the subjects was determined during a graded treadmill exercise protocol and anaerobic endurance was determined from an exhaustive sprint on the treadmill.

The first hypothesis of this investigation stated that there would be a statistically significant correlation between the recovery measurements from the modified field test and the aerobic power laboratory test VO values. Results revealed an r value of 0.38 which was significant at the 0.05 level. This provides further evidence of the association between maximal oxygen consumption and recovery heart rate as reported in the literature.

The second hypothesis predicted that there would be a statistically significant correlation between the performance times (total repetition time and drop-off index) of the modified test and anaerobic endurance laboratory test. Total repetition time was negatively correlated with VO max ($r=-0.52$, $P<0.01$) and negatively correlated with anaerobic endurance ($r=-0.63$, $P<0.01$). It was concluded that total repetition time is a better predictor of anaerobic endurance than of aerobic fitness. There was no statistically significant correlation between the drop-off index and any of the laboratory tests.

It was hypothesized that the modified test of squash fitness would discriminate between squash players of varying ability (A, B and C level). The assumption was made that the fitness levels of the players would vary according to their ranks. This did not prove to be the case. The modified test had no discriminant powers and as a result construct validity was not established.

The fourth and fifth hypotheses were concerned with the reliability and objectivity of the modified test. The intraclass correlation coefficients, using the ANOVA approach, revealed values of 0.89 for test-retest reliability, and values of 0.95 and 0.94 for objectivity (days one and two). These values confirm the reliability and objectivity of the modified test of squash fitness.

6.2 Conclusions

Within the limitations of this study, the following conclusions seem justified:

1. The modified test of squash fitness demonstrated criterion related validity.
2. The modified test of squash fitness did not discriminate between A, B and C level women squash players.
3. The modified test proved to have high reliability and objectivity.

It is recommended that the modified test of squash fitness be used for the general population involved in squash play. Because of existing discrepancies in research findings regarding the significance of the performance variables, it is proposed that the modified test be used in conjunction with laboratory tests.

6.3 Recommendations

The following recommendations are proposed for future investigations:

1) Further studies should be conducted to examine the relationship between the drop-off index and laboratory measurements.

2) Follow-up studies should be conducted using different samples including male players, youth players, and samples drawn from various geographical areas, in order to further test the construct validity of the modified test of squash fitness.

