AN ANTHROPOMETRIC, SOMATOTYPOLOGICAL AND PHYSIOLOGICAL STUDY OF TENNIS PLAYERS WITH SPECIAL REFERENCE TO THE EFFECTS OF TRAINING

by

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DECLARATION

This is to declare that the thesis entitled 'An anthropometric, somatotypological and physiological study of tennis players with special reference to the effects of training' is my own work and that no part of it has been submitted or is to be submitted for a degree in any university.

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ABSTRACT

While a considerable amount of research has been conducted on tennis equipment, the tennis player has received little scientific attention. As a result, players, coaches, trainers and selectors have had to formulate subjective theories concerning the structural and functional demands and effects of tennis playing.

The present study was conducted in order to present a comprehensive description and analysis of the morphological and physiological characteristics of professional and amateur tennis players.

Fifty-six professional (34 male and 22 female) and 48 amateur (33 male and 15 female) tennis players were studied during the 1977 South African Open Tennis Championships. A total of 208 observations were made on each subject willing to complete the battery of tests and measurements. These included a questionnaire, anthropometric, somatotypological, physiological and biochemical observations.

Oral questionnaires were used to obtain personal, tennis and medical history data. Standardised anthropometric techniques and equipment were used to measure mass, heights, diameters, girths and skinfolds. These basic anthropometric measurements were then utilized to obtain the following derived anthropometric measurements: limb and segment lengths; length, diameter and girth indices; body surface area and androgyny; lean volume and tissue indices; absolute and relative body fat; lean and 'ideal' body mass; and the Heath-Carter anthropometric somatotype.

The physiological observations included the following: maximal aerobic power (Åstrand-Ryhming nomogram); cycling and tennis playing efficiency; energy cost of tennis playing (portable respirometer); sweat-rate (net body mass change method); static and dynamic pulmonary volumes (expirograph); static flexibility (flexometer); and eye-limb concordance/discordance (binocular peep-hole test). The biochemical observations included pre- and post-match blood glucose, lactate and electrolyte (sodium, chloride, calcium and magnesium) concentrations. The methods used were based on the Biochemical Test Combinations from Boehringer Mannheim.

The Biomedical Data Package (BMDP) and the Statistical Package for Social Sciences (SPSS) were used for the computation of the univariate statistics and for the correlation, variance, covariance, linear regression, stepwise regression, stepwise discriminant and factor analyses. Specially prepared Fortran computer programmes were utilized for the somatotype analyses.

The data obtained from the oral questionnaires revealed the following: twenty-seven percent of the professional players did not participate in any form of physical training besides their tennis practice sessions; sprains of the shoulder and ankle joint are the most common type of tennis injury; the occurrence of 'tennis elbow' appears to be related to the level of tennis proficiency; and a young starting age is not a prerequisite for top class tennis performance.

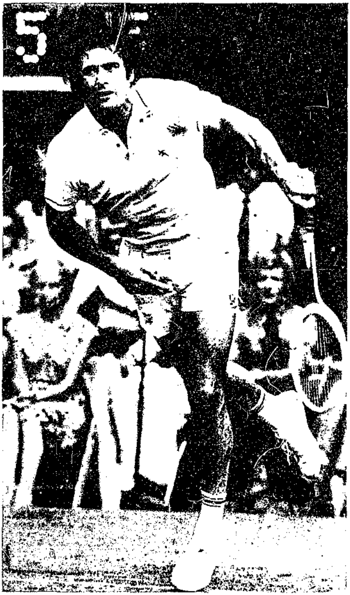
The morphological findings indicate the following: the professionals are significantly heavier and larger (BSA) than the amateurs but height differences are small; the professionals tend to have larger bone diameters and girth measurements than the amateurs; a more masculine physique (androgyny index) appears to be an advantage in women's tennis; the professional and amateur players have, on the average, a body mass which is between 2 and 3 kilograms heavier than the 'ideal' body mass for tennis playing; intensive tennis competition and training over a period of years causes marked bone and muscular hypertrophy in the dominant upper limb, particularly in the forearm; the frequency and intensity of tennis playing has little effect on absolute fat mass and local fat deposits; and somatotype analyses indicate that top class tennis performance, especially in females, is related to specific forms of physique.

The physiological findings revealed the following: the professionals have markedly higher absolute $\dot{V}O_2$ max values than the amateurs but relative $\dot{V}O_2$ max differences are small; the female players have higher relative $\dot{V}O_2$ max values than the male players, which may be due partly to differences in the cardio-respiratory demands of men's and women's tennis; the net mechanical efficiency of cycling, gross absolute energy cost of singles tennis playing and absolute and relative sweat-rate are

very similar among the professional and amateur tennis players; the relative energy cost of singles tennis playing ($\dot{V}O_2\%$ $\dot{V}O_2$ max) is considerably lower in the male professional than the male amateur, which indicates an inverse relationship between relative energy cost and the level of tennis proficiency; static and dynamic pulmonary volumes are considerably larger in the professional than in the amateur player and it would appear that intensive tennis playing has beneficial effects on respiratory structure and function; with the exception of trunk flexion-extension, strenuous competitive tennis playing does not appear to increase joint mobility, in fact, the indications are that it reduces joint mobility in the dominant upper limb; the majority of the professional players are unilateral and it appears that unilaterality is preferable to crossed laterality in tennis players.

The biochemical observations revealed that tennis playing has little effect on blood glucose, lactate and electrolyte concentrations and that biochemical responses are similar in professional and amateur players. Hypoglycaemia is unlikely to occur in tennis players. The low post-match lactate levels indicate that aerobic metabolism may be a greater contributor of energy for tennis than is generally believed.

Based on the findings of the present study, the following recommendations are made: an annual medical examination and exercise stress test for all competitive and professional tennis players; professional assistance and advice from a sport scientist on the formulation of a scientific tennis training and conditioning programme, with particular emphasis on strength (power), flexibility and aerobic training; and the ingestion of a balanced diet by professionals, especially females, and an adequate liquid intake during tennis competition.



Within every competitive tennis player there is the desire to reach upward, to surpass, to become better, stronger and more courageous. It is to these individuals that this study is dedicated.

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Modern scientific research requires team work and the contribution of every team member, whether great or small, is important for it is the parts that constitute the whole. To the members of my team, many of whom have subsequently become good friends, I would like to express my sincere appreciation.

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CHAPTER 1

INTRODUCTION

CHAPTER 1

INTRODUCTION

In this chapter the problem of the present thesis is stated and the approach to this problem discussed. Study objectives, hypotheses and limitations are also outlined.

1.1 STATEMENT OF THE PROBLEM

Tennis is a popular participant and spectator sport, a fact apparent from statistics throughout the world. It has been estimated that 1 in every 15 white South Africans plays tennis, while the number of players in the United States of America has more than doubled over the last decade (Chinn et al., 197[illegible]. Commercial companies conduct extensive research into the improvement and development of tennis equipment. This has resulted in greatly improved rackets, balls, synthetic court surfaces, electronic umpiring, computer ranking systems and many other innovations. Adali and Brannigan (1979), for example, have formulated a mathematical model to determine the mechanical characteristics of a tennis racket and its interaction with the player. These workers believe that this information can improve performance and also reduce shoulder and elbow disorders in tennis players.

In contrast, the player, who is, after all, the central element of the game, has received little scientific attention. Extensive literature surveys as well as discussions with human biologists have revealed that few studies have been conducted on tennis players. From the author's close association with tennis, as both an international player and professional coach, it has become apparent that players, coaches, selectors and administrators have had to formulate their own theories concerning tennis training, conditioning and teaching. These theories are often conflicting since they are based mostly on hunches, traditional beliefs, trial and error, and the practices of successful players. This has led to much confusion, frustration and ignorance among those associated with the sport. The recent death of Karen Krantzke, a leading professional player, is a tragic example of the serious consequences of ignorance. Apparently, she participated regularly in extremely strenuous training programmes and when she complained about feeling ill, was informed that this was the usual effect of training. In the present study, two of our male professional subjects were found to have potentially dangerous conditions of which they were unaware. One was a diabetic while the other appeared to have a cardiac abnormality (heart block).

A study conducted by the author (Copley, 1977a) revealed that both male and female international tennis players are generally not characterised by the excellent physical attributes that one would expect to find in world class performers. Of course, one might argue that this finding indicates the relative unimportance of physical fitness for the tennis player. However, there is little doubt that at high levels of competition there is a thin dividing line between success and failure. Tanner (1964, p.14) aptly summarises this when he states:

> 'In reaching the Olympic standard every little thing counts: and it is when two men are equally pushing themselves to their maximum capacity that a difference in physical structure may be decisive'.

The importance of physical fitness to the expert tennis player is obvious when one considers the power required to deliver a service at over 200 kilometres per hour, the endurance needed to complete a match that may last 5 hours and the mobility necessary to turn, twist, start and stop the body at near maximal speeds. It seems extremely unlikely that a player will attain his/her maximum level of tennis potential without a high degree of physical fitness.

Owing to the lack of morphological and physiological studies on expert tennis players, little is known about the structural and functional demands and effects of tennis playing. This information is important when one considers the number of regular tennis players, many of whom begin playing in early childhood and continue into old age. There appear to be three main reasons for the lack of scientific studies on expert tennis players. First, tennis is not an Olympic sport and players have been excluded from the large and comprehensive research studies conducted during the Olympic games (e.g. Kohlraush, 1929; Tanner, 1964; Correnti and Zauli, 1964; De Garay et al., 1974). Secondly, the average professional player is committed to tournament play for 47 weeks of the year and is, therefore, not readily available for scientific study. Thirdly, with their already large financial incomes, there is little incentive for professional players to participate in scientific projects aimed at optimising their training and conditioning programmes. This study, therefore, aims to present a comprehensive description and analysis of the morphological and physiological characteristics of male and female professional and amateur tennis players.

1.2 APPROACH TO THE PROBLEM

It is recognised that morphological, physiological, biomechanical and psychological studies of expert sport performers provide valuable and interesting information concerning the demands of, and responses to, a particular sport or physical activity. De Garay et al (1974) are of the opinion that the findings and conclusions of investigations of sport champions have applications in the fields of human biology, sport medicine and physical education and may benefit all humanity by providing a greater understanding of human excellence and diversity. Professional tennis players represent a select group of individuals whose biological characteristics are of particular interest to the tennis scientist.

This thesis is divided into 6 chapters: an introduction (Chapter 1); a survey of related literature (Chapter 2); a detailed description of the materials and methods used (Chapter 3); a presentation of the data (Chapter 4); a discussion of the important findings of this and other related studies (Chapter 5) and finally; the conclusions reached and the recommendations made (Chapter 6). The numbering system used in this thesis is: 1 (Chapter number), 1.1, 1.1.1, A, I, a, (i).

It was hoped that this investigation would provide a greater understanding of the morphology, physiology and biochemistry of the tennis player and, in so doing, would stimulate the ideas and efforts of those associated with the sport, find application in the early identification of individuals with tennis potential and finally, provide a better understanding of the nature of tennis excellence.

1.2.1 Study objectives

A number of primary and secondary objectives are envisaged.

A. Primary objectives

I. Evaluate physique in terms of body size, shape, proportions and composition.

II. Assess cardio-respiratory endurance, static and dynamic pulmonary volumes, mechanical efficiency, energy expenditure, sweat-rate and static flexibility in tennis players.

III. Establish morphological and physiological norms for professional and amateur tennis players.

IV. Assess the morphological and physiological effects of intensive tennis playing by a comparison of the data obtained from the professionals with those obtained from the amateurs (cross-sectional method of analysis).

V. Establish the biochemical responses to tennis playing by a comparison of pre-match glucose, lactate and electrolyte concentrations with post-match concentrations among and within each of the four groups.

B. Secondary objectives

I. Assessment of physical characteristics which contribute to proficiency in tennis.

II. Determination of methods for the assessment of 'ideal' body mass and tissue indices.

III. Assessment of morphological and physiological differences between male and female players.

IV. Obtaining of regression equations for the accurate prediction of important morphological and physiological characteristics.

V. Determination of the relationship between tennis proficiency, handedness, eye dominance and eye-limb concordance/discordance.

VI. Gathering of general information, such as the degree of tennis activity, incidence of injury, occupations, training programmes and leisure activities among professional and amateur tennis players.

1.2.2 Hypotheses

A number of working hypotheses were formulated prior to the collection and analysis of data. It was postulated that:

A. Significant differences in the somatotype and body composition of professional and amateur players would be found.

B. Body composition, particularly the bone, muscle and fat proportions of the dominant upper limb, would be significantly influenced by intensive participation in tennis.

C. There would be significant differences between professionals and amateurs in respect of most of the physiological characteristics, especially cardio-respiratory endurance ($\dot{V}O_2$ max), mechanical efficiency, sweat-rate, pulmonary power (FEV_1) and mobility or flexibility of joints.

D. Long-term tennis training and competition would have a marked influence on the mechanical efficiency and energy cost of playing, pulmonary function and joint mobility.

E. Strenuous, competitive tennis playing of long duration would have a marked influence on blood glucose, lactate and electrolyte concentrations.

1.3 LIMITATIONS OF THE STUDY

Although every effort was made to minimise the factors which could have reduced the validity of the present study, the following points are worthy of mention:

1.3.1 In the assessment of the morphological and physiological responses to tennis playing, use was made of the cross-sectional method of analysis. The disadvantage of this procedure was that it could not be established whether the observed morphological and physiological differences between the professionals and amateurs were the result of constitutional dissimilarities or the effects of tennis playing and training. Ideally, a longitudinal study would be preferable to a cross-sectional study for the assessment of the structural and functional effects of intensive tennis playing. In practice, however, such an approach would be hampered by a number of problems. Besides the main difficulty of follow-through of the initial group of subjects for many years of training, one would also have had to recognise and select subjects with natural tennis potential and ability. Åstrand and Rodahl (1970) are of the opinion that no method of investigation is presently available that can separate the influence of constitutional factors from the effects of physical training.

1.3.2 Although the total number of subjects in each of the 4 groups was adequate for the purpose of reliable statistical analysis and interpretation, not all the subjects were willing to complete the comprehensive battery of tests and measurements. Consequently, for certain variables such as energy expenditure, sweat-rate and biochemical concentrations, the number of observations was small, particularly in the two female groups. It would have been preferable to have had larger samples for these variables.

1.3.3 The sophisticated dispersion index was utilized for the description and analysis of the somatotype data. This study would probably have benefited from the incorporation of the new tri-dimensional technique. Unfortunately this new technique does not appear to have been published in any international journals and, as a result, came to the author's attention only at a recent international symposium. Nevertheless, it will be applied to the somatotype data later.

1.3.4 In the assessment of cardio-respiratory endurance ($\dot{V}O_2$ max) and body composition, use was made of recognised indirect methods. The use of the more accurate direct methods would have been preferable since the establishment of norms for tennis players was envisaged. However, these direct methods could not be used in the present study for two reasons. First, the players were not willing to be subjected to strenuous workloads and underwater weighing during a tournament and, secondly, the use of a treadmill and underwater weighing tank was impracticable in this field study.

1.3.5 In the assessment of upper and lower limb tissue asymmetry, it was assumed that the limb and segment lengths on the left side were equal to those measured on the right side. Preferably, the measurements should have been taken on both sides of the body. However, in the present study this was not done because the time available for anthropometric measurements was limited and, furthermore, it was felt that the assumption (equal right and left limb lengths) would have little effect on the accuracy of prediction.

CHAPTER 2

SURVEY OF THE LITERATURE

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CHAPTER 2

SURVEY OF THE LITERATURE

2.1 INTRODUCTION

In this chapter, relevant methods, techniques, concepts and research findings are briefly summarised. Justification for the choice of methods utilized in the present investigation is given. Besides the use of inter-library loans and a personal book and reprint collection, the following institutions made it possible to conduct a very extensive literature survey for the present investigation: the Anatomy Department reprint collection at the Witwatersrand University which has over 22 000 references; the journal collection of the Physical Education Department at Rhodes University which contains a wide variety of journals; the personal reprint collection of Professor P.J. Smit of the University of Pretoria which contains over 2 000 items; the extensive reprint collection of the Human Sciences Laboratory at the South African Chamber of Mines; and the Witwatersrand University Medline system, a computerised on-line medical literature analysis and retrieval system which is maintained by the National Library of Medicine in the U.S.A. and contains references to approximately half-a-million articles in 3 000 biomedical journals.

2.2 TENNIS

2.2.1 Origin and development

A. Early history

The sport of tennis originated in 1230 when a game known as 'Jeu de Paume' was played in France. The game was played by striking a cloth ball with the palm of the hand. Later a glove and then a racket was used. The early 'racket' was a solid wooden construction, actually a bat. It was only in the 16th century that strings were incorporated.

Ironically, the term tennis originated as a result of a misinterpretation by English tourists who came into contact with 'Jeu de Paume' in the 14th century. The French players repeatedly used the term 'tenez' and the tourists assumed this to be the name of the game. The term 'tenez' actually means 'hold' or 'ready' and was used by the Frenchmen to signify the start of a game or rally (Robertson and Kramer, 1974).

In the 16th century tennis became known as the 'game of kings' because of its great popularity among the royalty in France, England and other European countries. Since most courts were indoors, tennis was a game that was restricted to all but the very wealthy.

During the French Revolution a tennis court at Versailles achieved immortal historical fame when on 20th June 1789 it became the scene of the famous tennis-court oath, taken by the Third Estate, who vowed not to disband until France had a constitution.

The modern games of squash, badminton and table tennis all originated from the ancient game of 'Jeu de Paume' (Robertson and Kramer, 1974).

B. Lawn tennis

Major Walter Wingfield was the founder of lawn tennis. In 1874 he took out a patent for his game called 'Spharistike', the Greek word for 'ball game'. This name was probably used because it was assumed that all gentlemen were acquainted with the classics. It was later replaced by the term 'lawn tennis'. As the name indicates, lawn tennis was played on a grass surface. The question is often raised as to why lawn tennis originated only towards the end of the 19th century. The reason for this is that only in the 19th century did man learn to make a rubber ball that would bounce on grass. The earlier balls, made of tightly woven cloth, could be used on stone, concrete and wooden surfaces but were quite useless on grass (Robertson and Kramer, 1974).

Lawn tennis soon became very popular and began to replace croquet as a summer pastime. There were no standardised rules concerning the game, with the result that court dimensions, equipment and even scoring systems differed considerably from one place to another. Fortunately, the rules of the game were formally standardised in 1881 by the United States Lawn Tennis Association.

In 1877 the first Wimbledon championships were organised by the All England Croquet and Lawn Tennis Club and held at Wimbledon in England. Today this is the only major championship still played on grass (Robertson and Kramer, 1974). Even today many national tennis organisations still incorporate the traditional term 'lawn tennis' in their official titles even though few grass courts are in use.

C. Professionalism and modern day tennis

With the increasing popularity of tennis both as a participant and spectator sport it was not surprising that the financial potential of the game was recognised by a few astute businessmen. Although there is evidence that tennis players in France and England were paid for their services as early as the 16th century, professional tennis officially began in 1926. An American industrialist, Mr C.C. Pyle, who was appropriately nicknamed Mr 'Cash and Carry' saw the possibilities of a nationwide professional tennis tour and signed up the fabulous Suzanne Lenglen for a series of demonstration matches in 1926. Contrary to popular expectations, the tour proved extremely successful, for it not only satisfied the public who were hungry for entertainment, but also substantially increased the bank balances of Pyle and Lenglen.

As could be expected, this success led to many similar demonstration tours involving tennis players such as Richards, Tilden, Vines, Crocket and Budge. During the years 1926 to 1968 a great many professional tours were staged in all parts of the world. The custom was for a promoter to sign a contract with an amateur, whereby a set figure or a portion of the gate money for the tour was guaranteed. The demonstration matches, which were generally played indoors, had little impact on the sporting scene even though the professionals were the best players in the game. Traditional amateur fixtures such as Wimbledon, Forest Hills and the Davis Cup continued to carry the most prestige. Amateur and professional players were strictly segregated (Robertson and Kramer, 1974).

The International Lawn Tennis Federation (I L T F), the controlling tennis body, was totally opposed to professional tennis since it considered that one of its most fundamental objectives was to maintain the principle of amateurism. The Federation believed that it was wrong for anyone to make a living from tennis. All players who received money were regarded as non-amateurs and were banned from playing in I L T F tournaments which comprised nearly all the national and international competitions. The amateur was regarded as a 'gentleman' while the professional was regarded as an 'artisan' (Robertson and Kramer, 1974).

The professional players and a number of national tennis organisations, notably the British, American and Australian bodies, were strongly opposed to the 'outdated' approach of the I L T F. In 1968 matters reached a crisis point when the British Lawn Tennis Association defied the I L T F and staged the first 'open' tournament at Bournemouth in England. The tournament was won by the professional, Ken Rosewall. This action marked the start of a 4-year struggle between the amateur and professional bodies. A number of professional tennis organisations were established, notably the World Championship of Tennis (W C T), the Association of Tennis Professionals (A T P), World Team Tennis (W T T) and the Virginia Slims organisation for female professional players. After nearly 4 years of heated discussions and arguments, the I L T F accepted 'open' tennis in 1972 and contract professionals were allowed to play in I L T F tournaments (Robertson and Kramer, 1974).

Today, only social tennis can be termed amateur since competitive tennis, even at the lowest club levels, usually carries financial reward for the winner(s). While the successful tennis player of yesteryear had an impressive collection of trophies and an unimpressive bank balance, the position is exactly the opposite for the modern player. Trophies are either being replaced completely by prize money or presented with prize money as a 'traditional extra'.

Since its birth nearly 750 years ago, the game of tennis has undergone many changes, and has become one of the most popular participation and highly paid professional sports. The facts that it is an all-seasonal, international sport involving both sexes, that it is healthy and safe and can be played throughout the average person's lifetime, have probably contributed substantially to its popularity (Copley, 1979a).

2.2.2 Research studies

As stated in the previous chapter, few studies have been conducted on tennis players, particularly expert performers. A brief review of the relevant literature is presented.

A. Anthropometric and physiological studies

Buskirk et al (1956) studied the forearm bone and muscle development of 7 nationally ranked tennis players. Although no bone hypertrophy was evident, the lengths of the ulna and radius were significantly greater in the dominant forearm, indicating an altered response in the osseous response apparatus.

In 1972, a team of medical doctors conducted a study on 84 expert tennis players. The results of this study were reported in 4 separate papers. Chinn et al (1974) found a significant reduction in the joint mobility of the playing upper extremity as compared with the non-playing extremity. Priest et al (1974) reported that 37 percent of the players were found to have had major elbow symptoms related to playing. Jones et al (1977) found pronounced hypertrophy (cortical thickening) in the playing arm. Priest et al (1977) reported marked muscle hypertrophy in the dominant upper limb, especially in the forearm.

An earlier study by the author (Copley, 1976a) revealed that international, provincial and club tennis players differed little in body size but that the international players were significantly superior in respect of general motor ability, as determined by static grip strength, 'leg' power, dynamic flexibility and gross muscular co-ordination.

Slater-Hammel (1949) reported that of the 9 major muscle groups actively involved in the execution of the forehand drive in tennis, the pectoralis major, anterior deltoid and biceps brachii made the greatest contribution to the acceleration of the driving arm.

In a study by Landiss (1955), it was found that college tennis playing (3 hours per week for 3 months) did not promote motor ability or physical fitness beyond the levels initially attained. A seven-week conditioning programme conducted on 22 intercollegiate tennis players resulted in a significant improvement of cardiovascular efficiency as assessed by the Skubic-Hodgkins test (Dobie, 1969). Olivier and Smit (1970) found that male university tennis players achieved a significantly higher maximal oxygen uptake than a control group of non-players.

B. Psychological studies

Kane and Callagham (1965) found that proficient female tennis players were emotionally more stable and more self-confident with a greater frustration tolerance than players of lesser proficiency. Champion tennis players rated peak physical condition and concentration most important from a given list of 47 factors (Jones, 1968). Krahenbuhl (1971) reported that the psychic stresses of tennis competition contributed significantly to the overall stress associated with competitive playing.

C. Biomechanical studies

By means of cinematography and a computer digitizer, Ariel (1977) found that a tennis ball is in contact with the racket strings for only 4 milliseconds. Since human reaction time is about 120 milliseconds the ball will leave the racket before it even gives. Ariel (1977) has found that striking a tennis ball results in a jolt to the elbow joint which is 100 times greater than the force it has to withstand during throwing. Glencross and Cibich (1977) have calculated that when a tennis ball is served at 150 metres per second, the receiver has only 253 milliseconds in which to decide what to do.

D. Tennis skill studies

Contrary to the measurement of athletic skill in which both time and space can be accurately metered, tennis skill is generally assessed by comparing a player's wins and losses with those of contemporary players (Copley, 1975d). Today, computer ranking systems based on tournament wins and losses are commonly used to rank professional players.

Although a number of studies aimed at assessing tennis skill have been conducted (Cobane, 1962; Kreiger, 1962; Hewitt, 1967; Cotten and Nixon, 1968), the only test that has been universally accepted is that of Dyer (1935), which assesses general tennis ability.

Tennis ability or skill is a highly complex concept involving numerous physical, mental, emotional and social factors. The factors comprising tennis ability can generally be classified into two main categories, physical and non-physical. Whereas most of the physical components can be objectively measured, the non-physical components cannot. Tests which evaluate aspects such as anticipation and perception as they relate to tennis, have yet to be formulated. Expert tennis players generally acquire either predominantly physical or otherwise predominantly non-physical characteristics. Ultimately, however, a player's tennis skill is determined by the degree to which all the factors constituting tennis ability are developed (Copley, 1976a).

2.3 SURVEYING

Surveying is a form of non-laboratory research which involves the collection of data by means of either an oral or written questionnaire.

2.3.1 Written questionnaire

The written or mailed questionnaire, which is the investigative tool of the broad survey, is commonly used to obtain responses and reactions from a large number of individuals. It has many inherent drawbacks and should be used only when the necessary information cannot be reasonably obtained in any other way. Since this type of questionnaire is, in fact, the research instrument, it is essential that its construction, content and appearance receive very careful preparation and planning. A questionnaire mailed to a random selection of the population will very rarely yield even a 50 percent return (Clarke and Clarke, 1970).

2.3.2 Oral questionnaire

The oral questionnaire or personal interview is a far better method of obtaining information than the written questionnaire. The advantages of the personal interview are that it ensures a greater return, confidential information can be obtained, interpretation of the meaning of questions is possible, judgement of the adequacy of replies can be made and rapport with the respondent can be established (Clarke and Clarke, 1970). This method of surveying was employed in the present study to obtain quantitative data which included a number of attributes and variables.

The attributes were: sex, race, nationality, handedness, occupation, leisure activities, tennis representation, injuries incurred and physical training. It was felt that these attributes would not only be of academic interest but also would provide additional information about factors which, besides tennis participation, could possibly have a profound influence on the structure and function of the body.

The variables included the following: age, total number of years played, number of hours played per week and the number of weeks played per year. These data were utilized to determine starting age and to quantify the degree of tennis activity, both in terms of the total number of hours played and the total amount of energy expended.

2.4 ANTHROPOMETRY

2.4.1 Introduction

Anthropometry is a branch of anthropology that is concerned with the systematised measurement and quantification of the dimensions of the human body. Its origin can be traced back to the ancient Greeks and Egyptians (Seaver, 1909). According to Hrdlicka (1939), the major contributions to anthropometry have been made by physical anthropologists during the last two centuries with lesser contributions coming from artists, anatomists, evolutionists and physical educators. In spite of a number of attempts to standardise the science of anthropometry, there is still an obvious lack of uniformity among anthropometrists. Detailed descriptions of methods and techniques are essential in anthropometric investigations, particularly if objective comparisons are envisaged (Sills, 1960).

A comparison of the results of anthropometric studies on Olympic athletes conducted by Tanner (1964) and by Correnti and Zauli (1964), indicates the extent to which data obtained in two very similar studies can differ. According to Wartenweiler et al (1974), this was due directly to the different measuring techniques utilized by the investigators.

Anthropometry may be conveniently subdivided into somatometry, osteometry, craniometry and odontometry (De Villiers and Tobias, 1974). Anthroposcopy refers to the visual observation and description of physical traits that do not easily lend themselves to exact measurement (skin and eye colour, hair texture etc.). Such observations are frequently added to anthropometric studies (Montagu, 1960).

The terms dynamic anthropometry and physiological anthropometry have frequently been utilized to describe structure-function relationships in man. Recently, a new interdisciplinary scientific technology, referred to as Kinanthropometry, has emerged. The term is derived from the Greek Kin or kines meaning motion or movement, anthropos connoting man in the generic sense and metry or measurement (Ross, 1978). Kinanthropometry is defined by Ross et al (1978, p.1) as:

> 'the application of measurement to the study of human size, shape, proportion, composition, maturation and gross function'.

Although an infinite number of measurements can be taken on the human body, anthropometric measurements may be classified into three main categories, namely, measures of linearity, girth and fat (Sills, 1960). Single anthropometric measurements such as stature, mass, bone diameters and limb girths are indicative of size. When two measurements are considered together, an index or ratio is obtained that provides useful information about proportion. Since indices or ratios are relative measures, they can be utilized to compare subjects of different size, age and sex. From a series of anthropometric measurements a somatotype rating, which is indicative of overall body shape or form, can be obtained. Skinfold measurements can be used to assess body composition in terms of adipose, muscle and bone tissue. Anthropometry can thus be used to study and analyse the size, shape (form), proportion and composition of the human body. Although its application is very broad, anthropometry is useful particularly to the bio-engineer, anatomist, occupational therapist, artist, sculptor, criminologist, nutritionist, palaeoanthropologist, physical educator, exercise physiologist, sports coach, physician, paediatrician, growth specialist, endocrinologist and the designer of clothing, uniforms, etc.

Ross and Wilson (1974) have developed a 'phantom' stratagem for proportionality assessment. The 'phantom' is based on the concept of a theoretical reference human. It is a conceptual unisex (male/female), bilaterally symmetrical model that is derived from reference male and female data. The 'phantom' has over 100 designated lengths, breadths, girths and skinfold reference values. The application of the 'phantom' as a proportionality stratagem involves dimensionally adjusting each anthropometric item to 'phantom' size and then, expressing the difference from the phantom reference values in z-scores. The z-scores thus obtained can be utilized to analyse proportional differences within a subject, between subjects, between a subject and a prototype, between prototypes, or between the same subject measured on different occasions. The 'phantom' can also be used for the estimation of fractionated fat, skeletal, muscle and residual masses (personal communication with Professor W.D. Ross).

2.4.2 Basic anthropometric measurements

A. Body mass

Day to day mass changes in adults appear to be caused by differences in energy expenditure and food and liquid intake. Fluctuations in mass are probably greatest during active growth and, according to Edholm et al (1974), these fluctuations in children appear to be the result of variation in water retention.

Since mass and stature are highly correlated, it is obvious that mass comparisons necessitate adjustments for stature. In comparing the masses of Olympic athletes at a standardised stature of 173 centimetres, Khosla (1978) found that sprinters were 10,0 kilograms heavier than distance runners. In a study conducted by Malina (1972), it was found that American football players in 1970 were 16,05 kilograms heavier than players in 1900. This represents a secular increase in body mass of 2,29 kilograms per decade.

Body mass is included in most anthropometric investigations and should preferably be taken with a beam type weighing scale. Although nude mass is recommended, this is often not possible. In such cases it is advisable either to make a correction for the garments or to determine the mass with the subject minimally clothed. Body mass was determined in the present study to obtain information about somatotype (reciprocal ponderal index), body composition (tissue indices) and body surface area of tennis players.

B. Stature

Stature provides useful information concerning physical growth and development (Stewart, 1943). According to Bowles (1932), growth and development are influenced by a number of environmental factors such as geographical location (climatological, altitudinal etc.), local setting (urban, rural), immediate surroundings (social, home, occupation) and physical conditions (nutrition, exercise, medical aid, sleep, etc.). Todd (1935, p.259) succinctly summarises the importance of the environment when he states:

> 'The adult form of mankind is the outcome of growth enhanced, dwarfed, or mutilated by the adventures of life'.

In a study of Kalahari San (Bushmen), Tobias (1962) showed that improved nutrition is accompanied by an increase in the mean stature and that it leads also to an increase in the degree of sexual dimorphism.[✡] A secular increase in stature of 0,94 centimetres per decade was found by Malina (1972) in a study of American football players over a seventy-year span (1900 - 1970). Apparently this trend corresponds with the upper limit of

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[✡] Sexual dimorphism refers to the difference of the mean values between the sexes in relation to a particular variable (Tobias, 1972).

the data obtained from Western European countries and is greater than that reported for American adults in both the college and the general population (Malina, 1972).

In some sports stature appears to be related to proficiency. In a study by Alexander (1976) stature was found to be significantly related to proficiency in basketball, as assessed by the number of points scored. In tennis the taller player has an advantage when serving and smashing because of the greater angle at which the ball can be delivered over the net. If all other factors are held constant, the taller player is less likely to make a mistake and can therefore safely impart greater force to the ball than the shorter player (Copley, 1977d). According to Khosla (1978) tallness also appears to confer an advantage in most running events.

As with body mass, the determination of stature is included in the large majority of anthropometric studies. It is usually measured with an anthropometer or stadiometer. Stature was included in the present study to assess body surface area, somatotype(reciprocal ponderal index) and limb and segment proportions or ratios.

C. Linear measurements

Standing and sitting heights and diameters are classified as linear measurements in anthropometry. The larger heights and diameters are usually measured with an anthropometer, while the smaller diameters are measured with a flat sliding caliper. Linear measurements are not only a good gauge of general development but also provide the basis for many useful indices.

In addition to the measurement of stature, the acromiale, radiale, stylion, dactylion, trochanterion and tibiale heights were also determined in this study to obtain limb and segment lengths and ratios and tissue indices. The diameters taken comprised the biacromial, bitrochanteric, bicristal, A-P chest, bi-epicondylar (humerus), bicondylar (femur), and wrist and ankle. These were utilized to obtain various diameter indices, to assess masculinity (androgyny index) and to determine mesomorphy and the cross-sectional bone area of the upper and lower extremities.

Included in this study was a linear measurement of interpupillary distance (breadth) not commonly used in anthropometric studies. It was measured from the centre of the one pupil to the centre of the other. Bannister and Blackburn (1931) have postulated that the wider the interpupillary distance, the better will be the depth perception and consequent ability to judge relative distances of objects. Interpupillary distance was therefore included to assess its possible relationship with proficiency in tennis.

D. Girth measurements

Girth or circumferential measurements of the neck, chest, waist, thigh, calf, arm, and forearm are commonly recorded. These measurements are easily and rapidly determined and variations in these values reflect changes that may occur as a result of growth, training or inactivity. Use of a steel anthropometric tape is recommended because other tapes are subject to error caused by shrinkage or stretching (Sills, 1960).

The girth measurements selected for this study were contracted and uncontracted arm, forearm, thigh, calf and chest girths. They were utilized to determine girth and tissue indices and the Heath-Carter anthropometric mesomorphic rating.

E. Fat measurements

Fat measurements are taken by measuring the thickness of a fold of skin with a skinfold caliper. The skinfold, which comprises a double layer of skin and subcutaneous tissue, can be measured at various sites on the body. The triceps, forearm, supra-iliac, subscapular, thigh and leg sites are commonly used. Skinfold measurements can be used to predict body fat, to provide information about regional fat distribution and even to assess the effectiveness of a physical training programme and the level of physical fitness (Geyer _et al._, 1972).

In the present study the triceps, biceps, subscapular, supra-iliac and calf skinfolds were measured with a Harpenden skinfold caliper to assess body fat (relative and absolute), tissue indices and the Heath-Carter endomorphic and mesomorphic somatotype components.

Although it is generally recommended that a skinfold measurement be taken with skinfold calipers having a constant jaw pressure of 10 grams per square millimetre (Harpenden, Lange etc.), other instruments have been successfully used. Thornton (1974) found that skinfolds measured with a simple sliding caliper produced values that correlated highly with measurements taken with a Lange skinfold caliper. A very high correlation coefficienct of 0,98 was found between skinfolds measured with a Harpenden skinfold caliper and measurements taken with an ordinary bicycle trouser clip, the distance of which was read off on a ruler (Smit, 1979).

2.4.3 Derived morphological measurements

A. Stature-mass indices

Stature and body mass are frequently used to obtain the so-called height-weight or, more correctly, the stature-mass index or ratio. There are, in fact, a number of stature-mass indices (Khosla, 1978): the ponderal index which is the cube root of mass divided by stature, the reciprocal ponderal index which is stature divided by the cube root of mass, the Quetélet index which is mass divided by stature, the Kaup index which is stature divided by mass (Eiben, 1972) and the bulk index which is mass divided by stature squared.

Although the stature-mass index can be utilized to obtain the ectomorphic component of the somatotype (Sheldon et al., 1940; Hooton, 1951; Parnell, 1954; Heath and Carter, 1967), it cannot, without additional information, be satisfactorily utilized to assess physique as a whole. If physique were classified solely by means of any of the stature-mass ratios, it is possible that two individuals having the same stature and same mass would receive identical ratings, although one individual may be obese and the other muscular. Hirata (1978) appears to be one of the few investigators, if not the only one, who is of the opinion that the ponderal index provides the most suitable indication of physique.

In the present study the reciprocal ponderal index was used to obtain the Heath-Carter ectomorphic somatotype component.

B. 'Ideal' body mass

Standard height-weight (stature-mass) tables are commonly used in industry to facilitate the selection of individuals for appropriate occupations, and by life insurance companies where mass is related to life expectancy (Wyndham et al., 1970). Stature-mass tables have been used also to identify malnutrition in children (Vitayaraghavan and Gowrinathsastry, 1976). Since these tables do not consider body composition, they cannot be used to reliably predict an individual's 'ideal' or 'correct' body mass. Variations of as much as 10 kilograms have been found within one of the categories in these tables (Allsen, 1978).

A number of alternative methods can be used to predict optimal body mass. Montoye (1970) has developed a method based on measures of stature, biacromial and bi-iliac diameters. The Tipton-Tcheng prediction equation is based on a series of anthropometric measurements and has been found to be particularly useful for predicting the 'ideal' body mass of wrestlers (Landwer et al., 1975).

Corbin et al (1978) have developed tables for determining desirable body mass in men and women. They are based on fat-free body mass plus 16 percent fat for males and 20 percent fat for females. These tables, however, can be usefully applied only to sedentary subjects since the selected relative fat values are based on values obtained from sedentary subjects.

Densitometry can also be utilized to predict optimal body mass. Unfortunately this method requires special equipment and is not suited to field studies. In a study by Wickkiser and Kelly (1975), it was found that when football players and coaches predicted optimum body mass from personal experience, they consistently overestimated mass compared to predictions based on densitometric analyses.

The method used in this study to predict the 'ideal' body mass of tennis players was devised by the author. This anthropometric method, which is described in detail in the following chapter, involved the prediction of lean body mass from skinfolds and the selection of an 'ideal' percentage body fat[☆] for male and female tennis players. The 'ideal' body mass was obtained by adding the 'ideal' fat mass to the lean body mass. This method is versatile and practical and is well suited to field studies on sport participants.

C. Limb and segment lengths

Although it is possible to measure directly limb and segment lengths with an anthropometer, the commonly used procedure is to measure

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[☆] This selection was 9,5% for the males and 17,5% for the females and was based on a previous study conducted by the author on international tennis players (Copley, 1976a).

the various heights and then to calculate the limb and segment lengths by subtraction. The latter method was used in this study to obtain the upper and lower limb, arm, forearm and thigh lengths.

D. Length, diameter and girth indices

Linear and circumferential indices and ratios are frequently used to differentiate between the performance of sport participants who differ in body size, age and sex. Studies by Kohlraush (1929), Krakower (1941), Digiovanna (1943), Cureton (1951), Kroll (1954), Tanner (1964) and De Garay et al (1974) have indicated the relationship between body proportions and physical performance.

It should be pointed out that the exclusive use of length, diameter and girth indices in structure-function analyses may obscure important relationships. In the throwing of the discus, for example, it may well be the absolute and not the relative upper limb length that determines the level of proficiency or the distance thrown. It is clear, therefore, that both absolute and relative measures should be considered in structure-function analyses.

The linear and circumferential measurements selected for this study were used to obtain a number of standard indices and ratios, such as relative upper limb length, forearm-arm ratio, relative biacromial and bi-iliac diameters, humerus-femur ratio and relative chest girth. It was hoped that these relative measures would throw some light on the possible relationship between physique and proficiency in tennis.

E. Body surface area

The surface area of the human body can be either directly measured or indirectly predicted from regression formulae. The photometric, tape coating and surface integrator techniques are commonly used for the direct measurement, while stature and body mass are generally utilized to predict body surface area.

The popular photometric method is a very accurate, simple, rapid and relatively cheap technique which utilizes a photodermoplanimeter. This instrument measures the area available for absorbing light which, for any position, is identical to the area radiating heat. The standardised position used during the measurement is the spreadeagle posture. This standardisation is necessary since the absorbing or radiating area of the body varies with posture.

The Du Bois regression formula for the prediction of nude body surface area from stature and mass (Du Bois and Du Bois, 1916) is still the most popular indirect method, even though a number of other formulae have subsequently been developed, such as those of Sendroy and Cecchini (1954), Banerjee and Bhattacharya (1961) and Mitchell et al (1971).

Studies by Banerjee and Bhattacharya (1961) and Mitchell et al (1971) have indicated that the Du Bois formula tends to underestimate body surface area in adults. Mitchell et al (1971) have pointed out that results obtained by the prediction of body surface area by means of the Du Bois formula, are highly correlated with those obtained by the photometric technique when areas of greater than one square metre are involved. These workers have shown that the smaller the body surface area, the greater is the underestimation when the Du Bois formula for children is used. This finding is supported by Banerjee and Bhattacharya (1961) who proposed a formula for the prediction of body surface area in Indian children.

Body surface area was assessed in this study to obtain information about tissue indices and relative sweat-rate. The Du Bois method was selected because of its practicality and universal acceptance.

F. Masculinity - femininity

Masculinity - femininity ratings refer to the degree to which a male or female possesses physical and/or psychological characteristics of the opposite sex. The psychological ratings are usually based on behavioural, personality or interest scales, while the physical ratings are derived from body proportions or secondary sex characteristics.

A study of Oxford University honours graduates by Parnell (1954^{b}) indicated a significant positive correlation between academic performance and degree of femininity which was assessed from photographs of physical characteristics. Harris (1975) reported that female athletes tended to be less feminine in personality than non-athletes. Sheldon and Stevens (1942) and Seltzer (1945) developed ratings of androgyny or masculinity based on physical appearance and found significant deviant behaviour in male subjects whose physiques had strong feminine characteristics.

The degree of prominence of masculine or feminine characteristics in a male's or female's physique is referred to as the index of gynandromorphy by Sheldon et al (1940). Nude body photographs, taken from behind, were utilized by Bayley (1951) to devise somatic androgyny scales for males and females. A total of 10 androgyny categories ranging from hypermasculine to hyperfeminine were developed. Spence and Helmreich, (cited by Malina and Zavaleta, 1976) found that more female athletes were classified as androgynous than were college women.

The two most commonly used physical characteristics for the assessment of androgyny are the biacromial and bi-iliac diameters. Bayley and Bayer (1946) determined the degree of androgyny by expressing bi-iliac diameter as a percentage of biacromial diameter. Tanner (1951) also used the biacromial and bi-iliac diameters to devise an index of androgyny. In his formula, bi-iliac diameter was subtracted from biacromial diameter after the latter had been multiplied by three. Mean androgyny scores of 90,7 (male) and 73,9 (female) were found in non-athletic Oxford college students.

Milne (1972), using Tanner's index of androgyny, conducted an investigation on non-athletic Edinburgh men and women and reported mean values of 91,0 and 81,9 respectively. Malina and Zavaleta (1976) determined the androgyny indices of 66 female track and field athletes and 76 female non-athletes. The results showed that female athletes competing in jumping and throwing events had androgyny indices which overlapped considerably with those of non-athletic college males. The findings suggest that a masculine physique appears to be an important prerequisite for success in certain track and field events. These workers also calculated androgyny indices for male and female track and field participants at the 1960 Rome Olympics and the 1968 Mexico City Olympics from mean values reported by Tanner (1964) and De Garay et al (1974) respectively.

Tanner's (1951) androgyny index was used in this study establish norms for tennis players and to determine the extent to which masculinity in physique may be necessary for successful performance in tennis.

G. Dysplasia

Viola (cited by Battinelli, 1976) defines dysplasia in terms of the degree to which one part of the body is disproportionate to another. Bainbridge and Roberts (1966) are of the opinion that dysplasia is of

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G. Dysplasia

Viola (cited by Battinelli, 1976) defines dysplasia in terms of the degree to which one part of the body is disproportionate to another. Bainbridge and Roberts (1966) are of the opinion that dysplasia is of biological significance since it represents physique adaptations for the adequate performance of various physiological functions on a scale of priorities to which the utilization and distribution of constituent tissues is related.

The results of investigations concerning the relationship between physical performance and structural dysplasia are conflicting. Damon (1955) studied the physiques of over 3 000 pilots and found that the more successful pilots had fewer disproportions. Champion truck drivers were found to have far less bodily disproportion than their less proficient counterparts (Damon and McFarland, 1955). In contrast to these findings, Battinelli's (1976) study of 222 college students and athletes indicated that there was no significant relationship between motor ability and constitutional disharmony (dysplasia).

Dysplasia may be expressed also in terms of asymmetry. Wolański (1972) found that functional, dynamic and morphological asymmetries are largely dependent upon the age, sex and social environment of the subjects under study. He is of the opinion that development is channeled equally to both halves of the body and that only strong functional differentiation of the extremities can disturb this development.

A number of different methods and formulae have been developed to assess dysplasia. Viola (cited by Battinelli, 1976) determined structural dysplasia or disharmony by considering deviations from the total average of a particular series of structural measurements. Kretschmer (1925) used anthroposcopy and Sheldon et al (1940) measured dysplasia by the extent to which each of the 5 bodily regions (as defined by him) was characterised by an inconsistent mixture of endomorphy, mesomorphy and ectomorphy. Battinelli (1976) calculated dysplasia by considering various diameter/stature ratios and the extent to which these ratios departed from an established group norm.