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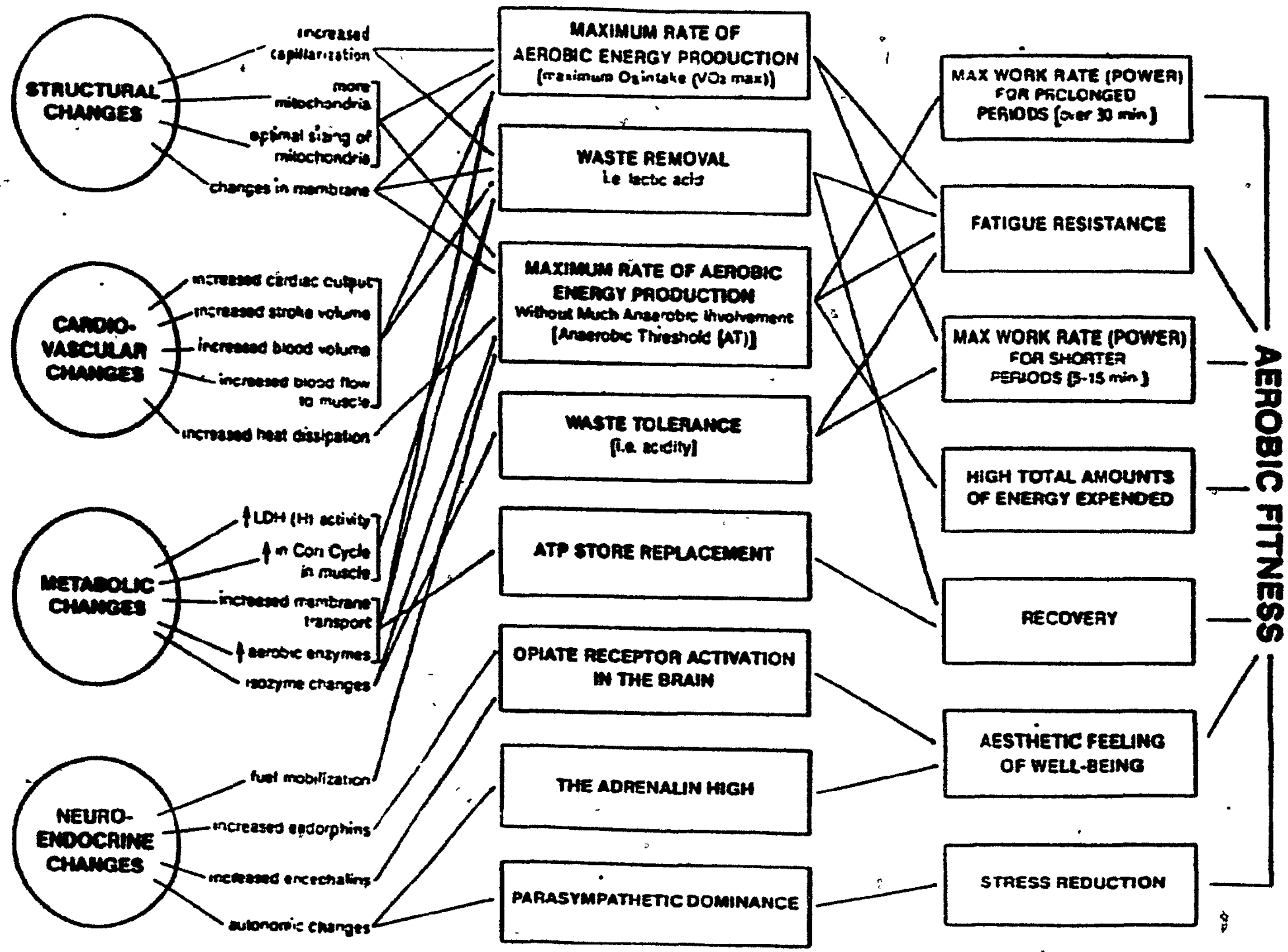
APPENDIX A

The many faces of aerobic fitness



(SOURCE: from H. Wenger, 1981. With permission)

APPENDIX B

Criteria for the evaluation of field tests (Reed, 1982)

Ten criteria have been identified as guidelines for the evaluation of field tests of fitness. The criteria suggest the basis of test validity, reliability and objectivity.

It is necessary to establish the validity of:

1) the simulation of the performance.

2) the selection of the physiological measurements.

The physiological measurements should be:

3) sensitive and responsive to the training for, and execution of, the target performance upon which the field test is based.

4) used to monitor the intensity of the effort.

5) recorded during recovery in field tests of intermittent sports.

The following criteria are suggested for establishing reliability:

6) use of standard test-retest procedures.

7) the conditions under which the reliability of the field test was established should be identified carefully.

8) field tests should be used under environmental conditions similar to those under which their

reliability was established.

9) where possible, field test reliability should be established over a range of environmental situations.

10) field test objectivity should be established by standard test-retest procedures using different test administrators.

APPENDIX C

Procedures for the administration of field tests.

I. Format.

1. Subject warms up (investigator sets up court markings).

2. Investigator verbally describes the pattern.

3. Investigator demonstrates the first three steps.

4. Advise subject that the investigator will give verbal cues.

5. Subject must touch inside all targets.

II. Six point squash fitness test pattern (verbal description).

Subject must run as fast as possible.

1. Stand inside 'T' box with both feet.

2. On word 'go' run to right side wall and touch wall inside the target with the racquet head.

3. Return to 'T' and touch one foot inside box.

4. Run to right front corner, touch racquet inside target and return to touch one foot inside the box at the'T'.

5. Run to touch right side wall and back to 'T' three times.

6. Run to back right corner and back to 'T'.

7. Run to left side wall and back to 'T'.

8. Run to front left corner and back to 'T'.

9. Run to left side wall and back to 'T' three times.

10. Run to back left corner and back to 'T'.

Test ends as one foot touches inside of box at the 'T'.