A practical formula for assessing dysplasia, known as the relative index of asymmetry (RIA), was developed by Wolański (1972). In this formula the differences between metrical traits of the right and left sides of the body are expressed as percentages of the sums of the right and left side traits. The degree of asymmetry of different traits can be directly compared with this formula. This formula was utilized in the present study to assess and compare the morphological and physiological effects of a strenuous unilateral sports activity.

2.5 BODY COMPOSITION

2.5.1 Introduction

In earlier times many anthropologists were interested mainly in the skeleton and paid little attention to the portion of the body between the skin and bone which, as Brozek (1960) commented, was regarded as 'no-mans-land lying fallow'. Matiegka (1921), a Czechoslovakian anthropologist, laid the foundation of the modern anthropological study of body composition when he outlined a technique for the quantitative appraisal of the mass of four main body compartments, accessible to the somatometric approach. In subsequent years body composition received increasingly more attention with the result that physical anthropology was brought into livelier contact with the dynamic problems of nutrition, growth, ageing and physical exercise (Brozek, 1960).

Body composition is particularly useful in the study of physical fitness since the adaptations to greater muscular demands are manifested both functionally and morphologically. Body density is higher in an active man than in an inactive man, indicating a greater lean mass and lower fat mass in the former. Although the compartments into which total body mass is separated depend upon the investigator's frame of reference, a distinction can be made between the direct and indirect determinations of body composition.

2.5.2 Direct method

This is the most reliable and accurate method of determining body composition. However, as it involves the chemical analysis of the organism, it can be conducted only on a cadaver. The results of chemical analyses on cadavers, conducted by Mitchell et al (1945), Widdowson et al (1951) and Forbes et al (1953), indicated the following average constituents of the human body: 62,6 percent water, 15,3 percent fat, 16,4 percent protein and 5,7 percent ash (Novak, 1974a).

2.5.3 Indirect methods

The indirect determination of body composition involves either a four-or two-compartmental analysis. In the four-compartmental analysis, the body is subdivided into fat, extracellular water, cells and bone minerals. Unfortunately, this procedure necessitates expensive equipment which, according to Novak (1974a), is available in only a few laboratories. The two-compartmental analysis involves the division of the body into a fat and fat-free (lean) mass. It is the most commonly used approach. A number of different methods or techniques utilize this approach. A brief survey of these methods is presented.

A. Densitometry

Historically, Behnke *et al* (1942) were the first to utilize densitometry and develop formulas for the analysis of the living human body into its fat and lean fractions.

Densitometry involves the determination of the total body volume by means of the hydrostatic or underwater weighing technique which is based on the Archimedian principle. The volume of the body is determined from its displacement in water. Corrections are made for the pulmonary and gastrointestinal residual volumes. Once body volume has been determined, body density can be calculated from the density formula ($D = \frac{M}{V}$). Body fat can then be estimated from body density. This principle is based on three assumptions (Novak, 1974a): first, that the separate densities of the body components are additive, secondly, that the densities of the constituents are relatively constant from person to person, and thirdly, that the subject differs from a 'standard reference man' only in respect of the amount of adipose tissue.

Although densitometric analysis provides an accurate determination of body density, it is based on the following interrelated assumptions: that lean body mass has a constant density and proportion of water, that bone is constantly proportional to lean body mass and, that cell water is constantly proportional to cell mass (Wilmore *et al.*, 1970). It should be pointed out also that this method is not suitable for young, elderly or hydrophobic subjects.

Little and Jessup (1977) have recently proposed the use of a point-gauge micrometer device for the measurement of limb volume according to the water-displacement technique. The volume of the body can also be very accurately measured from photographs of the nude body, taken from both sides, the rear and the front. By means of this technique it is even possible to determine the cross-sectional area of any part of the body very accurately (personal communication with Professor G. Reid).

B. Roentgenogrammetry and Ultrasound

Adipose (subcutaneous), muscle and bone tissue widths can be seen and measured on radiographs. Ultrasound also has been found to be useful in the measurement of subcutaneous adipose tissue. A beam of pulsed ultrasound emanating from an ultrasonoscope is applied to the skin through a layer of olive oil. The time lapse between the production of the pulse and of the first constant echo is a measure of the subcutaneous thickness at the site of application (Sloan, 1967).

Roentgenogrammetry has been extensively used to study the effects of physical activity and training on density of bone tissue. King et al (1969) found pronounced humeral hypertrophy in the throwing arm of professional baseball pitchers. Lewis (1971) conducted a roentgenographic analysis of the upper extremities of four professional tennis players and found an increase in the bone diameter and cortical thickness on the playing side. Jones et al (1977) studied and compared roentgenograms of the playing and non-playing humeri of 78 professional tennis players. The results indicated a highly significant hypertrophy of bone on the playing side, brought about by a thickening of the cortex. Nilsson and Westline (1971) found significant differences in bone density at the distal end of the femora of male athletes compared to those of non-athletes. The athletes' leg of preference was also found to have a denser femur than that of the opposite limb.

The evidence suggests that physical activity results in the hypertrophy of bone. On the other hand, extreme muscular inactivity results in a demineralization of the bone which, in turn, is linearly related to the likelihood of bone fracture (Montoye et al., 1976). Hattner and McMillan (1968) have suggested the following possible mechanisms to explain why muscular activity may serve to preserve bone integrity: direct neural influences on the bone, vascular and blood flow changes associated with physical activity, and mechanical stress and strain as a result of mass-bearing and muscular tensions. An interesting theory of these workers is that bone crystals may function as piezoelectric transducers, converting mechanical strain into electrical signals which, in turn, could stimulate bone formation.

C. Total body water

Total body water may be estimated by a number of methods. The dilution method is most commonly used. It requires the oral administration of deuterium oxide and the collection of urine samples. The principle involved in this method is the constancy of mass of the diluted solute or tracer substance before and after dilution. The oxides of the isotopic hydrogen, predicted theoretically, are ideal for the measurement of total body water since both deuterium oxide and water as well as tritium oxide and water are handled in the vascular, intercellular and intracellular compartments (Desiprès et al., 1978b).

When blood samples (plasma) are available several other methods may be used to estimate total body water: the falling drop method (Schloerb et al., 1950), the infra-red absorption method (Turner et al., 1960) and the gas chrometography method of Arnett and Duggleby (1963). Fat-free mass, or lean body mass, may be calculated from total body water on the assumption that the body has a 'constant' amount of water (73,2 percent) and that body fat is practically anhydrous (Novak, 1974a). The estimation of total body water by means of the methods described, requires expensive equipment and urine or blood samples which are not always conveniently obtainable. Other less complicated methods are available. For example, Hume and Weyers (1971) have developed regression equations for the prediction of total body water from measurements of stature and mass.

In a study conducted by Novak et al (1968), highly proficient college swimmers, track and field athletes and gymnasts were found to have significantly greater relative values of total body water than baseball and football players. Since total body water is confined primarily to lean tissues, information about fat-free mass or solids can be obtained from this information.

D. Total body potassium

A sophisticated method of determining lean body mass is the measurement of naturally occurring radio-activity of the body, arising from its 40 K content. A whole body counter is employed to measure the radio-active potassium (Novak, 1974a). As in the estimation of body water, this method requires expensive, sophisticated equipment

In a study conducted on 13 middle-aged women, it was found that habitual swimming significantly increased total body potassium, the latter being indicative of the body cell mass or so-called 'active tissue mass' (Novak, 1974b).

E. Anthropometry

Various anthropometric measurements can be employed to estimate lean body mass and body fat. These measurements must be taken with great care and precision since small errors will become greatly magnified.

I. Diameters

Behnke (1961) used an anthropometric assessment of body diameters to predict lean body mass. Numerous skeletal diameters were utilized and grouped into so-called 'd' quotients by dividing by a constant 'k', which was derived from 'reference man'. According to Wilmore and Behnke (1968) this method is suitable for general or clinical screening purposes. However, unless the measurements are taken with great care and precision, inaccurate estimations will result since small errors will become greatly magnified.

II. Girths and lengths

Katch and Katch (1974) have developed a simple anthropometric method for estimating segmental leg limb volume. This technique involves partitioning the lower limb into 6 truncated cones and determining the volume of each cone by means of girth and length measurements. A comparison of the results obtained from this technique and the water displacement method, indicated a very high correlation of 0,95 with a standard error of 480 millilitres. Limb volume can, of course, be employed to detect alterations in body composition. These workers postulate that by considering the head as a sphere, the neck as a cylinder, the trunk as a box, the hand and foot as wedges and the buttocks as a half sphere, it would be possible, as in the case of the truncated cones of the limb, to predict accurately the volume of sections of the body as well as of the body as a whole.

III. Lengths, diameters, girths and skinfolds

Wartenweiler et al (1974) have proposed an anthropometric technique for estimating the lean volume, bone, muscle and skin-fat indices of the upper and lower limbs. Girth, diameter, skinfold and length measurements are used to obtain lean volume and the tissue indices. The tissue index is obtained by expressing the estimated tissue mass as a percentage of the body mass. With this method, the absolute and relative bone, muscle and skin-fat values can be determined. This method was selected for the present study because of its practicality and because it was felt that it was particularly suited to an investigation of the effects of tennis, a strenuous unilateral sports activity, on the composition of the upper limb. Some of the formulae published by Wartenweiler et al (1974) were found to be incorrect. A detailed description of the errors and the corrected formulae of these workers is presented in the next chapter.

An alternative method of obtaining the tissue index is to express the tissue cross-sectional area as a percentage of body surface area. This method, which involv [illegible] lculations and is therefore less involved, was used also to cor [illegible] sults with those obtained by the method of Wartenweiler et al [illegible]

Bone, muscle and skin-fat indices were calculated by Wartenweiler et al (1974) from the measurements taken by Tanner (1964) on competitors in the 1960 Rome Olympic Games. The results indicated significant differences among competitors in various athletic events. An interesting finding in runners was that, whereas the muscle index was inversely related to the distance of the event, the bone index was directly proportional to the distance of the event. Throwers, wrestlers and weight lifters recorded the highest muscle and skin-fat indices.

Novak et al (1978) estimated the lean volume of the upper and lower limbs of Olympic water polo players, soccer players, swimmers and rowers by means of the corrected diameter anthropometric technique proposed originally by Brozek (1960). The rowers had the greatest upper and lower limb lean volumes, followed by the water polo players, swimmers and soccer players in that order.

In a study by Carter (1976) on the 1968 Mexico Olympic data, 'phantom' z-values for six anthropometric measures were calculated for 107 black and 88 white athletes. By means of discriminant analyses, Carter was able to distinguish clearly between the black and white athletes. The 'phantom' model proposed by Ross and Wilson (1974) appears to be able to detect subtle differences even in samples where there has been much performance selectivity.

IV. Skinfolds

Since about half of the total amount of adipose tissue in the human body is located in the subcutaneous layer, it is not surprising that skinfolds are the most frequently used anthropometric measurements for the prediction of body fat. Ultrasonic and roentgenogrammetric measurements of subcutaneous fat have been found to be very similar to skinfold caliper measurements (Sloan, 1967; Singh, 1967). Pace and Rathbun (1945), Brozek (1954), Pascale et al (1955), Siri (1956), Brozek et al (1963), Durnin and Rahaman (1967), Sloan and De V. Weir (1970) and Forsyth and Sinning (1973) have developed methods and formulae for the prediction of body fat from skinfolds. These prediction equations are, of course, population specific and are less accurate when utilized for members of other populations. Ward and Fleming (1964), for example, have found that the three skinfolds chosen to fit the Brozek et al (1963) formula for the estimation of body fat, are not suitable for negroid subjects. Most of these techniques involve the prediction of body density or specific gravity which is then used to assess body fat.

Both the number and locality of skinfold measurements used to predict body fat have varied considerably. Fellingham (1972) used only the triceps skinfold, Sloan and Shapiro (1972) the triceps and subscapular skinfolds, Brozek and Keys (1951) three skinfolds, Durnin and Rahaman (1967) four skinfolds, and Haisman (1970) nine skinfolds. The use of only one or two skinfolds has a number of disadvantages. First, one or two skinfolds do not adequately represent the distribution of fat in the body; secondly, the effects of dysplasia are not readily overcome, and thirdly, a small error in measurement will drastically influence the final outcome.

The method of Durnin and Rahaman (1967), which utilizes the triceps, biceps, subscapular and supra-iliac skinfolds, has been found to provide an accurate prediction of body density in studies conducted by Haisman (1970) and Desiprès et al (1978b). The equation for the determination of relative body fat, derived from the classic 'reference man' research of Keys and Brozek (1953) and Brozek et al (1963) has been widely used and recommended for its uniformity (Novak, 1974a). This equation, and the formulae of Durnin and Rahaman (1967), were used in the present study to predict relative and absolute body fat and lean body mass. This information was required to assess the long-term effects of intensive tennis playing on the composition of the body.

Adipose tissue has some important functions in the human body, such as the reduction of heat loss, the padding of internal organs and the provision of a secondary source of energy. However, being non-contractile tissue, it constitutes a burden to physical activities involving the displacement of the body mass (Copley, 1975b).

Parizkova (1959, 1968) and Smit (1973) have shown that habitual energy expenditure has a pronounced influence on the amount of fat in sport participants. Novak et al (1977) have found that one of the prerequisites for Olympic success in endurance swimming and running in females is that they should have relative body fat values ranging from 10 to 15 percent. Body composition is influenced not only by activity but also by inactivity. Greenleaf et al (1977) conducted a study on 7 males to determine the cause of body mass reduction arising from enforced bed rest. These workers concluded that the mass loss had two components, namely, a lean mass loss, which was caused by the assumption of a horizontal body position and which was independent of the metabolic rate and, a fat mass loss which was proportional to the metabolic rate.

2.6 SOMATOTYPE

The classification of physique can be traced back to the time of Hippocrates (400 B.C.). Classification has generally been by means of anthropometric measures and/or visual impressions. In the past 40 years a number of different somatotyping methods have been developed and used.

2.6.1 Somatotyping methods

A. Sheldon's method

Sheldon et al (1940) were the first to introduce the concept of somatotyping. Their definition of the somatotype, cited by Carter and Heath (1971, p.10) is:

> 'A quantification of the three primary components determining the morphological structure of an individual expressed as a series of three numerals, the first referring to endomorphy, the second to mesomorphy and the third to ectomorphy'.

According to Carter and Heath (1971) the Sheldonian somatotype was determined originally from 17 measurements taken on a negative or photograph. However, this method was seldom used after its replacement with the photoscopic method. In order to obtain a somatotype rating photographs were taken from the side, back and front. By means of height-weight ratio and age tables, and comparisons of the photographs with standardised somatotype photographs and descriptions, a somatotype rating was obtained. The Sheldonian method is purported to be essentially genotypical and to assess the constitutional and supposedly unchanging pattern of the somatotype. Although this method has enjoyed widespread implementation for the past 30 years, satisfactory ratings may be obtained only after considerable training and practice (Carter and Heath, 1971).

Sheldon (1961) subsequently modified his method again and the essential procedures, as summarised by Heath and Carter (1971) are: the standardised photograph, mass record and seven-point rating scale were used as before; the maximal stature and minimal height-weight ratios were determined from stature and mass; a new trunk index was derived from measurements of the thoracic and abdominal trunks as marked on the photographs; the somatotype was obtained from three tables; a table of height-weight ratios and trunk indices, a table of maximal stature, and the so-called 'basic tables'. These tables, which have been published by Sheldon et al (1968), are age-corrected and are read differently for males and females. Carter and Heath (1971) are of the opinion that this 'new' Sheldonian method is still inadequately described and that the new trunk index system bears little relationship to his previous methods and should, therefore, be regarded as another somatotype method.

B. Hooton's method

Hooton's (1951) method is essentially a phenotypic representation of the somatotype and is based on the inspection of a photograph and height-weight ratios. Fat, muscularity and attenuation are the terms used for the three components.

C. Cureton's method

Cureton's (1947) method combines inspectional rating of a photograph, palpation of the musculature, skinfold measurements, height-weight ratios and the determination of vital capacity and strength.

The somatotype triangle is constructed so that ectomorphy is on the left side and endomorphy on the right side.

D. Parnell's method

Parnell (1954a) used anthropometric measures of bone diameters, muscle girths and skinfolds in conjunction with photographs, to obtain an anthropometric somatotype. Special M.4 charts are utilized to obtain ratings for the three components of fat (F), muscularity (M) and linearity (L).

E. Damon's method

In this method the somatotype was predicted from 49 anthropometric measurements by means of multiple regression equations. The data were obtained from White and Negro soldiers (Damon, 1962).

F. Petersen's method

Petersen (1967) used Sheldon's somatoscopic criteria to somatotype a large number of Dutch children, ranging in age from 5 to 14 years. He subsequently published an atlas, which is probably the best series of somatotype photographs of children.

G. Heath-Carter method

Certain limitations of Sheldon's method were pointed out by Heath (1963). She stated that the seven-point rating scale was arbitrary and subsequently proposed an open-end scale starting, theoretically, at zero (at one half in practice) and having no upper end point. The restriction of the limit of the sum of the components was eliminated. Since it was found that Sheldon's height-weight ratios and somatotypes were not consistently linearly related, she reconstructed the table to ensure a linear relationship throughout. Heath (1963) questioned the permanence of the somatotype and, therefore, she eliminated extrapolations for age and utilized the same height-weight ratio table for both sexes and all ages. Heath and Carter (1967) incorporated Parnell's M.4 technique in Heath's (1963) system and subsequently developed the now widely used Heath-Carter somatotyping method. Heath and Carter (1967, p.57) define the somatotype as:

> 'a description of present morphological conformation - a size-dissociated descriptor of the shape and relative composition of the body. It is expressed in a three

> numeral rating always recorded in the same order. Each numeral represents evaluation of one of the three primary components of physique which describe individual variations in human morphology and composition'.

The Heath-Carter somatotype is a morphophenotype which reflects changing physical status with ageing, training and nutrition. In contrast to the Sheldonian somatotype, it is not an estimation of the somatotype at the age of 18 years or a prediction of the future somatotype. The Heath-Carter somatotyping procedure involves three methods of obtaining a somatotype rating, namely, the anthropometric, photoscopic and anthropometric plus photoscopic methods.

I. Anthropometric method of Heath-Carter

By means of a specially designed rating form and 10 measurements, the somatotype is directly obtained from the rating form. Computer programmes are now available for the calculation of the anthropometric somatotype and other useful somatotype statistics. This method provides an objective indication of the criterion somatotype rating.

The utilization of anthropometry in obtaining a somatotype rating has been used by a number of authors (e.g. Cureton, 1947; Parnell, 1954a; Damon 1962). According to Carter (1975), the anthropometric somatotyping method has a number of advantages: it is an objective method that can be easily and cheaply utilized in the field; it does not require that the subject should undress completely as in the case of somatotype photographs; the measurements can be used for other types of analyses (body structure and composition) and the anthropometric measurements provide a more precise measure of the somatotype components than the photoscopic method.

The Heath-Carter anthropometric somatotyping method was selected for this study because of these advantages and because it has been extensively used in the study of expert sport performers (Carter, 1970; De Garay et al., 1974; Hebbelinck and Ross, 1974; Hebbelinck et al., 1975). This somatotyping method was used also in the recent Montreal Olympic Games Anthropological Project (MOGAP) which was conducted by a team comprising M. Hebbelinck, J. Borms, W. Ross, L. Carter and others (personal communication). Somatotype analyses were included to establish norms for expert tennis players and to determine whether there are specific physique requirements for top class tennis performance. To the best of the author's knowledge, no somatotype data on expert players are available.

II. Photoscopic method of Heath-Carter

This technique is based on a standardised photograph and a table of the distribution of somatotypes according to height/ $\sqrt[3]{\text{weight}}$ (reciprocal ponderal index). To this basic information are added a knowledge of the Heath (1963) and Heath and Carter (1967) criteria and experience in the evaluation of the relative amounts of the components as observed in the somatotype photograph. This method is obviously subjective and practice and experience are prerequisites for valid and reliable results (Carter, 1975).

III. Anthropometric plus photoscopic method of Heath-Carter

This somatotyping method involves a combination of the anthropometric and the photoscopic procedures. A somatotype photograph, the anthropometric somatotype rating form and a distribution of the somatotypes according to the reciprocal ponderal index are required. This method ensures greater uniformity among raters than would be the case with only the photoscopic method (Carter, 1975). It should be borne in mind that a somatotype rating provides an easily interpreted summary or generalisation of the available data but at the same time sacrifices precision.

It is obvious that there are a number of different methods of somatotyping and that the ratings obtained are likely to be different. The word somatotype is therefore a generic term embracing a number of different concepts. Various somatotyping systems with different interpretations and meanings have been used to investigate the relationships between somatotype components and structural and functional variables. What is encouraging is that these different systems have revealed a number of important structure-function associations. An understanding of the various methodologies may well assist in the clarifying of some of the reported relationships and the discovering of still others (Carter and Heath, 1971).

2.6.2 *Description and analysis of somatotype data*

Since its inception in 1940 the somatotype rating system has posed numerous problems to researchers attempting to use it as an instrument in the study of human biology. Besides the difficulties involved in visualizing the three somatotype components, the quantitative analysis has until quite recently been restricted to percentage distributions of existing types or to the separate study of the individual somatotype components. The latter approach in particular has limited the effective use of the somatotype concept since it has violated the fundamental idea of the somatotype as a totality or 'gestalt' (Duquet and Hebbelinck, 1977). In recent years new techniques have been devised in an attempt to improve the methods of somatotype description and analysis. The most significant contributions have been the category comparisons of Walker (1962), the somatotype dispersion index of Ross et al (1974) and the three dimensional somatotype concept of Duquet and Hebbelinck (1976).

A. Dispersion index technique

The dispersion index technique of Ross et al (1974) is based on the somatotype dispersion distance (SDD), measured in Y-units of the two-dimensional somatochart and derived from the component units, between two somatoplots or points on the somatochart. From the SDD a series of other descriptive statistics may be calculated, such as the somatotype dispersion index (SDI), which is the SDD group mean. The variance of the points about the SDI permits useful statistical analysis of the somatotype data. This technique, which can be rapidly and accurately applied to somatotype data by means of specially prepared Fortran computer programmes, was used in this study. A detailed description of the technique is given in Chapter 3.

B. Tri-dimensional technique

The three dimensional somatotype concept proposed by Duquet and Hebbelinck (1976) is the most recent innovation. This technique was presented for the first time in 1976 at a symposium on Human Biology in Hungary and subsequently published by the Hungarian Academy of Sciences in 1977. Unfortunately this paper does not appear to have been widely circulated. The author learnt about this new technique at the 1979 International Symposium on Sport and Recreation (September) and was therefore unable to use it in the present study. Professor L. Carter is at present preparing a paper about the tri-dimensional approach which is to be published in a journal with international circulation (personal communication).

In the tri-dimensional approach, the somatotype is presented by a somatopoint or position in space located on an X, Y and Z co-ordinate (tri-dimensional grid system). These co-ordinates represent the three somatotype components. The units on the co-ordinates are component ratings with 0-0-0 at the origin of the three axes. The distance between any two somatopoints (somatotypes) is known as the somatotype attitudinal distance (SAD), while the somatotype attitudinal mean (SAM) refers to the mean of the SAD's around the mean somatopoint. The dispersion of the somatotypes about the mean of their distances from the somatotype group mean (in other words, the dispersion of the deviations from the mean somatotype) is known as the somatotype attitudinal variance (SAV) or somatotype attitudinal standard deviation (SASD).

According to Duquet and Hebbelinck (1977), the tri-dimensional approach has a number of applications: the SAD may be used in the description of a group with regard to statistics such as location, central tendency and absolute or relative dispersion or, it may be used to measure distances between individual ratings, group ratings or between a group and an individual rating. L. Carter, W. Ross and J. Borms are of the opinion that the tri-dimensional technique constitutes the best method of somatotype description and analysis (personal communication).

2.6.3 Somatotype and performance

Investigations by Cozens (1930), Cureton (1947), Miller (1952), Sills and Everett (1953), Lindegaard (1956), Tanner and Whitehouse (1956), Willgoose (1956), Correnti and Zauli (1964), Tanner (1964), Hirata (1966) and Carter (1970) have studied the relationship between body types and physical performance. It has become evident from these studies that competitive sport, especially at championship level, has definite physique requirements. The establishment of somatotype norms derived from studies of expert sport performers has made it possible to estimate accurately the appropriate structure for optimum performance of a particular task. The sport participant may now be identified and, in so doing, the right training be directed at the right person. The genetic basis of the somatotype has, according to Carter and Heath (1971), never been proven or even the possible magnitude of it established.

Besides the importance of physique, there are a number of other prerequisites for success in sport. Appropriate physiological capacities, attitudes and behaviour patterns are also very important. Seen in its whole context therefore physical performance is directly influenced by factors such as heredity, race, socio-economic conditions, nutrition and climate.

Somatotype analyses have not only been used to investigate structure-function relationships in sport participants but also utilized for the diagnosis and treatment of sociopathic children (Verdonck, 1972) and hypertensives (Chovanová et al., 1978), and for the investigation of the relationship between personality traits and physique (Sheldon, 1965; Slaughter, 1970). Somatotyping has even been used for the early identification of individuals who fall in the cardiac infarction 'prone zone' of the somatochart (Smit et al., 1978).

2.7 ASPECTS OF PHYSIOLOGY

Physiology is defined by Guyton (1976, p.2) as:

> 'The study of function in living matter: it attempts to explain the physical and chemical factors that are responsible for the origin, development and progression of life. Each type of life from the monomolecular virus up to the largest tree or to the complicated human being, has its own functional characteristics. Therefore, the vast field of physiology can be divided into viral, bacterial, cellular, plant and human physiology with many more subdivisions'.

2.7.1 Exercise physiology

Traditionally, the human physiologist was concerned only with the physical and chemical functions of the body under resting or basal conditions. In recent years, however, considerable attention has been given to the study of exercise or work physiology. In its broadest sense, exercise physiology is defined as the study of the structural, physiological, and biochemical effects of exercise and physical activity on the human body (Copley, 1975b, p.1). Exercise physiology provides basic information about the nature and range of the functional capacity of the different organ systems and, in so doing, enables one to better comprehend how the body integrates functions in order to produce optimal physical performance. Since every human being engages in physical exercise to some or other extent during the course of his/her life, it is essential to understand the acute responses to, and the long term effects of, physical exercise or work.

A number of factors have contributed to the importance of exercise physiology over the past few years, namely, the ever increasing popularity of sport and physical recreational activities, the growing awareness of the importance of physical fitness, professionalism in sport which is concerned primarily with the optimising of physical performance, and the realisation that manual labour is, and will remain, an essential part of society.

Physical exercise or work may be conducted under different environmental conditions and, as a consequence, exercise physiology has a number of subdivisions, namely, space, altitude, climatic (biometeorological) and underwater physiology. Each subdivision constitutes a comprehensive field of scientific study with its own methodology and terminology.

2.7.2 Fitness

The term fitness is frequently used and yet its meaning is still somewhat obscure. Since fitness involves many different factors, a multitude of interpretations thereof can be given. For example, the industrialist views it in terms of productivity, the sports participant sees it in terms of achievement and performance while to the public, it signifies health. The question, 'fitness for what?' must be answered before a suitable specific definition may be given (Copley, 1975a). Strydom (1977) distinguishes between the following types of fitness: total, psychological, physical, medical and technical. The individual who is physically, mentally, emotionally and socially well adapted and as a result lives a happy, full and balanced life, is said to be totally fit. This is the ideal state or ultimate goal but according to Frost (1971), no human being is able to achieve this state of perfection.

A. Physical fitness

As in the case of the term 'fitness', there is no universally accepted single definition of physical fitness. An individual may be physically fit to meet the requirements of a specific activity or sport but unfit for another. A champion marathon runner, for example, would be totally unfit for a sport such as wrestling. Generally speaking, however, physical fitness refers to an individual's ability to meet the physical requirements of strength, speed, power, agility, endurance, coordination, balance, flexibility and body control. These are the fundamental elements or components of physical fitness (De Vries, 1975). Strength, flexibility, balance, endurance, metabolic and environmental fitness are regarded as the main types of physical fitness (Strydom, 1977).

A further distinction may be made between basic and specialised physical fitness. Basic fitness involves the all-round development of the fundamental components of physical fitness, while specialised fitness involves the specific development of one or more of the fundamental components. Long-distance running, for example, necessitates high levels of endurance, metabolic and environmental fitness, while gymnastics require well developed strength, balance and flexibility fitness. Basic physical fitness is a prerequisite for specialised physical fitness which, in turn, is necessary for the attainment of a high degree of proficiency in sport.

I. Tennis fitness

To be able to answer the question 'How fit should I be for tennis?', consideration must be given to the individual's age, sex, physique, present standard of play, and future standard desired. It is obvious that an elderly man, who plays social tennis and has no desire to improve his game, will not need to be as physically fit as a young man who plays well and who is striving to become a world class performer.

Although a degree of proficiency in tennis can be developed without the player being physically fit, basic and specialised fitness are essential for the attainment of high levels of tennis proficiency. Specialised fitness for tennis necessitates the development of psychological, endurance, power, agility and environmental fitness. Of course, the development of the numerous individual skills also constitutes part of this specialised tennis fitness. Psychological aspects, such as determination, emotional stability, perseverance and frustration tolerance, are particularly important for the competitive tennis player. Muscular and cardio-respiratory endurance are important since a match can be expected to continue for at least 30 minutes and often exceeds 120 minutes.

The speed with which a player can move about the court and the force that can be applied to the ball, particularly in the execution of shots such as the service, smash and high backhand volley, are largely determined by muscular power and agility. Since tennis is played both outdoors and indoors in widely differing geographical areas, it is evident that environmental fitness and the ability to become acclimatised to heat, cold, altitude and time-zone are important to the top class performer.

Physical fitness is a fluctuating, dynamic process which cannot be stored away and then drawn upon months or years later. Certainly, physical fitness may be maintained only if we are prepared to work regularly and conscientiously towards it (Copley, 1977b).

B. Training

I. Introduction

The fundamental principle on which training is based is that the healthy human body thrives on use and, subsequently, adapts to maintain a functional reserve capacity above the habitual demand placed on the organs and systems. Training refers to the maintenance or improvement of one or more of the fundamental elements of physical fitness. The term 'practice', on the other hand, refers to the repetition of a skill or technique out of the game context, so that it may become more effectively executed (Williams and Sperryn, 1976).

The amount of time required to be spent on training and practising depends largely on the type of sport or physical activity. In sports demanding high skill such as golf, tennis and archery, much time is spent practising, while in sports such as running (sprinting and long distance), canoeing and cycling, the emphasis is on training. Modern sports competition is so fierce that success in many sports can be achieved only if the participant has natural talent and is prepared to be subjected to merciless, even ruthless physiological and anatomical stress. Long-distance runners, for example, may cover distances of over 400 kilometres a week, while swimmers often spend in excess of five hours a day in the pool. According to Corrigan (1967), sport participants nowadays spend five times as long in training as they did before World War II. It is not surprising, therefore, that Bannister (1967, p.5), the first man to run the mile in under 4 minutes states:

> 'I doubt that the cost of training in terms of sacrifice of other pursuits, would attract me to the sport of athletics'.

According to Williams and Sperryn (1976), the modern approach to training raises a number of serious questions regarding the desirability of participation by children and young adolescents when one considers their comparative immaturity, vulnerability to domination by parents and coaches, and the inappropriateness of *obsessional, single-minded* behaviour during a period of growth, development and education. Few children are aware of their physiological limits and, when highly motivated, may easily over-exert *themselves* (Copley, 1977a).

Intensive physical *training acts upon the homeostatic,* physiological equilibrium and brings about measurable circulatory, metabolic, respiratory, thermal and chemical responses (Malina, 1969). Of course, only a *select few are prepared* to subject themselves to this type of training. The majority of sport participants are content to participate in light to moderate forms of training and physical exercise. *Studies by De Vries* (1968), Morgan (1976) and Sime (1977) have indicated that light to moderate exercise can effectively be utilized to alleviate the acute symptoms of both mental *and physical tension and* stress.

Physical activity has received an *increasing amount of* scientific attention in recent years. Banister et al (1975) have proposed a mathematical quantification of athletic progress in which the exercise *impulse, fatigue and training* effects are utilized. Cafarelli et al (1977) have developed an equation for the assessment of perceived physical effort during dynamic exercise. According to these workers, the *perceived physical* effort, which may be expressed in terms of power output per unit of muscle mass, grows as a power function of the physical level of exertion. The exponent of the function is *about 1,7 and varies* little from one exercise task to another. The perceived effort increases much more rapidly with force than with time. This relationship is particularly evident *when one compares* interval training (of high intensity and short duration) with long-distance running training (of low intensity and long duration). Interval training is always rated as more *strenuous and* stressful than long-distance running. Edwards et al (1972) found that intermittent cycling was more effor[illegible]ontinuous exercise when both tasks were matched in terms [illegible]aged *power* output.

Athletic performance is dependent upon [illegible] *physical (physiological* and morphological) and non-physical (psychological) factors (Copley, 1977c).

Sometimes, athletes appear to lack the physiological or psychological prerequisites for success and yet perform at very high levels. It is obvious that morphological, physiological or psychological data alone cannot be used to predict accurately success in sport. It is only when the athlete is viewed as a complex psychobiological organism that one may predict levels of performance with accuracy (Morgan, 1979). There is little doubt that only the rare combination of genetic endowment, generally good environmental conditions and special training will produce performances of Olympic or top international standard (De Garay et al., 1974).

II. Types of training

Although many individual exercises may be used to construct a great variety of simple and/or elaborate training programmes, Munrow (1962) distinguishes between strength, endurance, mobility and skill training.

a. Skill training

Skill training or practising involves the repetition of a specific skill or technique. Although the saying 'practice makes perfect' has received general acceptance, this statement lacks an important word. It is the 'correct' practice that makes perfect. For example, the regular and repeated practice of a technically incorrect tennis stroke would result in a perfectly 'incorrect' stroke. There is little doubt that skill training is essential for proficiency in tennis (Copley, 1975c).

b. Strength training

Strength training may be done isotonically, isometrically or isokinetically.

(i) Isotonic training

Muscle contraction is said to be isotonic when the muscle shortens but the tension on the muscle remains constant (Guyton, 1976). According to Mathews and Fox (1976), the tension developed by an intact muscle varies as it shortens over the full range of motion and, therefore, the more correct term is dynamic rather than isotonic contraction. Classical weight training, or progressive resistance training, still forms the basis of most strength training. It has the disadvantage of unidirectional resistance, in other words, always combatting gravity. However, this disadvantage has been overcome by the development and use of various pulleys, springs and rubber strands. High resistance, low repetition exercises promote muscular strength and power while low resistance, high repetition exercises promote muscular endurance.

Although it is generally accepted that an increase in strength is accompanied by muscular hypertrophy, no precision has been achieved in the attributing of a standard amount of contractile force to a unit of muscle cross-sectional area. Hypertrophy does not, therefore, appear to be the inevitable consequence of all strength increases (Williams and Sperryn, 1976). Rasch and Morehouse (1957) are of the opinion that strength increases could well be the result of 'learning'. They found that strength increases resulting from isotonic training disappeared when their subjects were tested in unfamiliar positions, even though the angle of pull in all the positions was carefully standardised.

(ii) <u>Isometric training</u>

An isometric or static muscle contraction involves an increase in tension but no change in the length of the muscle (Mathews and Fox, 1976). In a study conducted by Müller (1957), it was claimed that one isometric contraction, held for a few seconds once a day, at 40 percent of the maximum, would result in the best possible increase in muscular strength. However, a number of comparative studies of isometric and isotonic methods revealed that isotonic training was generally the more effective method (Williams and Sperryn, 1976).

Girth differences between the predominantly active and less active upper limb in international tennis players indicate that intensive habitual racket manipulation provides an isometric training stimulus that results in hypertrophy of the forearm muscles, but that the isotonic stimulus is not adequate to bring about hypertrophy of the arm muscles (Copley, 1978b).

(iii) <u>Isokinetic training</u>

This type of training [illegible] special apparatus which ensures that the tension developed by the muscle (shortening) is maximal over the full range of motion (Mathews and Fox, 1976). De Vries (1975) is of the opinion that this type of training is superior to both isotonic and isometric strength training. Pipes and Willmore (1975) found that isokinetic training produced significantly greater changes in strength than did isotonic training. High speed isokinetic training, in particular, was found to be effective.

c. Endurance training

This is the most complex type of training. A distinction can be made between local and general endurance training (De Vries, 1975).

(i) Local endurance training

The basic principle involves exposing muscles to high lactate concentrations through maximal work of short duration. This has the effect of improving the processes which depend upon the high-energy phosphate compounds. These compounds provide most of the energy for anaerobic metabolism (Åstrand and Rodahl, 1970). Anaerobic capacity can be determined by means of simple field tests such as short or long sprints, more involved laboratory tests such as the step-running test and even biochemical analyses at the muscle cell level (Bar-Or, 1978).

According to Williams and Sperryn (1976), the endurance of a maximal, static, muscular contraction rarely exceeds 30 seconds and is determined by the interaction of motivation with pain and exhaustion consequent upon the production and accumulation of acid metabolites in the active tissue. Local or muscular endurance can be improved by the specific strengthening of the active muscles since they then contract at a smaller percentage of their maximum voluntary force (Kay and Shephard, 1969).

(ii) General endurance training

This form of training involves activities which bring about maximal loading of the oxygen transporting system. Increases in the myoglobin content and more efficient oxidation of glycogen and fat, result from general endurance or aerobic training (Mathews and Fox, 1976).

Interval training, comprising a system of repeated efforts in which a set distance is run at a timed pace a certain number of times with a set rest period between bouts, may be effectively utilized for both local and general endurance training. The shorter work bouts of high intensity promote strength and anaerobic power, while the longer bouts of lower intensity develop aerobic capacity (Williams and Sperryn, 1976).

d. Mobility training

Joint mobility or flexibility training is necessary for optimum performance in sports such as gymnastics, swimming and hurdling.

Whereas there is generally no limit to the desirable degree of development of factors such as skill, endurance and power, mobility does have upper limits. When a certain position required for an activity such as hurdling can be achieved, then there is no need for any further mobilization (Williams and Sperryn, 1976).

III. Training and exercise in females

In ancient Greece women were allowed to participate in running and wrestling until they were married. Married women were not allowed to participate in any form of sport and were even barred from being spectators. Their practical role, however, was not ignored and the first prize at the Olympic Games was a woman "skilled in the domestic arts", while the second prize was a pregnant mare (Noakes, 1977).

It is generally believed that the physical differences between the sexes is very great and that women are too 'soft' for sport. However, some investigations have indicated only small differences between the sexes while others have actually revealed female superiority. Wilmore (1973) found no sexual differences in running efficiency, muscular structure as revealed by skeletal muscle biopsies and physiological adaptations to running or training. Handel et al (1976) conducted a study on sedentary middle-aged males and females and found negligible sex differences in both the magnitude and direction of cardio-respiratory trainability.

Heyward and McCreary (1978) found that the relative endurance performance at submaximal tension levels in females was superior to that of males. Morimoto et al (1967) found that women are able to regulate body temperature with lower sweat-rates than men, a finding corroborated by Wyndham et al (1965), who reported that females have a relatively more efficient sweating mechanism than males.

Until the age of about 12 the physical maturation of girls slightly precedes that of boys, but after the male puberty boys become taller and develop a greater muscle and bone mass. Although the male generally has greater absolute strength and endurance, these differences become less pronounced when corrections are made for body size (mass and stature) and composition (body fat). For example, when muscular strength is expressed in terms of lean body mass, sex differences are negligible. This indicates that there are no intrinsic qualitative muscular differences between males and females (Noakes, 1977).

It has not yet been established to what extent male-female differences in muscular strength signify a real hereditary sexual difference, rather than differences arising from the cultural environment and social mores which encourage males to be physically more active. In everyday life the lower limbs of both sexes are subjected to more similar conditions of physical activity than are the upper limbs. Consequently sex differences in absolute muscular strength are less pronounced in the legs than in the arms and it would appear that cultural differences are partly responsible for male-female differences in absolute muscular strength (Copley, 1977f).

2.7.3 Maximal aerobic power

A. Introduction

Maximal aerobic power ($\dot{V}O_2$ max)* refers to the maximal amount of oxygen that can be absorbed during strenuous physical activity. Åstrand and Rodahl (1970, p.286) define maximal aerobic power as:

> 'The highest oxygen uptake the individual can attain during physical work breathing air at sea level'.

Hill and Lupton (1923) were the first workers to demonstrate practically the attainment of $\dot{V}O_2$ max. In a study of athletes they showed that oxygen consumption ($\dot{V}O_2$) increased linearly with running speed until a point was reached when the $\dot{V}O_2$ remained the same even though the running speed was increased. At this point, the $\dot{V}O_2$ constituted the $\dot{V}O_2$ max. In recent years maximal aerobic power has received a tremendous amount of attention and is probably the most analysed and discussed component of physical fitness (Bar-Or, 1978). It is regarded by many exercise physiologists as the most appropriate measure of cardio-respiratory fitness and perhaps even of physical fitness. Strictly speaking, however, it is not synonymous with the broad concept of physical fitness since it measures only one element thereof. Nevertheless, the cardio-respiratory system is always actively involved (to a greater or lesser extent) in exercise and physical work and, therefore, the $\dot{V}O_2$ max is undoubtedly a major element of physical fitness (Clarke D.H., 1975).

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* The terms maximal oxygen uptake, intake, consumption and physical work capacity, are frequently used to describe maximal aerobic power.

Maximal aerobic power may be expressed in absolute (litres of oxygen per minute) or relative (millilitres of oxygen per kilogram body mass per minute) units. In an endurance activity such as running, where the energy cost is largely dependent upon body mass, it is more appropriate to express $\dot{V}O_2$ max in relative units, while in endurance sports such as rowing, swimming and cycling, where the body mass is supported, absolute values are more appropriate (Williams and Sperryn, 1976).

It is accepted by authorities such as Cooper (1968), Åstrand and Rodahl (1970), D.H. Clarke (1975), Bar-Or (1978), Wright et al (1978), that $\dot{V}O_2$ max (directly measured) provides the best single measure of cardio-respiratory fitness. This statement implies that an individual with the highest $\dot{V}O_2$ max will have the best cardio-respiratory fitness. Theoretically this is true but in practice a number of additional factors determine success in aerobic-type activities. For example, an individual with a lower $\dot{V}O_2$ max may be more successful in aerobic-type activities such as long-distance running, cycling and swimming, than an individual with a higher $\dot{V}O_2$ max. The author contends that $\dot{V}O_2$ max should be regarded as a measure of cardio-respiratory fitness potential rather than as a measure of fitness per se.

B. The measurement of $\dot{V}O_2$ max

An individual's $\dot{V}O_2$ max may be directly measured in a laboratory or indirectly predicted by means of various submaximal work tests.

I. Direct method

This is the most objective, reliable and accurate method of determining the $\dot{V}O_2$ max. The open-circuit method of indirect calorimetry (described in detail under sub-section 2.7.5) is generally utilized for the direct measurement of $\dot{V}O_2$ max. The subject performs a series of exercise bouts on a cycle ergometer* or treadmill. The exercise workload is progressively increased and when the $\dot{V}O_2$ fails to increase with a further increase in workload, the subject is said to have attained his/her $\dot{V}O_2$ max. An all-out test is not necessary for the attainment of $\dot{V}O_2$ max (Åstrand and Rodahl, 1970).

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* This instrument is commonly referred to as a bicycle ergometer in spite of the fact that it usually has only one wheel (flywheel). The more accurate term, cycle ergometer, is used in this study.

Although the directly measured $\dot{V}O_2$ max is a highly reproducible characteristic with a coefficient of reliability of 0,95 and a day-to-day variability of between 2 and 4 percent (Rowell, 1974), several studies have indicated that the values obtained are largely determined by the active muscle mass involved (Simmons and Shephard, 1970; Blaauw and Thiart, 1977), the subject's physical condition (Saltin et al., 1968), the working posture (Åstrand and Saltin, 1961; Stenberg, 1966) and the type of apparatus used (Hermansen et al., 1970; Faulkner et al., 1971). It is important to distinguish between the unique or true $\dot{V}O_2$ max and the $\dot{V}O_2$ peak, the latter being the highest oxygen consumption attained under a specific set of circumstances. Frequently it is the $\dot{V}O_2$ peak and not the $\dot{V}O_2$ max that is measured (Blaauw and Thiart, 1977).

The direct measurement of $\dot{V}O_2$ max has a number of disadvantages: it is not suitable for unconditioned, aged or convalescent subjects because of the strenuous workloads involved, it is time-consuming, requires expensive equipment and trained personnel and it necessitates a high degree of motivation even in trained subjects (Copley, 1972).

II. Indirect methods

In view of the practical problems involved in the direct measurement of $\dot{V}O_2$ max, a number of simpler, shorter methods have been developed. These methods usually involve submaximal workloads and are generally based on the principle of the linear relationship (within limits) between heart rate, $\dot{V}O_2$ and workload. The indirect methods which have a coefficient of variation of between 15 and 20 percent cannot, of course, replace the direct measurement of $\dot{V}O_2$ max which has a coefficient of variation of between 3 and 5 percent (Andersen, 1964).

a. Indirect $\dot{V}O_2$ max test

This test involves a series of progressively increasing submaximal workloads provided either by means of bench stepping (Maritz et al., 1961) or by means of a cycle ergometer (Andersen and Hermansen, 1965). Heart rate is monitored in the final minute of each exercise bout and is then plotted on a graph against workload and the corresponding oxygen consumption. A straight line is drawn through the respective points on the graph and extrapolated to the estimated maximal heart rate (ordinate). From this extrapolated point a vertical line is drawn to intersect the oxygen consumption scale located on the abscissa. The value at this intersection is *the predicted* $\dot{V}O_2$ *max. According to Åstrand* and Rodahl (1970), this method often results in an underestimation since the $\dot{V}O_2$ may increase relatively more than the heart rate as the workload becomes heavier.

b. *The Cooper field test*

Cooper (1968) studied 115 male subjects and found a correlation of 0,84 between the distance walked or run in a twelve-minute period and the directly measured $\dot{V}O_2$ max during treadmill running. He subsequently formulated a useful table for the prediction of $\dot{V}O_2$ max (ml/kg/min) from the distance run or walked in the twelve-minute period.