III. Modified test of squash fitness pattern.

Subject must run as fast as possible.

(Repetition numbers 1, 3, 5, 7 and 9)

1. Stand inside 'T' box with both feet.

2. On word 'go' run to right side wall and touch wall inside the target with the racquet head.

3. Return to 'T' and touch one foot inside the box.

4. Run to front right corner, touch racquet inside target and return to touch one foot inside box at the 'T'.

5. Run to left side wall and return to 'T'.

6. Run to left back target and return to 'T'.

(Repetition numbers 2, 4, 6, 8 and 10)

1. Run to left side target and return to 'T'.

2. Run to left front target and return to 'T'.

3. Run to right side target and return to 'T'.

4. Run to right back target and return to 'T'.

Test ends as one foot touches inside of box at the 'T'.

APPENDIX D

Sample data sheets

The six-point squash fitness test

Date:__________ Court temperature:__________

Name:__________ Player Level:__________

Rep. No.	Time	Finish (s)	Total Time (s)
1	0:00	______	______
2	0:40	______	______
3	1:20	______	______
4	2:00	______	______
5	2:40	______	______
6	3:20	______	______

Slowest Time:	______	s
Fastest Time:	______	s
Drop Off:	______	s
H.R. at 0:00 (end of last rep)	______	$beats \cdot min^{-1}$
H.R. at 0:30	______	$beats \cdot min^{-1}$
H.R. at 1:00	______	$beats \cdot min^{-1}$
H.R. at 1:30	______	$beats \cdot min^{-1}$
H.R. at 2:00	______	$beats \cdot min^{-1}$
H.R. at 2:30	______	$beats \cdot min^{-1}$
H.R. at 3:00	______	$beats \cdot min^{-1}$
Recovery heart rate difference	______	$beats \cdot min^{-1}$

Modified test of squash fitness

Date:______________ Court temperature:__________

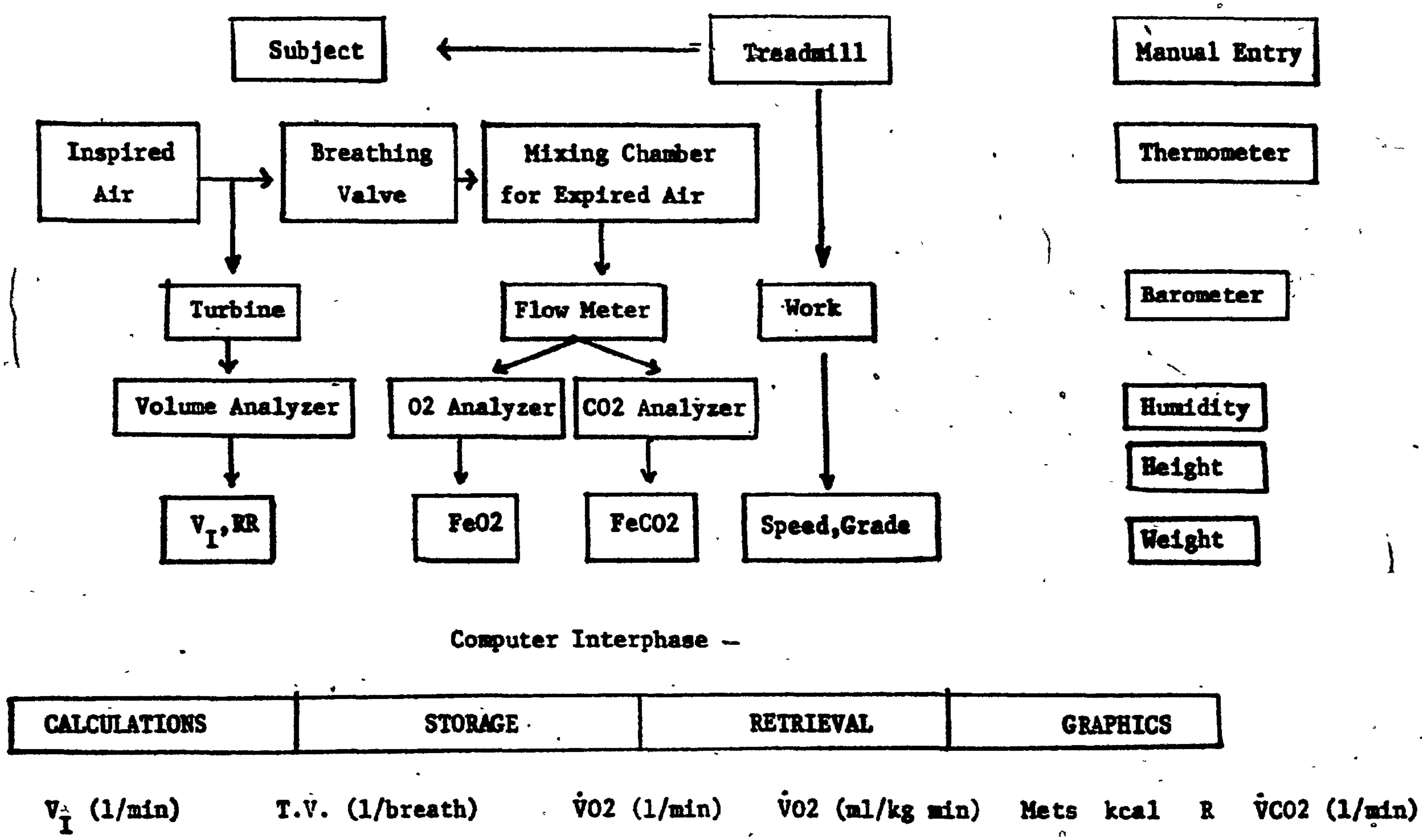
Name:______________ Player Level:____________