According to Wyndham et al (1971), Cooper did not account for the effects of altitude, age or sex and subsequently proposed that 10 percent be taken off the values for each decade after 40 years of age, a further 10 percent for females, and 10 percent for each 200 metres above sea level. A correlation of 0,94 was obtained between the directly measured $\dot{V}O_2$ max and that estimated by the Cooper field test. [illegible] et al (1978) have found that the Cooper test is inclined to overestimate the $\dot{V}O_2$ max of conditioned subjects and underestimate the $\dot{V}O_2$ max of unconditioned subjects. The reason for the overestimation is that the distance covered in twelve minutes may increase considerably as a result of regular exercise without a concomitant increase in the actual $\dot{V}O_2$ max. Wyndham et al (1971) have suggested that different regression lines for the Cooper test may be needed for the very fit, the fit and the very unfit.

Although the Cooper test is a useful, practical method of assessing the $\dot{V}O_2$ max, its validity is largely dependent upon the motivation of the subject. Since the test requires the subject to cover the greatest possible distance in a twelve-minute period, it is obvious that it involves a maximal or near maximal workload. As in the case of the direct $\dot{V}O_2$ max test, it is not suitable for unconditioned, aged or convalescent subjects.

c. The Åstrand-Ryhming nomogram

From data obtained in a study conducted at sea-level on 27 male and 31 female subjects, Åstrand and Ryhming (1954) constructed a nomogram for the prediction of $\dot{V}O_2$ max. The nomogram, which is probably the most frequently used indirect method (Terry et al., 1977), is based on the principle of the linear relationship (within limits) between heart rate, $\dot{V}O_2$, cardiac output and workload. The predictive validity of the nomogram has been substantiated by a number of studies. Åstrand and Ryhming (1954) reported a validity index of 0,709 when values derived from the original nomogram were correlated with values obtained from the direct measurement of $\dot{V}O_2$ max.

An age correction factor was introduced by I. Åstrand (1960) when it was found that the values obtained for subjects over the age of 25 years were being consistently overestimated. Utilizing the adjusted nomogram (Figure 2, Chapter 3), I. Åstrand (1960) reported a validity index of 0,778. Similar validity indices have been reported by Rowell <u>et al</u> (1964), Glassford <u>et al</u> (1965) and Davies (1968).

The Åstrand-Ryhming test involves one submaximal, six-minute workload on either a treadmill or cycle ergometer, or by means of bench stepping. The step test involves a stepping rate of 22,5 steps per minute and bench heights of 40 and 33 centimetres for males and females respectively. The subject's body mass provides the workload. In the final minute of the exercise bout the heart rate, which should fall within the range of 120 and 170 beats per minute, is recorded. A line is then drawn between the points on the heart rate scale and the body mass or $\dot{V}O_2$ scales.* At the point where this line intersects the middle scale, the predicted $\dot{V}O_2$ max (ℓ/min) is read off. An age correction factor (Table I, Chapter 3) is used for subjects younger than 25 and older than 34 years.

Studies by Glassford <u>et al</u> (1965), Wyndham (1967) and Davies (1968) have revealed that a relatively high workload intensity, with a heart rate of 160 to 165 beats per minute, is necessary for the Åstrand-Ryhming test to yield its most accurate prediction of $\dot{V}O_2$ max.

The adjusted Åstrand-Ryhming nomogram was utilized in the present study because of its international recognition and also because it constituted the most practical method of assessing $\dot{V}O_2$ max in this field study. The standardised Åstrand-Ryhming step test constitutes a very light workload to the conditioned subject and rarely induces a cardiac frequency in

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*The line is not drawn from a point on the cycling workload scale but from a corresponding point on the $\dot{V}O_2$ scale. The directly measured $\dot{V}O_2$ during stepping, cycling or running may also be used in the nomogram to predict $\dot{V}O_2$ max.

excess of 120 beats per minute. Consequently, it was decided to use the cycle ergometer on which workload could be adjusted according to the capacity of the individual. In addition, the $\dot{V}O_2$ during the cycling workload was determined to compare the values obtained from the nomogram when workload and heart rate, and $\dot{V}O_2$ and heart rate were used to predict $\dot{V}O_2$ max.

C. Research findings

The $\dot{V}O_2$ max (ml/kg/min) of male and female athletes has been found to be approximately twice as high as that of sedentary subjects (Åstrand and Rodahl, 1970; Costili, 1979). Success in endurance activities is determined not only by the actual size of the aerobic capacity but also by the ability to utilize a large percentage of the $\dot{V}O_2$ max without increasing blood lactate levels. While conditioned athletes can utilize as much as 90 percent of their $\dot{V}O_2$ max for prolonged periods, this figure is only about 40 percent in unconditioned subjects (Costill, 1979).

The influence of heredity and physical training on the $\dot{V}O_2$ max has been of particular interest to the exercise physiologist. It is now generally accepted that an individual's $\dot{V}O_2$ max is largely genetically determined (Geddar, 1960; Åstrand and Rodahl, 1970; Klissouras, 1971; Wessels and Thiart, 1977; Wolański, 1978). Studies by I. Åstrand (1960), Wyndham *et al* (1969), Eriksson (1972) and Wessels and Thiart (1977) have indicated that training can bring about an improvement of only 10 to 15 percent in the relative $\dot{V}O_2$ max (ml/kg/min). This improvement appears to be the result of an increased arteriovenous oxygen difference and stroke volume (Ekblom *et al*., 1968). Åstrand and Rodahl (1970) are of the opinion that the $\dot{V}O_2$ max may be significantly influenced by training in early life between the ages of 10 and 20 years.

Other studies, notably those of Ekblom (1969) and Hickson *et al* (197), have reported increases in $\dot{V}O_2$ max of as much as 55 percent after training. A possible explanation for these findings may well be that the initial pre-training assessment constituted the $\dot{V}O_2$ peak and not the true $\dot{V}O_2$ max because the subjects were unaccustomed to the strenuous physical demands made by the test. However, after a period of training the subjects developed a greater exercise tolerance and, consequently, were able to achieve their true $\dot{V}O_2$ max in the post-training assessment. It should be pointed out also that a marked improvement in the relative $\dot{V}O_2$ max (ml/kg/min) may be the result of a significant reduction in body mass and not of an improvement in cardio-respiratory function.

The $\dot{V}O_2$ max appears to be limited by the following factors: diffusion capacity in the lungs and muscle tissue, pulmonary ventilation, cardiac output, oxygen carrying capacity of the blood, capillarisation of muscle tissue and oxidative processes in the muscle cell (Noakes, 1972). According to Jooste et al (1975), the largest increase in the $\dot{V}O_2$ max occurs between the ages of 10 and 15 years. After the age of about 30 *there is a decrease in* $\dot{V}O_2$ *max which appears to be caused by a reduced* stroke volume, maximal heart rate, maximal pulmonary diffusion capacity and elasticity of the myocardium and blood vessels. Habitual training appears to reduce the rate of decline in physiological functions associated with ageing (Webb et al., 1977).

2.7.4 Mechanical efficiency

To those engaged in physical activity, efficiency or the ability to accomplish the most with the least effort, is an important consideration. Efficiency of physical performance is expressed as the ratio between the physiological effort required and the physical work accomplished. The physiological effort is determined from the oxygen consumption ($\dot{V}O_2$), while the physical work is calculated from the applied force (weight) and the distance through which the force is applied. Both $\dot{V}O_2$ and work are converted to caloric or work rate equivalents. When the physical activity involves a steady state condition, the $\dot{V}O_2$ need only be determined during the work period in order to assess the caloric output. However, when the activity is partly anaerobic and no steady state is reached, the determination of caloric output necessitates the measurement of $\dot{V}O_2$ during both the work and subsequent recovery periods.

A. Types of efficiency

Depending on the base-line correction factor, efficiency (%) can be expressed as gross, net, absolute (work) or delta efficiency (Alpert, 1965). The formulae are:

$$\text{ME (Gross)} = \frac{W}{E} \cdot 100$$

$$\text{ME (Net)} = \frac{W}{E - e} \cdot 100$$

$$\text{ME (Absolute)} = \frac{W}{E_1 - E_u} \cdot 100$$

$$\text{ME (Delta)} = \frac{\Delta W}{\Delta E} \cdot 100$$

where W = caloric equivalent of external work performed,

E = gross caloric output, including resting, exercising and recovery metabolism,

e = resting metabolic caloric output,

E_1 = gross caloric output, loaded,

E_u = gross caloric output, unloaded,

ΔW = caloric equivalent of increment in work performed above the previous work rate, and

ΔE = increment in caloric output above that at previous rate.

While the efficiency of the electric motor is extremely high (80 to 90 *percent), it is considerably lower in the human body and varies between* about 10 and 40 percent (De Vries, 1975). Although it is possible to assess the efficiency of various systems in the body, such as the cardiovascular and respiratory systems (Morehouse, 1972), efficiency generally refers to muscular efficiency in the body. The improvement of physical fitness signifies increased mechanical efficiency since it is then possible to produce more work with the same caloric output or to produce a given amount of work with a smaller caloric output.

B. Research findings

The importance of mechanical efficiency depends to a large extent on the duration of the physical activity. In activities where a single explosive effort is required (e.g. jumping and throwing), it is obvious that power rather than efficiency is the critical factor. On the other hand, physical activities involving endurance are greatly influenced by muscular efficiency. It is not surprising, therefore, that running efficiency has been found to be 5 to 10 percent higher in marathon than in middle-distance runners (Fox and Costill, 1972). Muscular efficiency is influenced by a number of factors such as skill, diet, body size and mass, environment, speed of movement, workload and fatigue (De Vries, 1975).

Reasonably accurate estimates of work output are possible during treadmill, cycle ergometer and step testing, but in many other physical activities it is impossible to calculate accurately the external work output. This is due to the difficulty of estimating the energy absorbed in frictional heat loss and the work involved in maintaining static loads, overcoming wind resistance and the acceleration and deceleration of the arms and legs (Falls, 1968). Cinematographic analyses provide a means of assessing the work output of some physical activities, as Fenn (1930) demonstrated in his study of the forces and energy involved in running.

Heat acclimatisation over a period of seven days was shown to improve the mechanical efficiency of treadmill running at room temperature (Jooste and Strydom, 1978). In Black mine workers, gross mechanical efficiency during cycling was positively correlated with stature and negatively correlated with mass (Williams *et al*., 1966).

The influence of air resistance (external force) on mechanical efficiency can be quite considerable, as a study by Di Prampero *et al* (1976) revealed. The efficiency of top class, long-distance runners (running at a speed of 22km/hour) and cyclists (cycling at a speed of 50km/hour) was found to be 40 and 25 percent respectively. Both groups had similar oxygen consumption values. The difference in efficiency was attributed to the forces opposing progression. Whereas only 7,5 percent of the total external work was used to overcome air resistance in running, nearly all the external work was used to overcome air resistance in cycling.

The influence of skill on mechanical efficiency was demonstrated by Wyndham and Strydom (1971) in a study of champion walkers. The technique of rolling the pelvis, which constitutes the skill aspect of competitive walking, was shown to improve significantly the mechanical efficiency of walking at speeds in excess of 8,1 kilometres per hour. These workers found that, at speeds in excess of 8,1 kilometres per hour in normal subjects and at speeds in excess of 9,8 kilometres per hour in champion walkers, it was actually more efficient to run than to walk.

Although it is obvious that any method of determining mechanical efficiency is subject to criticism, research workers appear to have definite preferences. Durnin (1955) is of the opinion that little purpose is served by quoting efficiencies other than the gross efficiency. Benedict and

Cathcart (1913), on the other hand, believe that gross efficiency is of little value since it does not indicate the potentialities for severe muscular work and gives no conception of efficiency of the body as a machine.

Dickensen (1929) and Gaesser and Brooks (1975) have found that although the absolute (work) efficiency formula is theoretically sound, it is difficult to apply in practice because of the problems encountered in obtaining the caloric cost of unloaded physical activity. Whipp and Wasserman (1969) developed a novel theoretical-thermodynamic approach which was used to validate the various efficiency methods. They concluded that the absolute or work efficiency method was the most suitable. Gaesser and Brooks (1975) are of the opinion that the delta formula provides the most accurate and appropriate method of assessing muscular efficiency since it correctly indicates the linear or slightly exponential relationship between caloric output and work rate.

The determination of an individual's efficiency during the performance of a particular physical task provides useful and interesting information. Ideally, of course, this determination should be made under the conditions in which the physical activity would normally and practically take place. Unfortunately, standardised work tests under laboratory conditions are necessary for the accurate determination of mechanical efficiency. This is primarily due to the difficulty of accurately measuring external work output. Even with sophisticated cinematographic analytical techniques, it would not be possible to measure accurately the external work output of the tennis player.

An estimation of the efficiency of tennis playing was made in this study by expressing $\dot{V}O_2$ during tennis playing as a percentage of $\dot{V}O_2$ max. In contrast to the conventional expression of mechanical efficiency, the lower the derived percentage of this expression, the greater the efficiency. Although treadmill running more closely resembles the tennis playing activity than cycling does, it was felt that cycling efficiency would nevertheless provide useful information about the muscular efficiency or physical fitness of tennis players. Net efficiency, which is the most frequently used traditional method (Gaesser and Brooks, 1975), was therefore assessed during steady-state cycling in the present study.

2.7.5 Energy expenditure

Information pertaining to the energy expenditure* of different kinds of physical activity is not only of theoretical interest, but also of practical importance. Besides providing data concerning the energy cost of physical activity, it also provides information concerning the caloric output required for the maintenance of body mass. This is particularly important in countries where the economy is poor and food availability restricted, or when rationing programmes are devised during war time or other emergencies (Åstrand and Rodahl, 1970).

A. Methods of calorimetry

Two methods, direct and indirect calorimetry, may be utilized to measure energy expenditure. Several different but related units may be used to express energy expenditure. Those most commonly used are: kcal/unit of time, $\dot{V}O_2$ litre/unit of time, $\dot{V}O_2$ ml/kg body mass/unit of time and multiples of basal metabolic rate (Met). In indirect calorimetry when energy cost is expressed in kilocalories (kilojoule is the Standard International unit of energy), the calorific value of oxygen is simply multiplied by the $\dot{V}O_2$. In activities involving anaerobic metabolism, the RQ and calorific values of oxygen are subject to inaccuracies and then energy cost is often expressed in terms of $\dot{V}O_2$ (litres per minute).

I. Direct calorimetry

Direct calorimetry involves the measurement of heat production by means of a special chamber or bomb calorimeter. Towards the end of the 19th century, Rubner demonstrated that the energy produced by the metabolism of foodstuffs is exactly equal to the heat produced by the body (Mathews and Fox, 1976). Because of the expense involved and other practical factors, direct calorimetry is seldom used by the exercise physiologist as a means of measuring energy expenditure (De Vries, 1975).

II. Indirect calorimetry

Energy expenditure is directly related to the utilization of oxygen and the production of carbon dioxide. The measurement of the

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* The term caloric cost or output is frequently employed to describe energy expenditure.

quantities of these two gases in the expired air constitutes what is known as indirect calorimetry. This process is much simpler than direct calorimetry and is commonly used in exercise physiology. There are two techniques of indirect calorimetry, namely, the open-circuit and closed-circuit approaches.

a. Closed-circuit

In the closed-circuit method the subject is connected to an oxygen chamber by a face mask and series of pipes. The expired air is returned to the chamber via a soda lime cannister which absorbs all the carbon dioxide. In this way it is possible to monitor and record on a kymogram the oxygen remaining in the chamber at the end of each respiratory cycle. Although this method has the advantage of simplicity, it has two serious drawbacks (De Vries, 1975). First, readings obtained in this way yield values that are 10 percent of the true value and secondly, since the carbon dioxide production is not measured, it is not possible to determine the respiratory quotient accurately.

b. Open-circuit

The open-circuit method of indirect calorimetry is most frequently used, even though it is more involved than the closed-circuit technique. The high degree of accuracy (error ± 1 percent) and the fact that the carbon dioxide concentration and thus the respiratory quotient may be determined, are probably the main reasons for its general preference. In the open-circuit method the subject inspires directly from the atmospheric air and then expires into a container. The expired air is analysed to determine the oxygen and carbon dioxide concentrations.

In this study, portable respirometers and electronic gas analysers were used in the open-circuit method of indirect calorimetry to determine both the absolute (kJ/min) and relative ($\dot{V}O_2$ % $\dot{V}O_2$ max) energy costs of singles tennis playing. This measurement was included to establish the energy cost of expert tennis players and to determine whether there was an inverse relationship between energy cost and tennis proficiency. Studies by Karpovich and Millman (1947) and Banister et al (1964), for example, have shown that this inverse relationship applies to swimmers and handball players.

B. Results of studies on energy expenditure

Energy cost may be influenced by a number of factors such as environmental conditions, posture, skill, $\dot{V}O_2$ max and the number of actively involved muscles (Åstrand and Rodahl, 1970). Clearly, therefore, reported values should be recognised as average values for particular activities.

Van der Walt and Wyndham (1973) have developed regression formulae for the prediction, from body mass and speed, of energy expenditure ($\dot{V}O_2$) during running and walking. Heart rate and pulmonary ventilation ($\dot{V}_E$) may also be utilized to predict $\dot{V}O_2$. The latter approach appears to be more accurate than the former (Wyndham, 1974).

In a study of a large variety of activities, Passmore and Durnin (1955) found wide individual variation in energy expenditure, depending on profession, leisure and recreational activity. They reported values ranging from 7 kilojoules per minute for miscellaneous office work to 778 kilojoules per minute for sprint running. The energy cost of singles tennis playing was reported to vary between 29 and 42 kilojoules per minute by Passmore and Durnin (1955).

Telemetered heart rate was used to assess the relative strenuousness of singles tennis playing (Kozar and Hunsicker, 1963). The results indicated that peak heart rates were attained after 8 minutes and that tennis playing was not a steady-state activity because of the ever changing cardiovascular responses to the varied demands of physical and mental involvement. Skubic and Hodgkins (1967) reported a mean $\dot{V}O_2$ value of 1,33 litres per minute for singles tennis playing. This was classified as moderately strenuous and was very similar to the value obtained in singles badminton playing. This $\dot{V}O_2$ is equivalent to an energy expenditure of about 28 kilojoules per minute if the calorific value is taken as 5,0 kilocalories per litre of oxygen. Squash appears to be the most strenuous of the racket sports and values ranging from 44 to 84 kilojoules per minute have been reported (Passmore and Durnin, 1955).

An energy expenditure value represents only the energy cost of work (absolute cost) and does not reflect the relative strenuousness or strain imposed upon the subject performing this work. Two methods generally used to assess relative energy cost are to express $\dot{V}O_2$ as a percentage of $\dot{V}O_2$

max and to express energy cost in terms of multiples of the basal metabolic rate (Met). When the activity is standardised, these methods also provide an indication of mechanical efficiency.

In a study by I. Åstrand (1967), it was found that manual labourers who were free to set their working pace had an energy expenditure which was normally 40 percent of their $\dot{V}O_2$ max. Obviously, the higher the $\dot{V}O_2$ max, the smaller the $\dot{V}O_2$ and subsequent fatigue for a given workload. This inverse relationship between $\dot{V}O_2$ max and fatigue was appropriately demonstrated by Hansson (1965) in a study of lumberjacks. The subjects were divided into two groups on the basis of earnings. Skill and muscle strength differences between the groups were small but the high income group had a significantly greater $\dot{V}O_2$ max than the normal income group. Owing to his superior $\dot{V}O_2$ max, the top worker was able to attain a higher work output and became less fatigued than his less-productive colleague.

2.7.6 Thermoregulation

Although a suitably protected man may tolerate extreme variations in environmental temperature (between -50°C and 100°C), he can tolerate a variation of only about 4 degrees Celsius in his own deep body temperature without marked impairment of his optimal physical and mental work capacity (Åstrand and Rodahl, 1970).

The temperature-regulating centre is located mainly in the hypothalamus. An elevated body temperature stimulates the anterior hypothalamus and this results in an increased heat loss from the body in two principal ways: vasodilatation of peripheral blood vessels which increases the heat transfer from the 'core' to the 'shell' and, stimulation of the sweat glands resulting in evaporative heat loss. A reduced body temperature stimulates the posterior hypothalamus, resulting in incrsased metabolic heat production by shivering and reduced heat loss (radiation and convection) by vasoconstriction of the peripheral blood vessels.

A brief discussion of sweat-loss and liquid balance in the human body is presented.

A. Water loss

In order to maintain a liquid balance,* water loss must equal water intake. According to Åstrand and Rodahl (1970), the normal total daily loss of water from the human body is about 2,6 litres, of which 200 millilitres is lost from the gastro-intestinal tract, 400 millilitres from the respiratory tract, 500 millilitres from the skin and 1,5 litres from the kidneys. This loss is balanced by an intake of 1,3 litres of water by drinking, 1,0 litres of water in ingested food and 300 millilitres of water liberated during cell oxidation. Of course, when the body is subjected to physical exercise and/or a hot environment, water loss by sweating may increase considerably.

I. Sweating

The evaporation of sweat from the skin surface plays a major role in reducing an elevated body temperature. In fact, when the environmental temperature is higher than that of the body, evaporative heat loss is the only means of thermoregulation. Since about 99 percent of sweat is water, it is well suited for its role in evaporative cooling. At normal skin temperature the evaporation of one gram of sweat requires 0,58 kcal (Åstrand and Rodahl, 1970). Sweating may commonly exceed 2 or sometimes even 3 litres per hour (Robinson and Robinson, 1954; Åstrand and Rodahl, 1970). A study by Dancaster and Whereat (1971) revealed that runners competing in the Comrades Marathon (94 km) had total sweat-losses ranging from 4,3 to 12,8 litres.

Sweat-rate,☆ which is an indication of the magnitude of heat stress, may be determined by the assessment of evaporation or sweat run-off from the skin by means of either the net body mass change method or, an infra-red gas analyser (Robinson and Robinson, 1954). Nadel et al (1971) have developed a formula for predicting sweat-rate in which skin wetness, state of acclimatisation and oesophageal and skin temperatures are used.

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*The terms liquid and fluid are often used synonymously. A fluid refers to a gas or a liquid. It is more appropriate, therefore, to refer to a liquid balance rather than to a fluid balance. Liquid intake is also a more appropriate term than fluid intake.

☆ Sweat-rate may be expressed absolutely in litres or grams per hour, or relatively in litres or grams per square metre of body surface area per hour.

In this investigation sweat-rate was determined in order to assess the magnitude of heat stress in professional and amateur tennis players. The change in net body mass was assessed as this method is particularly suited to field studies.

Heat acclimatisation increases the sensitivity of the sweat-rate response as well as the sweat production. This increased sensitivity initiates the sweating response sooner than would normally be the case. According to Knip (1975), the increased sweat production is the result of an enhanced secretory activity of the individual sweat glands and/or an increase in the number of glands brought into action. The latter process appears to make the most significant contribution to the increased rate of sweating.

When sweat-rate is expressed per degree of rise in rectal temperature, the relative degree of heat acclimatisation may be assessed (Strydom et al., 1965). Pandolf et al (1977) are of the opinion that cardio-respiratory fitness is a prime factor in the ability to become acclimatised to heat. These workers have developed a formula for the prediction (from $\dot{V}O_2$ max) of the day on which optimum heat acclimatisation will be attained when a prescribed acclimatisation programme is being followed.

Hidromeiosis (reduced sweat-rate) occurs when the body is exposed to heat for extended periods (> 5 hours). Wyndham et al (1966) are of the opinion that hidromeiosis is due to fatigue of the sweat glands, while Falls and Humphrey (1976) support the theory that hidromeiosis is directly related to the wetness of the skin. According to the latter workers, hydration of the stratum corneum causes a swelling of the sweat gland duct which inhibits sweating.

II. Dehydration

Dehydration or hypohydration may occur when a high sweat-rate is maintained for prolonged periods. A large amount of the liquid lost during exercise is drawn from the intracellular space and not from the plasma as is generally believed (Costill, 1979). According to Åstrand and Rodahl (1970), temperature regulation in the body has priority over water regulation and, consequently, dehydration may reach a stage when it becomes a threat to life. Physical work capacity is reduced by dehydration even if the water loss constitutes only 1 percent of the subject's body mass. Although the body can tolerate a mass loss of up to 3 percent, larger losses result in progressively higher rectal temperatures. The danger zone of 40 degrees Celsius is reached at a 5 percent mass loss (Williams and Sperryn, 1976).

III. Liquid intake

The maximum amount of liquid that can be absorbed during physical activity remains a debatable point. Williams and Sperryn (1976) reported a value of 0,8 litres per hour, while Costill (1979) believes that 1,5 litres per hour is the maximum amount that can be absorbed. Besides indicating the range of subject variability, these findings show conclusively that the rate of gastric emptying (0,8 to 1,5 litres per hour) cannot match the rate of water loss during profuse sweating (2,0 to 3,0 litres per hour). Therefore, it is evident that dehydration is inevitable (to a lesser or greater degree) in individuals who participate in strenuous endurance-type activities. Costill (1979, p.66) states:

> 'Laboratory measurements demonstrate that marathoners are physically incapable of consuming sufficient amounts of fluids to keep pace with sweat losses'.

According to Åstrand and Rodahl (1970), the rate of absorption of water, glucose and other minerals in the gastro-intestinal tract is unaffected by exercise involving 70 percent or less of the $\dot{V}O_2$ max.

A great variety of replacement liquids, ranging from plain water to liquids with varying concentrations of glucose and mineral salts, have been proposed for sports participants. While the ingestion of liquid containing glucose may have the advantage of elevating blood glucose levels, it has the disadvantage of causing a marked reduction in the rate of gastric emptying (Åstrand and Rodahl, 1970; Costill and Saltin, 1974). Benade and Jooste (1976) found that an orally ingested solution of 8 percent sucrose was, for long-distance runners, the most suitable of the three solutions they tested. These workers studied the effects of this solution compared with those of water and a solution containing sodium, chloride, potassium and sucrose (8%), as well as to the effects of drinking no water.

A number of studies (Ladell, 1955; Costill et al., 1975; Jooste et al., 1978; Shapiro et al., 1978) have indicated that the ingestion of salt (sodium chloride) during endurance activities in hot environments is of little physiological benefit and, under certain conditions, is contraindicated. Since sweat is hypotonic to body liquids, relatively more liquid than salt is lost during sweating. This has the effect of increasing the concentration of salt in the body. The ingestion of additional salt compounds the position. Salt loading may even cause a significant increase in rectal temperature (Shapiro et al., 1978). Additional salt is necessary only when prolonged daily physical activity, resulting in profuse sweating, is continued for a week or longer (Åstrand and Rodahl, 1970).

A litre of cold water ($4^{0}C$) containing less than 25 grams of glucose and few if any electrolytes (at most 2 grams of salt) and, having an osmolality of about 200 milliosmol per litre, is regarded by Costill (1979) as the most suitable for ingestion during physical activity. Of course, the liquid should be ingested in small amounts (100 - 200 ml) at frequent intervals.

A number of commercial firms produce replacement liquids which are claimed to be superior because they are isotonic.[*] However, it is unlikely that these liquids do what is claimed, since the osmolality of the body liquids not only differs from person to person but continually changes in the extracellular and intracellular compartments during strenuous physical activity.

Competitive tennis playing frequently necessitates prolonged strenuous physical activity and exposure to heat. Many players either do not ingest any liquid or commence doing so towards the end of the match. In both instances it is very likely that the player will become dehydrated and that performance will be influenced. Since absorption from the gastrointestinal tract continues at a constant rate, the player should commence drinking at the start of the match. It is unlikely that a player will be able to 'catch up' once a water deficit has been incurred (Copley, 1978a).

2.7.7 Respiration

A metabolic link with the atmosphere is established by the act of breathing. The consumption of oxygen is dependent upon the maintenance

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[*] A fluid into which normal body cells can be placed without causing either swelling or shrinkage of the cells is said to be isotonic with the cells (Guyton, 1976).

of free airpassage and the proper diffusion and transportation of respiratory gases. Normally respiration proceeds extremely well and efficiently and is not a limiting factor in exercise (Clarke D.H., 1975). The measurement of pulmonary function and efficiency involves the determination of various static and dynamic pulmonary volumes.

A. Static volumes

When the respiratory muscles are relaxed, the amount of air left in the lungs is the functional residual capacity (FRC). A forced maximal expiration reduces this volume to the residual volume (RV) by expiration of the expiratory reserve volume (ERV). A maximal inspiration from FRC adds the inspiratory capacity (IC) and the volume of air in the lungs is the total lung capacity (TLC). The vital capacity (VC) is the maximal amount of air that can be expelled from the lungs after a maximal inspiration. The tidal volume (TV) is the amount of air moved during each respiratory cycle. The inspiratory reserve volume (IRV) is the difference between the IC and the TV.

The vital capacity and its subdivisions are usually measured with a spirometer while the RV and FRC may be determined by the gas dilution, gas wash-out or body plethysmograph methods (Åstrand and Rodahl, 1970). The static pulmonary volumes and capacities are converted from ambient temperature and pressure saturated (ATPS) to body temperature and pressure saturated (BTPS), since the volume of air and not the number of gas molecules present is of particular concern. All respiratory gas measurements dealing with volume only should be corrected to BTPS (Mathews and Fox, 1976).

The VC, RV and TLC are related to body size and, according to Åstrand and Rodahl (1970), very approximately as the cube of a linear dimension (stature) up to the age of 25 years. Hepper <u>et al</u> (1960) have proposed a formula for the prediction of VC from stature. Although the magnitude of the VC cannot be considered as a criterion of physical fitness per se, Balke (1974) maintains that it has an essential bearing on the maximal breathing capacity. While only about 20 percent of the VC is used during rest, this volume can be increased to between 66 and 75 percent during strenuous physical exercise. An oxygen consumption of 4 litres per minute or more, requires a VC of at least 4,5 litres (Åstrand and Rodahl, 1970).

The effects of training on the VC have been extensively studied but the results show no general agreement. Bachman and Horvath (1968) found a significant increase in the VC of swimmers undergoing a 4-month training programme. This increase was the result of an increased IC. A group of wrestlers was studied but, in contrast to the swimmers, no significant changes in VC were found after a 4-month training period. Shaver (1974), on the other hand, studied a group of university wrestlers and found that a 6-month training programme resulted in significant increases in VC. There is little doubt that a thorough assessment of alterations in the respiratory apparatus requires a study of a number of static as well as dynamic pulmonary volumes.

B. Dynamic volumes

The functional capacity of the respiratory system may be assessed from the forced expiratory volume (FEV_1) and the maximal voluntary ventilation (MVV) or maximal breathing capacity. A spirometer is commonly used to measure these dynamic volumes. Kory (1961) has developed a formula for the prediction of MVV from stature and age.

The FEV_1 is the maximum amount of air that can be expired in one second after a maximal inspiration. The maximal flow is limited by a rising flow resistance and the rate at which the muscles convert chemical into mechanical energy (Åstrand and Rodahl, 1970). The FEV_1 is usually expressed as a percentage of the VC and is then referred to as the forced expiratory volume index (FEV_1 I).

The MVV is used to assess the mechanical properties of the lungs and chest wall and it provides a measure of the overall capacity of the breathing apparatus to pump air. According to Åstrand and Rodahl (1970), the maximal air flow during short periods of peak expiratory flow may be as high as 400 litres per minute. A limiting factor is the rising air-flow resistance in the tracheobronchial tree which becomes progressively compressed with increasing intrathoracic pressure. The pulmonary ventilation ($\dot{V}_E$) varies from about 6 litres per minute at rest, to about 150 litres per minute and higher during maximal physical exercise. The $\dot{V}_E$ is usually lower during maximal work than during the measurement of the MVV (Åstrand and Rodahl, 1970).

The larger the tidal volume and the lower the respiratory frequency for a given total ventilation, the greater is the efficiency of pulmonary ventilation (Balke, 1974). The ventilation-oxygen uptake ratio ($\dot{V}_E/\dot{V}O_2$) and the ventilation-perfusion ratio may also be used to evaluate ventilatory efficiency (Edington and Edgerton, 1976).

The effects of training on the functional capacity of the respiratory system have been extensively investigated. In contrast to the conflicting reports concerning the effects of training on static pulmonary volumes, there is general agreement as to the effects of physical activity on the dynamic pulmonary volumes. D.H. Clarke (1975, p.171-172) states:

> 'The effect of training on ventilation can best be described as one of improving the efficiency of breathing. The trained individual reduces the rate of breathing and increases the depth, yet for a given level of submaximal exercise he is able to achieve a $\dot{V}O_2$ with less overall respiration. This means that he is able to extract a greater proportion of oxygen from the air he breathes than the untrained person. The air is now able to reach a wider alveolar area at rest and during exercise; in short, there is an increased aeration as a result of training'.

In a study by Scotti (1962), it was found that football players had significantly greater FEV_1 and FEV_1 I's than sedentary subjects. Zamora (1964) reported increases in MVV with training. A 4-month swimming programme resulted in pronounced decreases in FRC, RV and the RV/TLC ratio, which indicated an improved alveolar ventilation (Bachman and Horvath, 1968). A 6-month training programme produced significant improvements in the MVV of wrestlers (Shaver, 1974).

In the present investigation, the following static and dynamic pulmonary volumes were determined: tidal volume, inspiratory reserve volume, expiratory reserve volume, inspiratory capacity, vital capacity, forced expiratory volume per second and forced expiratory volume index. These measurements were taken to assess the effects of professional and amateur tennis competition and training on the structure and function of the respiratory system.

2.7.8 Flexibility

Flexibility is generally described as anything capable of being flexed, turned, bowed or twisted without breaking. Flexibility as it relates to the joints of the human body can be either dynamic or static (De Vries, 1975). Dynamic flexibility is a measure of the resistance or opposition offered by a joint or sequence of joints to motion. It is concerned therefore with the forces that oppose movement over any range rather than with the range itself. Static flexibility is defined as the range of possible movement about a joint or sequence of joints.

The ability to extend and flex a joint through a wide range of motion is very different from the ability to rapidly move a joint with little resistance to the motion. De Vries (1975) is of the opinion that dynamic flexibility provides greater insight into the potential performance in speed activities than does static flexibility or the ability to achieve an extreme degree of flexion or extension in a joint. Dynamic flexibility is more difficult to measure than static flexibility and this is probably why the latter, in contrast to the former, has been extensively assessed and investigated.

A. Dynamic flexibility

This may be assessed by directly measuring, with a special dynamometer, the torque forces required to move a joint through various ranges of motion at varying speeds. In a study by Wright and Johns (1960), it was found that elasticity and plasticity were the major factors contributing to reduced dynamic flexibility in the wrist and finger joints. Although this technique does not appear to have been applied to research in physical performance it does, according to De Vries (1975), have distinct possibilities for such use.

Another less sophisticated method of assessing dynamic flexibility was developed by Fleishman (1964). The test involves the execution of a series of prescribed bending, twisting and turning movements of the trunk in a set time. It is primarily a measure of dynamic trunk flexibility and, as in the case of the more sophisticated method, has not been widely used. In a previous study by the author (Copley, 1976a), male international tennis players were found to have significantly greater dynamic trunk flexibility as measured by the Fleishman test, than male provincial and club tennis players.

B. Static flexibility

I. Direct method

Static flexibility can be either directly or indirectly measured. In its classic form the direct method utilizes a goniometer, which is a protractor-like device used to measure angles. Applied here, it measures the angle through which two segments of the body may move vis-a-vis each other. Since body parts are not regular geometric forms, it may be difficult to decide the position of the axes of the bony lever system. Hence goniometric measurements may have a high observer error.

A simple but ingenious device developed by Leighton (1955), the Leighton flexometer, largely overcomes the disadvantage of the goniometer. The flexometer is attached to a body part and records the range of motion in degrees in respect of a perpendicular related to the pull of gravity. It may be used to measure the static flexibility of 19 joints throughout the body including the trunk and the extremities. Reliability coefficients of between 0,90 and 0,99 have been obtained by Leighton (1955) and H.H. Clarke (1975). The Leighton flexometer was used to measure static flexibility in the present study, because of its practicality, versatility and accuracy and because it has been much used in the study of sport participants. Static flexibility was assessed to investigate the long term effects of intensive tennis playing on joint motion.

II. Indirect method

The indirect method of assessing static flexibility involves measuring how closely a body part can be brought into position with another body part or some other reference point. A number of tests have been devised by Cureton (1951), Wells and Dillon (1952), Kraus and Hirschland (1954) and Scott and French (1959) for the indirect measurement of static flexibility. These tests, however, lack the versatility and precision of tests conducted with the flexometer in which the range of movement is directly recorded in degrees of a circle.

C. Research findings

Holland (1968) conducted an extensive review of the research literature pertaining to static flexibility. This review revealed the following: flexibility is highly specific and its measurement at one body joint cannot be utilized to predict the range of motion at other joints; participation in specialised forms of physical activity results in the development of specific patterns of flexibility; and there appears to be little agreement with regard to the definition and range of motion of so-called hypo-average or hyperflexibility.

In a study of the static flexibility of boys aged 6 to 10 years, Leighton (1964a) found that age changes in the range of various joints were not necessarily due to growth and could have been the result of changing movement patterns. Laubach and McConville (1966) conducted a study on college males and found that anthropometric measures and Sheldonian somatotype components were non-significantly correlated with the results of tests of static flexibility measured with a flexometer. Gardiner (1972) compared flexion and extension of shoulder, trunk, hip and ankle in proficient college springboard divers, gymnasts and swimmers. The range of motion was measured with a Leighton flexometer. The divers had the greatest shoulder flexibility while the swimmers recorded the lowest hip flexibility.

Progressive resistance training or weight training is commonly thought to result in a 'muscle-bound' condition which is associated with a reduction in the range and speed of joint movement. However, studies by Zorbas and Karpovich (1951), Wickstrom (1960) and Leighton (1964b) have indicated that champion body builders and weightlifters do, in fact, have greater range and speed of joint movement than non-weightlifters.

Recent advances in physical medicine and rehabilitation have indicated that flexibility is important to general health and physical fitness. Flexibility training has been successfully used in the treatment of dysmenorrhea, general neuromuscular tension and lower back pains (Mathews and Fox, 1976). The maintenance of good joint mobility prevents, or to a large extent relieves, many of the aches and pains associated with ageing (De Vries, 1975). Increasing the range of motion can play an important role in the prevention of both extrinsic and intrinsic injuries (Sheehan, 1977; Williams, 1977). Many of the intrinsic muscle and tendon injuries in sport are a direct result of a lack of flexibility and also muscle strength imbalances between the agonists and the antagonists. A strong complementarity of both strength and flexibility is essential for maximum protection from injury. Either one without the other is likely to produce potential harm. The so called 'lengthening-strengthening' principle is used to develop a compatible relationship between strength and flexibility. This principle applies when there is shortened tissue (muscle, tendon, ligament) on one side of the joint and/or weakened muscle on the other (Johnson, 1969).

Joint flexibility can be significantly improved by flexibility training. This generally involves stretching exercises that may be performed either statically (held position) or ballistically (bobbing, active movements). Both types of stretching are effective but the static method is regarded as the most beneficial and has been found to be effective in the prevention and relief of muscle soreness (De Vries, 1975).

Although joint flexibility can be improved by training, Gevlich (1964) has shown that the range of motion in the upper extremities can actually be reduced by changes in the bone tissue. In a study of 640 subjects in which X-rays were used, it was found that activities requiring greater strength led, over a period of time, to an increased diameter of the joint surfaces, a decrease in the curvature of the joint capitulum and an increase in bony prominence. The latter change was considered as the most important in the inhibiting of motion.

2.7.9 Vision

Vision is an essential element of sport performance, particularly ball-striking sports, a fact which is usually taken for granted. According to Fine (1978), vision is subject to many errors which ultimately influence the level of performance in racket sports. For example, in menstruating women there is a minor rise in intra-ocular pressure which reduces visual acuity (Williams and Sperryn, 1976). Besides the obvious importance of visual acuity, a number of other visual factors play an important role in skilled motor performance. These include the following:

A. Ocular movement and tracking

The monitoring and processing of sensory information constitute important preliminary tools for decision-making in motor performance. According to Glencross and Cibich (1977), the speed of the decision-making processes is an important limiting factor in skilled performance. Two major eye movement systems are responsible for the monitoring of sensory information: the smooth pursuit eye movement system (SPEMS) and the saccadic eye movement system (SEMS). When the velocity of a moving object is high, the SPEMS appears to break down and then all sensory information is provided by the SEMS (Williams and Helfrich, 1977). In a study of baseball players these workers found that batting performance was significantly better in subjects with faster SEMS and that specific training programmes improved or quickened the SEMS.

The importance of the SEMS in tennis can be appreciated when one considers that the velocity of a served ball is about 150 metres per second and this allows the receiver only 253 milliseconds to make a decision (Glencross and Cibich, 1977). This means, in effect, that in order to return a fast service the receiver must start executing the appropriate movement before the ball has crossed the net.

Although coaches of many ball striking sports advocate that the ball be watched until it makes contact with the striking implement, this does not actually appear to happen (Moss, 1956; Hubbard and Seng, 1954). Whiting (1969) is of the opinion that proficient performers of ball games do not need to track the ball visually for the whole of its trajectory. A careful examination of action photographs depicting the moment of racket-ball impact in tennis, has shown that the player directs his vision to a point about 10 centimetres ahead of the racket-ball contact (Copley, 1976a). There appear to be two reasons for this: no additional information is required after the racket is on its way and/or the SPEMS breaks down at high relative velocities.

B. Depth perception

Stereopsis or depth perception is defined as the ability to see similar images falling on slightly disparate retinal points and to blend them into one with the appreciation of perception of depth by parallax (Hurtt *et al.*, 1972). Depth perception,which plays an important part in ball-striking sports where precise predictions are necessary, is normally a function of both eyes in stereoscopic vision. Although Whiting (1969) is of the opinion that depth perception is possible also with monocular vision, it is doubtful that this is true depth perception. It is rather depth estimation by use of visual, experimental and other clues.

The Howard-Dolman test is most commonly used to assess depth perception. (1956) used this test and found that athletes had superior depth perception compared with non-athletes. In another study, Krestovnikov found tennis players to have considerably better depth perception than football players (cited by Graybiel *et al.*, 1955). In both the tennis and football players stereopsis was found to be highly correlated with proficiency.

C. Peripheral vision

Peripheral vision is the observation of objects outside the field of central vision. The periphery of the retina is particularly sensitive to movement. However, although stimulation of the retinal edge provides awareness of the movement and direction of an object, the object is not easily identified. Expectation of a ball or player in the periphery obviously facilitates identification (Whiting, 1969). A number of studies have shown that peripheral vision is superior in proficient ball game performers. Williams and Thirer (1975) found that horizontal and vertical peripheral vision were superior in athletes compared to non-athletes. By means of a standard Bausch and Lomb perimeter, these workers found that females had significantly better vertical peripheral vision than males. In basketball, peripheral vision is regarded as particularly important since the good dribbler never looks at the ball (Whiting, 1969).

One would expect peripheral vision to be important in racket sports since it provides vital information concerning opponent strategy. In squash, in particular, where players are positioned side by side, horizontal peripheral vision would seem to be of importance. Peripheral vision appears to be important in other sports. Krestovnikov showed that the performance of javelin throwers and skiers was significantly reduced when their peripheral vision was excluded. In fact, they appeared to rely more on their peripheral than on their central vision (cited by Graybiel, et al., 1955).

D. Ocular dominance

In normal binocular vision one directing or controlling eye is used. According to Zagora (1959), by the age of five, 95 percent of children have become definitely right-or left-eyed. Ocular dominance can be assessed by a number of simple tests. The binocular peep-hole or hole-in-card test and the pencil alignment test are used most frequently. Buxton and Crosland (1937), who evaluated the majority of eye dominance tests, concluded that the binocular peep-hole test was to be preferred. Duke-Elder (1939) found that 64 percent of adults were right-eyed while 33 percent were left-eyed.

The binocular peep-hole test was utilized in this study to assess ocular dominance, required for the determination of eye-limb concordance or discordance. The relationship between ocular dominance and tennis proficiency was also investigated.

E. Eye-limb concordance/discordance

Eye and limb dominance are usually described in terms of crossed laterality and unilaterality (Adams, 1965; Whiting and Hendry, 1968; Whiting, 1969). The crossed lateral individual is either right-eyed and left-handed, or left-eyed and right-handed. The unilateral individual is either right-eyed and right-handed or left-eyed and left-handed. Since there does not appear to be a term that collectively describes crossed laterality and unilaterality the term eye-limb concordance/discordance, as suggested by P.V. Tobias, is used in this study. Eye-limb concordance refers to unilaterality while eye-limb discordance refers to crossed laterality.

Whiting (1969) is of the opinion that ocular and limb dominance are usually congenital but that it is possible for a congenital left-hander to become a trained right-hander or vice versa.

A popular view concerning eye-limb concordance/discordance is that the crossed lateral player has an advantage. According to this view when a side-on stance is assumed (forehand side), the crossed lateral player has an unobstructed view of the approaching ball, whereas the unilateral player's nose bridge partly obstructs either the right or left eye from viewing the oncoming ball (Adams, 1965). However, this view was not borne out by the results of studies conducted on rifle shots (Bannister, 1935), baseball batters (Adams, 1965) and table tennis players (Whiting and Hendry, 1968). The majority of the baseball batters and table tennis players were unilateral. The unilateral batters were found to be more proficient than the crossed lateral batters. Unilaterality was more advantageous than crossed laterality for rifle shooting (handedness was determined by the shoulder used for firing).

Handedness or upper limb dominance was determined in order to assess eye-limb concordance/discordance and the possible relationship between handedness and tennis proficiency. Eye-limb concordance/discordance was assessed to determine the possible relationship with tennis proficiency and the frequency of crossed laterality and unilaterality among tennis players.

2.8 ASPECTS OF BIOCHEMISTRY

Biochemistry involves the study of the chemical factors responsible for the origin, development, functioning and progression of life. As stated in the previous sub-section (2.7.1), considerable attention has been given to the physiology of exercise. Within the field of exercise physiology a new sub-discipline, exercise biochemistry, has emerged. Exercise biochemistry is the study of the acute and chronic chemical responses and reactions to physical activity and exercise. In spite of the fact that the first international symposium on exercise biochemistry was held only in 1968, great strides have been made in this field. Hormonal control, energy substrates and adaptations to exercise have been extensively investigated since 1968,with the result that far more is known about the biochemical control of exercise than was the case a few years ago (Jooste, 1979).