Rep. No.	Time	Finish (s)	Total time (s)
1	0:00		
2	0:20		
3	0:40		
4	1:00		
5	1:20		
6	1:40		
7	2:00		
8	2:20		
9	2:40		
10	3:00		

Slowest time:		s
Fastest time:		s
Drop Off:		s
H.R. at 0:00 (end of last rep)		$beats \cdot min^{-1}$
H.R. at 0:30		$beats \cdot min^{-1}$
H.R. at 1:00		$beats \cdot min^{-1}$
H.R. at 1:30		$beats \cdot min^{-1}$
H.R. at 2:00		$beats \cdot min^{-1}$
H.R. at 2:30		$beats \cdot min^{-1}$
H.R. at 3:00		$beats \cdot min^{-1}$
Heart rate recovery difference		$beats \cdot min^{-1}$

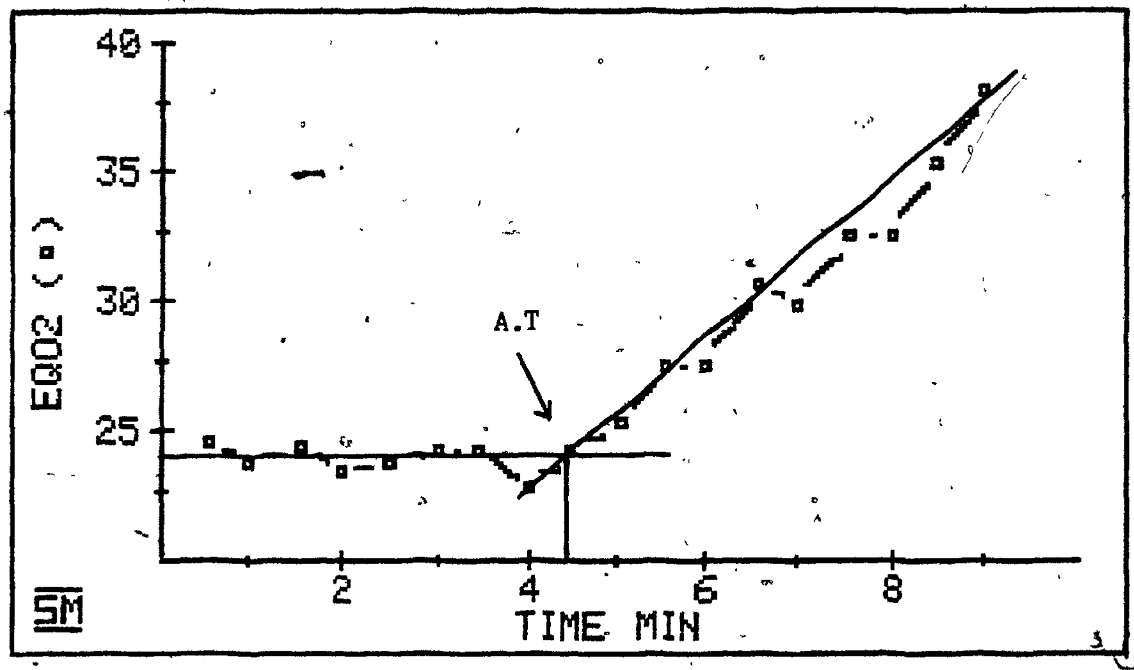
APPENDIX E

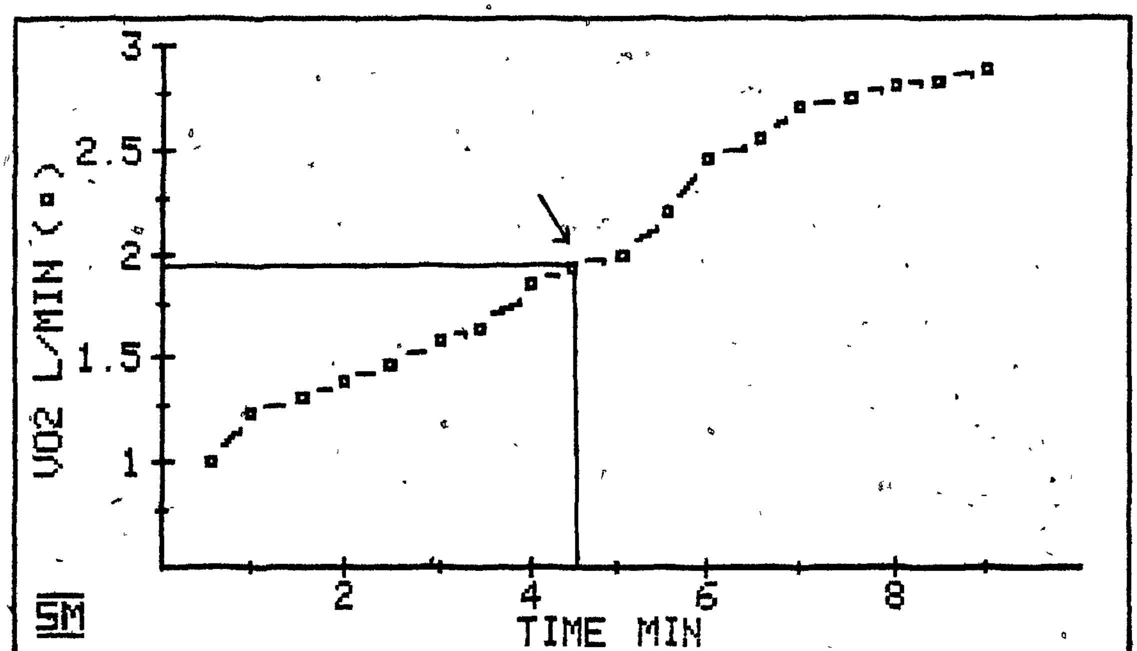
Computerized systems approach for the collection and analysis of respiratory and metabolic data



APPENDIX F

Determination of anaerobic threshold





APPENDIX G

Court markings

A. Six point squash fitness test

Spot 1: 60 cm back from front wall.
60 cm from the floor.

Spot 2: 140 cm directly above the short line.

Spot 3: 60 cm forward from back wall.
60 cm from the floor.

Three corresponding markers are also located on the left hand wall.

B. Modified test of squash fitness

Spot 1: 60 cm back from front wall.
60 cm from the floor.

Spot 2: 140 cm directly above the short line.

Spot 3: 140 cm directly above the short line (left hand wall).

Spot 4: 60 cm forward from back wall.
60 cm from the floor.

Court markings