2.8.1 Energy substrates

Substrates providing energy for muscular contraction can either be transported from a distant deposit to the muscle cells by the blood stream (blood-borne substrates) or be stored in the working tissue itself. Both carbohydrates and lipids are utilized as substrates in muscular work. The relative contribution of these substrates may be determined from the respiratory exchange ratio or quotient (RQ).

A. Carbohydrates

Carbohydrates are an important source of energy during most types of physical activity and are supplied by the liver* as blood glucose, or stored in the form of glycogen in the muscles. Muscle glycogen is the main source of energy substrate at the onset of physical activity but, as these stores decline, there is an increased uptake and utilization of blood-borne glucose (Costill, 1979).

The immediate source of energy for muscular contraction is the splitting of adenosine tri-phosphate (ATP) which is in equilibrium with phosphocreatine (PC). Until the recent needle biopsy technique, little was known about the size of the energy stores in skeletal muscle. The amount of

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* Liver glycogen constitutes the main extramuscular carbohydrate store (Saltin, 1978).

energy stored as ATP and PC has been found to be small compared to the amount of energy stored as glycogen and triglycerides (Bergström and Hultman, 1972).

I. Glucose

Blood glucose, which is the principal source of fuel for the nervous system, is derived from liver glycogen by the process of gluconeogenesis. The hepatic glucose output rises promptly in response to physical exercise and is directly proportional to both the workload and duration of the exercise. During high intensity, short duration activity (40 to 60 minutes) the increase in hepatic glucose output is achieved by an augmented glycogenolysis with gluconeogenesis accounting for only 5 to 15 percent of the total glucose output. However, in prolonged, moderately light or heavy activity (3 to 4 hours), hepatic gluconeogenesis is far more important and may contribute more than 50 percent of the total glucose production (Jooste, 1979). The total amount of glycogen stored in the liver is normally about 55 to 90 grams but only one day of starvation or food intake without carbohydrates is sufficient to produce almost complete depletion of liver glycogen stores. When the muscular demands for glucose are greater than the liver's output, then blood glucose levels may fall quite low (50mg%) with the occurrence of hypoglycaemia (Hultman, 1978).

In this study, blood glucose concentrations before and after matches were determined by means of enzymatic spectrophotometric methods, in order to assess blood glucose responses to strenuous competitive tennis playing. The possible occurrence of hypoglycaemia was of particular interest.

II. Glycogen

Muscle glycogen stores are important to the endurance athlete and may be the limiting factor in the final effort of an endurance event or when successive days of intense physical activity are required. The rate of muscle glycogen deflection depends upon the percentage of $\dot{V}O_2$ max employed during physical exercise. At exercise levels below 95 percent of the $\dot{V}O_2$ max, both carbohydrates and fats are used, but above this level the energy is supplied almost exclusively by carbohydrates. Total or near total depletion of muscle glycogen occurs only when the activity lasts for more than 50 to 60 minutes at greater than 80 percent of the $\dot{V}O_2$ max (Costill, 1979). Cross-country skiers, who covered a distance of 45 kilometres, were found to have completely exhausted the muscle glycogen stores in their arms with substantial depletion in their legs (Bergström et al., 1973).

In a study by Costill et al (1974) on long-distance runners, muscle glycogen stores were depleted substantially more in the leg than in the thigh. Only during uphill and downhill running were the thigh muscles required to metabolise glycogen at rates approximating those of the muscles of the leg. Costill et al (1973) have demonstrated that physical exercise involves a selective depletion of the muscle glycogen stores. Long-distance runners were found to have significantly lower glycogen stores in their slow twitch than in their fast twitch muscle fibres. These workers are of the opinion that this selective depletion is undoubtedly the cause of the muscle distress frequently experienced by marathoners.

Fink et al (1975) have demonstrated recently that physical exercise in the heat (40°C) places greater demands on muscle glycogen metabolism than exercise in the cold (9°C). Intensive physical exercise over a period of days drastically reduces the muscle glycogen stores. Even with a high carbohydrate diet it may take 2 to 5 days to restore muscle glycogen to its pre-training level (Costill, 1979). Professional tennis players frequently have to play successive long-duration matches (5 sets) under hot environmental conditions. In addition to these matches, the players often participate in strenuous on-court practice sessions.
It is more than likely that the frequently observed poor performances of professional players in the latter stages of a tournament are the direct result of muscle glycogen depletion.

a. Glycogen loading

A method of increasing muscle glycogen stores was developed as a result of work done by Bergström and Hultman (1966). Muscle glycogen loading, boosting or supercompensation involves first emptying the glycogen stores through intensive physical exercise and then ingesting a high protein diet for 2 to 3 days and, thereafter, consuming a high carbohydrate diet for 3 days. This procedure enables the muscle glycogen stores to increase from 1,5 to 4,0 grams per 100 gram wet muscle mass (Noakes, 1972). Muscle glycogen storage is accompanied by a storage of water which may amount to as much as 2 to 3 litres (2,5 to 3,5 kg increase in body mass). In this way, the body may acquire a water reserve that helps prevent dehydration resulting from sweating. Under these conditions a reduced body mass does not necessarily indicate a decline in functional water volume (Saltin, 1978). Although the benefit resulting from glycogen loading is limited to the muscles that have been exercised, the factors that determine the magnitude of this glycogen deposit in the musculature have not yet been established (Saltin, 1978). Unless the glycogen stores are initially depleted, a high carbohydrate diet will result in only a small increase in the glycogen stores (Costill, 1979).

There are differences of opinion regarding the methodology of glycogen loading. Åstrand (1967) and Bergström and Hultman (1972) advocate a fat-protein diet prior to the final rich carbohydrate diet, while Costill (1979) recommends that only a high carbohydrate diet is necessary after the initial glycogen depletion. Personal experience has shown that glycogen depletion followed by a 2-to 3-day fat-protein diet may result in hypoglycaemia and an increased susceptibility to respiratory infections. Costill (1979) states that a fat-protein diet following glycogen depletion produces a slow, incomplete replacement of glycogen in the exhausted muscles. Glycogen loading without a fat-protein diet appears to be the most suitable method.

An increased storage of muscle glycogen may be of value to tennis players competing in Davis Cup competitions, challenge matches or endurance stints. Since the professional tournament player is usually committed to at least one match per day, it is evident that the practical application of glycogen loading is restricted to the relatively unimportant first round match of a tournament. Obviously, it would be preferable to have a high glycogen storage for the final rather than the first round match.

There is little doubt that glycogen loading significantly reduces the chance of premature exhaustion during strenuous physical activities lasting an hour or longer (Åstrand and Rodahl, 1970; Williams and Sperryn, 1976; Saltin, 1978; Costill, 1979). However, a number of practical problems are involved. Extremely high muscle glycogen storage cannot be attained at more frequent intervals than a few weeks (Saltin, 1978). Jooste et al (1976) are of the opinion that it is neither advisable nor practical to change an individual's nutritional routine on a weekly or bi-weekly basis.

The increased storage of water associated with glycogen storage may result in a body mass increase of as much as 3,5 kilograms (Saltin, 1978). This mass increase frequently causes a feeling of heaviness or bloatedness that could be detrimental to performance, particularly in the initial stages of an endurance event.

B. Lipids

In the past, the Hill-Meyerhof energy source theory was generally accepted. According to this theory, carbohydrates were the primary source of energy, while fat was only a reserve fuel utilized primarily when at rest and during recovery. However, as a result of experiments conducted by Christensen and Hansen (1939), it is now clearly established that fat is an important source of energy for the working muscle. The proportion of fat and carbohydrate utilization is determined by factors such as diet, exercise duration and exercise intensity in relation to the total work capacity (Åstrand and Rodahl, 1970).

Fat is an ideal energy store and, with an energy density of 9 kilocalories per gram, has more than twice the storage efficiency of carbohydrates (4 kcal/g). The total reserves of energy stored in extra- and intramuscular fat depots constitute about 70 000 kilocalories of energy which, if we accept an expenditure of 10 kilocalories per minute, will provide some 7 000 hours' supply. Unfortunately, most of this fat is stored outside the active muscles and, since the intramuscular lipids are soon exhausted, the subsequent fat utilization is determined by the rate of mobilisation from extramuscular stores and/or the transport across the membrane of the muscle cell. The maximum amount transported is probably 1 to 2 grams per minute (Williams and Sperryn, 1976).

Free fatty acids (FFA), which are released from the fat cells and transported by the blood to the muscles, are an important source of energy, especially during endurance activities. The oxidation of lipid fuels has been shown to inhibit glucose phosphorylation, glycolysis and the oxidation of glucose (Jooste, 1979). According to Costill (1979), fat metabolism has a glycogen sparing effect. Training has been found to increase substantially the relative role of fat as a fuel for muscular exercise. Trained muscles appear to develop an enhanced oxidative potential (Saltin, 1978).

The determination of plasma FFA requires about 5 millilitres of whole blood. In the present study, blood sampling was made under match conditions and, for obvious reasons, only small samples (4 ml) could be drawn. Hence FFA levels could not be determined.

C. Proteins

It is generally believed that when the caloric supply is adequate, protein is not used as fuel to any appreciable extent (Åstrand and Rodahl, 1970). However, a study by Felig et al (1970) has shown that alanine, which is the principal gluconeogenic amino acid, is released in significant amounts from exercising skeletal muscle and taken up by the liver where it is converted to glucose. These workers have postulated that alanine may be synthesised from pyruvate by transamination.
Saltin (1978) is of the opinion that the quantitative role of the alanine-glucose cycle during exercise is modest but that, in starvation or with a noncarbohydrate diet for an extended period, the conversion of alanine to glucose in the liver may play an important role in maintaining blood glucose levels. Costill (1979), on the other hand, believes that the alanine-glucose cycle constitutes a significant source of energy during long runs in excess of 42 kilometres or 3 hours.

2.8.2 Lactate

In exercise biochemistry, blood lactate[☆] is probably one of the most intensively studied constituents of the blood. Since the early work of Hill and Lupton (1923), it has been known that lactate increases during muscular work. The lactate diffuses into the blood and is then transported to the liver and kidneys where it constitutes substrate for gluconeogenesis by the Cori cycle (Mann and Garrett, 1978).

An increase in the normal blood lactate concentration (10 mg/100 ml blood) indicates the involvement of anaerobic processes and the accumulation of an oxygen debt. Blood lactate levels give a good indication of the degree of exhaustion in activities of high intensity and short duration.
Blood lactate concentrations may exceed 20 millimoles per litre in well-trained athletes competing in events of one to two minutes' duration

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[☆] Although the terms lactic acid and lactate are used interchangeably, the molecule in question is usually in an ionised or dissociated form and is correctly referred to as lactate. In its non-ionised form the molecule is correctly termed lactic acid. The same applies to pyruvic acid and pyruvate.

(Åstrand and Rodahl, 1970). However, Costill (1978) believes that there is little relationship between lactate levels and exhaustion in light to moderate physical exercise continued for long periods

According to Jooste <u>et al</u> (1977), the so-called lactate turning point (the point at which excess lactate is produced), which is expressed as a percentage of $\dot{V}O_2$ max, appears to be a far better measure of endurance fitness than the directly measured $\dot{V}O_2$ max.

According to Mann and Garrett (1978), the capacity to dispose of lactate generated by the working muscles is an important component of fitness. This lactate clearance may be limited by the transport of lactate across membranes or by some enzymatic step in gluconeogenesis. These workers are of the opinion that training and/or carbohydrate-free diets will augment both physical fitness and lactate clearance.

Training results in lower blood lactate levels for a standardised workload, but higher values are attained during maximal workload. Blood lactate levels at the end of various running races are inversely related to the distance covered (Costill, 1978). There are two main reasons for this. First, the longer the event, the smaller are both the percentage of $\dot{V}O_2$ max utilized and the subsequent production of lactate. Secondly, the lactate produced during the early stages of a race may be removed by the liver and kidneys during the race.

Pre- and post-match blood lactate concentrations were determined in this study by means of enzymatic spectrophotometric methods in order to assess the lactate response in professional and amateur tennis players. Post-match blood samples were taken within 5 minutes of completion of the match, as recommended by Åstrand and Rodahl (1970).

2.8.3 <u>Electrolytes</u>

Studies by Veller (1969), Rose <u>et al</u> (1970), Noakes and Carter (1976) and Costill (1976) have been conducted to determine electrolyte losses during physical exercise. Electrolytes may be lost in the sweat, urine or faeces. There are about 25 different electrolytes in the plasma, comprising a total amount of 900 milligrams per 100 millilitres (Åstrand and Rodahl, 1970). According to Saltin (1976), the difficulties encountered in sweat sampling make it impossible to determine the exact content of electrolytes in sweat. The ionic concentration of sweat is significantly affected by the sweat-rate and the degree of heat acclimatisation. The principal ions of sweat are those of the extracellular compartment, namely, sodium and chloride. In contrast to the relatively small potassium and magnesium losses in the sweat (approximately 1% of body stores), 6 to 8 per cent of the total exchangeable sodium and chloride ions may be lost through sweating (Costill, 1978). Studies by Rose et al (1970), Beller et al (1975) and Jooste et al (1977) have shown that physical exercise can bring about significant decreases in serum magnesium. Apparently this reduction [illegible] due to the loss of magnesium in the sweat and the possible redistribution of free diffusible magnesium from the plasma to other compartments such as the erythrocytes.

According to Costill (1978), exercise water loss through sweating results in only a relatively small electrolyte loss which probably has little effect on electrolyte function in the muscle. Even with successive days of intensive training, the electrolyte balance is maintained by a normal dietary intake of ions and compensatory renal function (Costill, 1979). In addition to the transcapillary flux of water from the plasma into the working musculature at the onset of strenuous physical exercise (Costill, 1979), dehydration results in a relative increase in plasma electrolytes, haematocrit, haemoglobin and erythrocyte count (Noakes and Carter, 1976).

In the present investigation, pre- and post-match sodium, chloride, magnesium and calcium concentrations were determined in order to assess electrolyte responses during strenuous competitive tennis playing.

CHAPTER 3

MATERIALS AND METHODS

CHAPTER 3

MATERIALS AND METHODS

Detailed descriptions of the methods, formulae and equipment used in the present investigation are presented in this chapter.

3.1 SUBJECTS

A total of 104 tennis players competing in the 1977 South African Open Tennis Championships in Johannesburg were studied. The subjects, representing nine nationalities, were divided into four groups on the basis of sex and playing proficiency:* a male professional group (n=34), a female professional group (n=22), a male amateur group (n=33) and a female amateur group (n=15). The professional subjects were highly proficient tennis performers whose primary financial income was derived from competitive participation. The amateur subjects comprised established players from all walks of life who were involved in part-time tennis competition.

Consideration was given to the possibility of grouping on the basis of the total number of hours played rather than on playing proficiency. The former method was not used for two reasons. First, the grouping of subjects in 'hours played' categories resulted in too few cases within each category for the purpose of reliable statistical analysis and interpretation. Secondly, 'hours played' categories provided a quantitative rather than a qualitative categorisation of playing activity. Although playing duration is obviously an important factor, it was the effect of playing intensity on the structure and function of the body that was of particular concern in this investigation. Grouping on the basis of playing proficiency ensured both a quantitative and a qualitative categorisation.

Previous experience has shown that data collection from tournament tennis players is a somewhat frustrating and harassing task (Copley, 1976a).

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* When the term male or female is used, it refers to both professional and amateur subjects unless otherwise specified. When the term professional or amateur is used, it refers to both male and female subjects unless otherwise specified.

Altruism seems to be suppressed when players are competing for large sums of money.

To ensure as large a sample as possible, it was decided to establish an advisory clinic as part of the study. All the competitors in the South African Open Tennis Championship received an introductory brochure (Appendix A), in which the professional services offered and the general objectives of the study were outlined. This approach had the desired effect and there was no shortage of enthusiastic subjects.

Although some verbal information and advice were provided during the eleven-day data collection period, it was decided that test results, detailed comments and advice would be forwarded to participants in written form. This decision necessitated far more work and time than originally expected. Three months later, the results with relevant comments and advice (Appendix B), and a brief explanation of the nature and relevance of each assessment (Appendix C), were mailed to the 104 subjects.

3.2 RESEARCH TEAM

The research team comprised the author and five assistants, who were all university graduates. The senior assistant who, with the author, was responsible for the anthropometric measurements, was an experienced scientist who had conducted numerous anthropometric and physiological studies.

Each of the other four assistants was responsible for the administration of one or two tests. They received special training from the author one month prior to the data collection. Particular care was taken to ensure that they were thoroughly acquainted with the necessary techniques and equipment. The necessity of accuracy was strongly emphasised. To minimise recording errors, the data recording assistant called back each item of measurement immediately after it had been announced by the tester. Once confirmed, the item was recorded on a specially prepared heavy-duty data card (Appendix D).

3.3 STUDY OBSERVATIONS

The measurements and tests were conducted in a well equipped mobile laboratory erected in the grounds of the Ellis Park tennis stadium in Johannesburg.

Ambient temperature (^{o}C), relative humidity (%) and barometric pressure (mmHg) were measured twice a day (am and pm) during the eleven-day period. Each day's morning and afternoon readings were averaged to provide daily values, which were then averaged to determine a mean value for the entire eleven-day period. A Darton mercury barometer was used to measure atmospheric pressure, which was required for oxygen and carbon dioxide volumes, and a hygrometer to determine ambient temperature and humidity which was required for sweat-rate evaluation.

The test battery comprised a total of 208 variables. These included questionnaire, anthropometric, somatotypological, physiological and biochemical variables which are diagrammatically illustrated in Figure (p. 96). Unfortunately, not all the subjects were willing to complete the entire battery of tests. This was due largely to the discomfort and/or long duration of some of the tests and measurements.

3.4 QUESTIONNAIRE

Before commencing the tests and measurements, the subjects were interviewed in order to obtain the following data:

3.4.1 Personal data

This included the recording of the subject's name, postal address, date of birth, nationality, race, sex, past and present occupations, and physical leisure-time activities. The subject's age on 1st December 1977 was determined and recorded to two decimal places.

3.4.2 Tennis data

This comprised the determination of handedness, highest level of representation (club, provincial, national or international), total number of years played, number of hours played per week, number of weeks played per year and regular participation in a specialised training or conditioning programme, past and present.

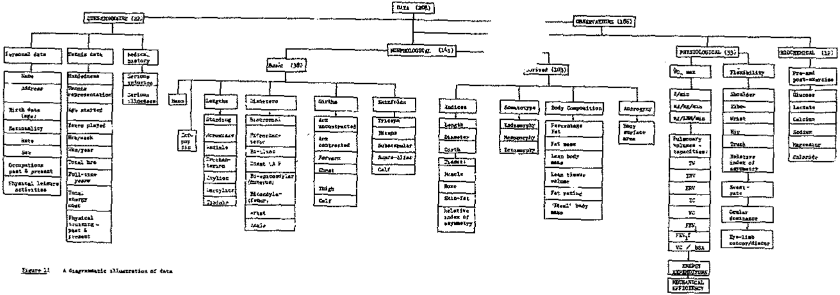

Figure 11 A diagrammatic illustration of data

A number of simple formulae were utilized to derive the following additional information:

A. Age at which regular playing was first commenced was calculated from the formula:

$$\text{Age started} = \text{age} - \text{years played}$$

B. Total number of hours played was determined from the formula:

$$\text{Total hrs} = \text{hrs/wk} \times \text{years} \times \text{wks/yr}$$

C. Number of full-time years played (comprising a normal eight-hour day, five days per week and twenty-eight days' annual leave) was calculated, from the following formula:

$$\text{Full-time years} = \frac{\frac{\text{Total hrs}}{8}}{233^{\star}}$$

D. Total energy expended in kJ was determined from the formula:

$$\text{Total energy} = \text{Total hrs} \times \text{Energy cost} \times 60$$

where energy cost = the measured energy cost in kJ/min

3.4.3 Medical history

This involved the establishment of whether the subject had sustained any serious injuries (e.g. dislocations, fractures, hernias etc.), had suffered from any serious illnesses or diseases (.e.g. rheumatic fever, hypertension, diabetes etc.), or had undergone major surgery.

Care was taken to ensure that all questions were clearly understood by the subjects.

3.5 MORPHOLOGICAL OBSERVATIONS

All the anthropometric measurements were taken by the author and an experienced senior assistant. Standardised calibrated anthropometric equipment was used. Since the mobile laboratory was equipped to handle two subjects simultaneously, the observers measured an equal number of subjects. Measurements were taken on the right-hand side of the body, as recommended by the International Committee for the Standardization

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★365 days - [52 wks x 2 (Sat & Sun)] - 28 days of Physical Fitness Tests (Larson, 1974). Each measurement was taken twice by the same observer and when the two readings differed by more than three millimetres in the case of stature, diameter and girth measurements, and by more than 0,4 millimetres in the case of skinfolds, a third reading was taken. The two nearest readings were then averaged. When the observations did not differ by more than the stipulated values, the average of the two readings was recorded. The two observers conducted a number of trial measurements on the same subjects prior to the data collection and the results indicated a high degree of uniformity.

3.5.1 Basic anthropometric measurements

Thirty-eight basic anthropometric measurements, recommended by the International Committee for the Standardization of Physical Fitness Tests (Larson, 1974), were taken.

A. Body mass was measured, with a Seca beam balance scale and recorded to the nearest 0,5 kilogram. The males were measured in their underpants and the females in their bra's and pants.

Since body mass was measured to the nearest 0,5 kilogram, it was not deemed necessary to make a small correction for the light underclothing in order to obtain the nude mass of the subjects.

B. Height measurements

Seven standing height or length measurements were taken and recorded to the nearest millimetre.

I. Stature, or the distance from the soles of the feet to the highest point on the head in the median sagittal plane, was measured with a portable Harpenden stadiometer.

Subjects were measured while standing barefoot, with the heels (in contact with each other), buttocks, upper back and rear of the head in contact with the vertical section of the stadiometer. The upper limbs were pendent with the palms of the hands turned inwards and the extended fingers pointing downwards. The shoulders were relaxed and the head was held in the Frankfurt horizontal with the line of sight horizontal. Before the observer took the measurement, the subject was instructed to inhale deeply and stretch upward to the fullest extent. This procedure was adopted to eliminate the 'diurnal variation' (Carter, 1975).

The correct body position for stature was also used for the other height measurements, taken with a Harpenden anthropometer from the soles of the feet to the various standardised anatomical points.

The height measurements, as defined by De Villiers and Tobias (1974) but measured on the right-hand side, included the following:

II. Acromiale height or height of the right acromiale above the ground.

III. Radiale height or height of the right radiale above the ground.

IV. Stylion height or height of the right stylion above the ground.

V. Dactylion height or height of the midpoint of the tip of the middle finger above the ground.

VI. Trochanterion height or height of the right trochanterion above the ground.

VII. Tibiale height or height of the right tibiale above the ground.

During the measurement of the acromiale, radiale, stylion and dactylion heights, particular care was taken to ensure that the shoulders were not tilted.

C. Diameters

During the taking of all these measurements, firm pressure was applied and the readings were taken with the measuring instrument in position to avoid altering the position of the sliding arm of the anthropometer.

The following diameters or widths as defined by De Villiers and Tobias (1974), were determined with a Harpenden anthropometer and recorded to the nearest millimetre:

I. Biacromial diameter, which is the maximum breadth between the right and left acromialia, was measured with the subject standing and the shoulders braced. The measurement was taken from behind, the points of the anthropometer being brought down on to the acromiale points from above.

II. Bitrochanteric diameter, which is the distance between the most lateral projections of the greater trochanters, was measured from behind with the subject standing and heels together. Moderate to strong pressure was required for this measurement to overcome the thickness of the cutaneous, adipose, fascial and muscular tissues.

III. Bicristal or bi-iliac diameter, or the maximum breadth between the right and left iliocristalia, was measured from behind with the subject standing. As in the case of the bitrochanteric diameter, moderate to strong pressure was necessary for the measurement of this body diameter.

IV. Anterior-posterior chest diameter, or chest depth, was measured at the line of the upper border of the 4th chondrosternal articulation at the end of a normal expiration. The anthropometer was fitted with curved arms and the measurement was taken with the subject standing, upper limbs hanging loosely at the sides of the body.

The following diameters were measured on both sides of the body and recorded to the nearest millimetre, with a stainless steel Harpenden caliper.

V. Bi-epicondylar diameter (humerus), which is the distance between the outermost parts of the medial and lateral epicondyles of the humerus, was measured with the elbow flexed at right angles.

VI. Bicondylar diameter (femur), or the distance between the lateral and medial femoral condyles, was measured with the subject seated and the knee flexed at right angles.

VII. Wrist diameter, which is the distance between the styloid processes of the radius and ulna, was measured with the upper limb hanging loosely at the side.

VIII. Ankle diameter, or the distance between the malleoli of the tibia and fibula, was measured with the subject seated.

D. Girth measurements

A flexible anthropometric steel measuring tape was used for all the girth or circumferential measurements, taken on both sides of the body and recorded to the nearest millimetre. Care was taken to ensure that the tape made firm and continuous contact but, at the same time, did not deform the contours of the skin.

I. Uncontracted arm girth was taken with the upper limb hanging relaxed at the side of the body. The girth was measured in a plane at right angles to the long axis of the arm, halfway between the acromion and olecranon.

II. Contracted arm girth, or the maximum circumference of the arm with the biceps fully contracted, was measured with the subject's upper limb abducted, the fist clenched, the forearm supinated and the limb fully flexed at the elbow. This measurement also was taken at right angles to the long axis of the arm.

III. Forearm girth was measured at the maximum circumference of the forearm with the upper limb hanging loosely at the side.

IV. Thigh girth was taken just below the gluteal fold with the subject standing erect, legs slightly apart. Only the right thigh girth was measured.

V. Calf girth was measured at the greatest circumference of the calf with the subject standing erect, legs slightly apart. Care was taken to ensure that the subject's weight was equally distributed through both lower limbs.

VI. Chest girth was measured at the level of the 4th chondrosternal articulation and below the inferior angle of the scapulae, at the end of a normal expiration. The subject was in a standing position. Since chest girth is influenced by breast size it was not measured in the female subjects.

E. Skinfold measurements

These were taken with a Harpenden skinfold caliper with a jaw pressure of 10 grams per square millimetre. All the skinfolds were taken on the right side of the body in a vertical plane, with the exception of the subscapular and supra-iliac skinfolds which were taken in oblique planes (Carter, 1975).

A fold of skin was picked up between the thumb and index finger and the caliper jaws were placed one centimetre from the fingers at a depth approximately equal to the thickness of the fold. The skinfold was held throughout the measurement and, when the indicator of the caliper had become steady, a reading to the nearest 0,1 millimetre was taken (De Villiers and Tobias, 1974).

The following skinfolds were taken:

I. <u>Triceps</u> was measured on the posterior surface of the arm midway between the acromion and olecranon with the upper limb pendent. This skinfold was taken also on the left side.

II. <u>Biceps</u> was measured on the anterior surface of the arm at the same level as the triceps skinfold, with the upper limb pendent. This measurement was taken also on the left side.

III. <u>Subscapular</u> was taken below the inferior angle of the scapula with the upper limbs pendent. The fold was measured in an oblique plane ascending medially at an angle of approximately 45^{o} to the horizontal.

IV. <u>Supra-iliac</u> skinfold was measured just above the anterior superior iliac spine with the fold oblique, extending forwards and slightly downwards (Carter, 1975).

Although the position of this skinfold appears to have been standardised, the plane in which the fold is elevated has not been and it can be <u>vertical</u> (De Villiers and Tobias, 1974; Sloan and De V. Weir, 1970; Wilmore <u>et al.</u>, 1970), <u>oblique</u> (Sloan, 1967; Carter, 1975) or <u>horizontal</u> (Tanner, 1964; Van der Merwe and Daehne, 1975).

A number of vertical supra-iliac skinfolds were taken and compared with those taken in an oblique plane. Differences as large as six millimetres were observed. Skinfolds taken obliquely were consistently smaller than skinfolds taken vertically at exactly the same sites.

The Langer's stress-lines (cleavage lines), which are brought about by the orientation of the subcutaneous fibrous connective tissue bundles, run forwards and downwards at approximately 45^0 to the horizontal at the supra-iliac site.

Any skinfold which is not elevated along the line of Langer's stress-lines will normally have reduced compressibility because of increased cutaneous and subcutaneous tissue tension. This should be borne in mind when the supra-iliac skinfold is used for the assessment of the endomorphic somatotype component (Heath-Carter) and body composition (percentage body fat).

V. Calf skinfold was measured on the medial side of the calf at the level of the greatest circumference, with the subject seated, the foot placed on the ground and the knee flexed at right angles. The left calf skinfold also was measured.

3.5.2 Interpupillary distance

This linear measurement, which is not frequently included in anthropometric studies, refers to the distance between the two eyes. A rigid steel ruler was used to measure the distance from the centre of one pupil to the centre of the other. The subject was instructed to look directly ahead with the head held in the Frankfurt horizontal. The ruler was placed on the bridge of the nose and the zero point aligned at right angles to the centre of the right pupil. The interpupillary distance [illegible] read off, to the nearest millimetre, at a point on the ruler which [illegible] perpendicular to the centre of the left pupil. Care was taken to ensure that the observer avoided the parallax error and that the subject did not squint during the measurement.

The measurement could be determined with a high degree of reliability, since differences between two or more observations on the same subject were very rarely greater than one millimetre.

3.5.3 Derived morphological measurements

The basic anthropometric measurements were substituted in specially designed formulae to obtain 103 derived morphological measurements. All the formulae were programmed with a Hewlett Packard (HP - 67) fully programmable calculator.

A. Limb and segment lengths, with the exception of the lower limb, were *calculated by subtraction and expressed* as percentages of stature.

I. Upper limb length = Acromiale Ht - Dactylion Ht

II. Arm length = Acromiale Ht - Radiale Ht

III. Forearm length = Radiale Ht - Stylion Ht

IV. Lower limb length = Trochanterion Ht

V. Thigh length = Trochanterion Ht - Tibiale Ht

Lower limb length, which is difficult to measure because of the inaccessibility of the hip-joint from the surfaces, can also be estimated by means of the formula:

Lower limb length = Stature - Sitting height.

B. *Length indices*

Each of the following lengths:

I. *upper limb*

II. arm

III. forearm

IV. lower limb

V. thigh

was expressed as a percentage of stature by the formula:

$$\frac{L}{S} \cdot 100$$

where L = *length (cm)*

S = stature (cm)

VI. *arm-forearm* length index

C. Diameter indices

I. Biacromial diameter as a percentage of stature.

II. Bicristal diameter as a percentage of stature.

III. Anterior-posterior chest diameter as a percentage of stature.

IV. Bicristal diameter as a percentage of biacromial diameter.

V. Bi-epicondylar diameter (humerus) as a percentage of upper limb length.

VI. Bicondylar diameter (femur) as a percentage of lower limb length.

VII. Bicondylar diameter (femur) / Bi-epicondylar diameter (humerus) index.

D. Girth indices

I. Chest girth as a percentage of stature.

II. Forearm girth as a percentage of upper limb length.

III. Thigh girth as a percentage of lower limb length.

IV. Calf girth as a percentage of lower limb length.

E. Body surface area

Predicted nude body surface area was determined from the Du Bois height-weight formula (Du Bois and Du Bois, 1916).

The use of the formula is standard practice in Physiology, Ergonomics and Clinical Medicine (Mitchell *et al.*, 1971).

$$BSA = 71,84 \; (M^{0,425} \times S^{0,725})$$

where BSA = nude body surface area (cm^2)
M = body mass (kg)
S = stature (cm)

Body surface area was expressed in square metres (÷ 10 000).

F. Body composition

Lean volume, bone, muscle and skin-fat indices, percentage body fat, fat mass, lean body mass and 'ideal' body mass were assessed by means of basic anthropometric measurements and specially designed formulae.

I. Lean volume and tissue index errors and corrections

The formulae of Wartenweiler et al (1974), some of which were found to be incorrect and were subsequently corrected, were utilized in this study for the calculation of lean volume and tissue indices. The errors in and corrections of the formulae and terminology of Wartenweiler et al (1974) have been brought to their attention and are discussed below.

a. Tissue surface area

The formula used by Wartenweiler et al (1974) for the calculation of tissue surface area is given as:

$$A = \frac{d^2}{4} \cdot \pi$$

where A = tissue surface area
d = limb or segment diameter

This formula (πr^2) is, of course, the formula used to calculate the cross-sectional area and not the surface area of a limb-segment, of which the diameter has been measured, it being assumed that the cross-section of the limb-segment is circular.

The correct formula for the calculation of the surface area of a regular cylinder is:

$$S.A. = 2\pi r \times L + 2\pi r^2$$

where $S.A.$ = surface area (cm^2)
L = length (cm)
r = radius $\left(\frac{d}{2}\right)$
d = diameter (cm)

b. Lean diameter (muscle plus bone)

Wartenweiler et al (1974) use the following formula for the calculation of the lean diameter:

$$d_{MB} = d - (\text{SF biceps} + \text{SF triceps})$$

where d_{MB} = lean diameter (muscle plus bone)

d = diameter of the arm

SF biceps = biceps skinfold

SF triceps = triceps skinfold

Since a skinfold measurement comprises two layers or thicknesses of skin and fat, it is evident that in this formula four thicknesses are subtracted from the diameter of the limb, whereas only two thicknesses participate in the composition of a limb diameter. The sum of the two skinfold measurements should therefore be halved and the formula expressed as:

$$d_{MB} = d - \frac{(\text{SF biceps} + \text{SF triceps})}{2}$$

c. <u>Muscle area</u>

The following formula for the calculation of muscle area is presented by Wartenweiler <u>et al</u> (1974):

$$\text{Muscle area (surface)} = \left[d_{MB}^2 - d_B^2 \right] \cdot \frac{\pi}{4}$$

where d_{MB} = lean diameter

d_B = measured epiphysial diameter (epicondylar)

This formula does not allow for correction of the measured epiphysial diameter to the required diaphysial diameter.

The formula should be:

$$\text{Muscle area (cross-sectional)} = \left[d_{MB}^2 - \left(\frac{d_B^2}{(3{,}0)^2} \right) \right] \cdot \frac{\pi}{4}$$

where d_{MB} = lean diameter = $d - \frac{(\text{biceps} + \text{triceps})}{2}$

d_B = measured epiphysial diameter (epicondylar)

3,0 = constant designating the relation of the epiphysial diameter (epicondylar) to the diaphysial (shaft) diameter [*]

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[*] Wartenweiler <u>et al</u> (1974) found a value of 3,1 for the humerus of the male and propose that a value of 3,0 be uniformly used for the arm, forearm, thigh and calf.

d. Units of measure

Wartenweiler et al (1974) express tissue area in square centimetres (cm^2) and tissue volume in cubic decimetres (dm^3) and make no mention of the fact that tissue area is converted from square centimetres (cm^2) to square decimetres (dm^2) and that the upper limb length is expressed in decimetres (dm). These workers also do not point out that the skinfolds in the lean diameter formula are expressed in centimetres. *These various unnecessary conversions appear to be of* no practical value and are apt to confuse.

e. Terminology

The term 'specific weight of tissue' is used by Wartenweiler et al (1974) instead of the correct term, relative density of tissue.

II. Lean volume

This refers to the volume of muscle and bone tissue. The lean volume of both the upper and lower limbs and of both arms and forearms were determined by means of the techniques described by Wartenweiler et al (1974). A specially prepared Fortran computer programme was used for the calculation of lean volume.

There was a limited amount of time available for the large number of measurements and tests and as a result limb and segment lengths were measured only *on the right-hand side of the body. In order to compare* dominant and non-dominant sides of the body (right and left) in terms of lean volumes and tissue indices, the author was obliged to assume that the left side lengths were equal to those on the right. It was felt that this assumption would have little effect on the accuracy of prediction because of the relatively small limb and segment length differences between right and left sides of the body (Wolański, 1972).

Limb and segment diameters, areas and lean volumes were calculated by means of the following series of formulae:

a. Lean limb and segment diameters:

i) Upper limb and arm

$$d_{MB} = \frac{c}{\pi} - \left[\frac{\left(\frac{BS + TS}{10} \right)}{2} \right]$$

where d_{MB} = lean or corrected diameter (cm)

c = uncontracted arm circumference (cm)

BS = biceps skinfold (mm)

TS = triceps skinfold (mm)

ii) <u>Lower limb and forearm</u>

$$d_{MB} = \frac{c}{\pi} - \left(\frac{S}{10}\right)$$

where d_{MB} = lean or corrected diameter (cm)

c = circumference (cm)

S = skinfold (mm)

For the calculation of lower limb diameter, the average of the thigh and calf circumferences was used. Since only the right thigh circumference was measured, the average of the right thigh circumference and the left calf circumference was used for the left lower limb circumference. The calf skinfold represented the lower limb skinfold.

For the calculation of the forearm diameter, the forearm circumference was used. Since the forearm skinfold was not measured and is usually thicker than the biceps skinfold and thinner than the triceps skinfold (Ward and Fleming, 1964; Desiprès et al., 1978b), it was decided to use for each subject, the average of the biceps and triceps skinfolds for the calculation of lean forearm diameter.

b. <u>Lean limb and segment areas</u>

The formula used for the upper and lower limb, arm and forearm was:

$$A_{MB} = \frac{(d_{MB})^2}{4} \cdot \pi$$

where A_{MB} = lean cross-sectional area (cm^2)

d_{MB} = lean or corrected d[illegible] (cm)

c. <u>Limb and segment lean volumes</u>

The formula used for the upper an[illegible] limb, arm and forearm was:

$$V_{MB} = A_{MB} \times LL$$

Where V_{MB} = lean volume (cm^3)
A_{MB} = lean cross-sectional area (cm^2)
LL = limb or segment length (cm)

These formulae are based on the assumptions that the cross sections of the limb-segment are circular, that the limb-segments are cylindrical without tapering and that half of the summed respective skinfolds represents the average skin-fat layer in each limb-segment (Wartenweiler et al., 1974).

III. Tissue indices

The bone, muscle and skin-fat indices of the upper and lower limbs (right and left) and of the arms and forearms (right and left) were determined by means of the methods described by Wartenweiler et al (1974). The tissue index was determined by expressing tissue mass as a percentage of body mass. The determination of tissue mass necessitated the calculation of tissue area and volume. A specially prepared Fortran programme was utilized for calculation of the tissue indices.

a. Bone index was calculated by the formulae:

i) Bone area

$$A_B = \frac{d^2}{4(\alpha)^2} \cdot \pi$$

where A_B = cross-sectional bone area (cm^2)
d = bone diameter (cm)
α = 3,0

The bi-epicondylar diameter (humerus) was used as the bone diameter in the calculation of upper limb and arm bone areas. Wrist diameter was used for the forearm and the average of the bicondylar (femur) and ankle diameters was used for the lower limb bone diameter.

ii) Bone volume

$$V_B = A_B \times LL$$

where V_B = bone volume (cm^3)
A_B = cross-sectional bone area (cm^2)
LL = limb or segment length (cm)

iii) <u>Bone mass</u>

$$M_B = V_B \times 1,4$$

where M_B = bone mass (g)
V_B = bone volume (cm^3)
1,4 = relative density of bone tissue

iv) <u>Bone index</u>

$$BI = \frac{M_B}{BM} \cdot 100$$

where BI = bone index
M_B = bone mass (kg)
BM = body mass (kg)

b. <u>Muscle index</u>

i) <u>Muscle volume</u>

Since the calculation of lean and bone volume was included in the Fortran programme, muscle volume was determined by subtracting bone volume from lean volume.

$$V_M = V_{MB} - V_B$$

where V = muscle volume (cm^3)
V_{ML} = lean volume (cm^3)
V_B = bone volume (cm^3)

ii) <u>Muscle mass</u>

$$M_M = V_M \times 1$$

where M_M = muscle mass (g)
V_M = muscle volume (cm^3
1 = relative density of muscle tissue

iii) <u>Muscle index</u>

$$MI = \frac{M_M}{BM} \cdot 100$$

where MI = muscle index
M_M = muscle mass (kg)
BM = body mass (kg)

c. Skin-fat index

i) Skin-fat volume

Since the calculation of lean, whole limb and whole segment volumes was included in the Fortran programme, skin-fat volume was determined by subtracting the lean volume from the whole limb or segment volume.

$$V_{SF} = V_{WL} - V_{MB}$$

where V_{SF} = skin-fat volume (cm^3)

V_{MB} = lean volume (cm^3)

V_{WL} = whole limb or segment volume (cm^3)

The whole limb or segment volume was calculated from the formulae of diameter $(\frac{c}{\pi})$, area $(\frac{d^2}{4} \cdot \pi)$ and volume $(A \times LL)$ (Wartenweiler et al. 1974).

ii) Skin-fat mass

$$M_{SF} = V_{SF} \times 0{,}9$$

where M_{SF} = skin-fat mass (g)

V_{SF} = skin-fat volume (cm^3)

$0{,}9$ = relative density of fat tissue

iii) Skin-fat index

$$SFI = \frac{M_{SF}}{BM} \cdot 100$$

where SFI = skin-fat index

M_{SF} = skin-fat mass (kg)

BM = body mass (kg)

All tissue masses in grams were converted to kilograms by dividing by 1 000.

d. Tissue area as a percentage of body surface area

An alternative method of calculating the tissue index was devised and utilized in the present study. Cross-sectional tissue area was expressed as a percentage of predicted nude body surface area. The latter was determined by means of the Du Bois height-weight formula (Du Bois and Du Bois, 1916).

The bone, muscle and skin-fat indices of both upper limbs were determined by means of this alternative method.

i) Bone index (BSA)

$$A_B = \frac{d^2}{4\,(\alpha)^2} \cdot \pi$$

where A_B = cross-sectional bone area (cm^2)
d = bi-epicondylar diameter (humerus)
α = 3,0

$$\text{BI (BSA)} = \frac{A_B}{\text{BSA}} \cdot 100$$

where BI (BSA) = bone index (body surface area)
A_B = bone area (m^2)
BSA = body surface area (m^2)

ii) Muscle index (BSA)

$$A_M = \left[d_{MB}^2 - \left(\frac{d_B^2}{(3,0)^2} \right) \right] \cdot \frac{\pi}{4}$$

where A_M = cross-sectional muscle area (cm^2)
d_{MB} = lean diameter (muscle + bone) (cm)
d_B = bi-epicondylar diameter (humerus) (cm)

$$\text{MI (BSA)} = \frac{A_M}{\text{BSA}} \cdot 100$$

where MI (BSA) = muscle index (body surface area)
A_M = muscle area (m^2)
BSA = body surface area (m^2)

iii) Skin-fat index (BSA)

$$A_{SF} = \frac{(d^2 - c^2_{MB})}{4} \cdot \pi$$

where A_{SF} = cross-sectional skin-fat area (cm^2)
d = diameter of the arm (cm)
d_{MB} = lean diameter (muscle + bone) (cm)

$$SFI\ (BSA) = \frac{A_{SF}}{BSA} \cdot 100$$

where SFI (BSA) = skin-fat index (body surface area)
A_{SF} = skin-fat area (m^2)
BSA = *body surface area* (m^2)

All the tissue areas expressed in square centimetres were divided by 10 000 for conversion to square metres.

IV. Adipose tissue

a. Percentage or relative body fat, which refers to the total fat mass as a percentage of body mass, was determined by means of the technique employed by Durnin and Rahaman (1967).

Four skinfolds, the triceps, biceps, subcapular and supra-iliac skinfolds, were summed and converted into a logarithmic value which was then substituted in the following regression equations:

Male $D = 1{,}1610 - (0{,}0632S)$ $S_E = 0{,}0069$

Female $D = 1{,}1581 - (0{,}0720S)$ $S_E = 0{,}0096$

where D = predicted body density (g/ml)
S = log (10^x) of the sum of the 4 skinfolds
S_E = standard error of the estimate

Percentage body fat was then determined by the formula of Brozek et al (1963). This formula has been recommended for its uniformity by Novak (1974a).

$$F = 100\ (\frac{4{,}570}{D} - 4{,}142)$$

where F = body fat as a percentage of body mass
D = predicted density (g/ml)

b. Fat mass or absolute body fat was calculated by the formula:

$$FM = \frac{F \times BM}{100}$$

where FM = fat mass (kg)
F = percentage body fat (predicted)
BM = body mass (kg)

V. Lean body mass

Lean body or fat-free mass was calculated by the formula:

$$LBM = BM - FM$$

where LBM = lean body mass (kg)
BM = body mass (kg)
FM = fat mass (kg) (predicted)

VI. 'Ideal' body mass

Standard height-weight tables are generally used to predict the 'normal' or 'average' weight from height. Although these tables are of some practical value, they do have a number of serious shortcomings. The fact that body composition or the gross proportion of bone, muscle and fat is completely neglected is probably one of the most serious faults (Clarke H.H., 1976).

The term 'ideal' weight, defined as the weight associated with the most favourable mortality, is often used instead of average or standard weight, which implies normality and biological desirability (Keys and Brozek, 1953).

The terms 'ideal' body mass and 'ideal' percentage fat are used in this study and they refer to the most favourable mass and percentage fat for a particular type of physical activity or sport, in this case tennis.

An alternative practical method of predicting 'ideal' body mass which considers body composition and is therefore believed to be superior to the standard height-weight method, was devised by the present writer and used in this study after consultation with Professor L.P. Novak. The method involved the following procedures:

a. The determination of percentage body fat, fat mass and lean body mass according to the methods and formulae previously presented in this study.

b. The determination of 'ideal' fat mass (IFM) by the formula:

$$IFM = \frac{I\%BF}{100} \cdot BM$$

where IFM = 'ideal' fat mass (kg)
I%BF = 'ideal' percentage body fat (9,5% males, 17,5% females)
BM = body mass (kg)

Percentage body fat norms for a large variety of physical activities and sports, have been established by numerous investigators (Sloan, 1967; Novak *et al.*, 1968; Girandola and Katch, 1973; Behnke and Wilmore, 1974; Van der Merwe and Jaehne, 1975; Copley, 1976a; Lubbert 1978). On the basis of these norms a fairly objective selection of 'ideal' percentage body fat can be made for an individual. In the case of a sedentary adult male for example, a value of 16,5% would be appropriate since values range from 15% to 18%.

From a study conducted on international tennis players (Copley, 1976a) the 'ideal' percentage body fat values selected for the male and female were 9,5% and 17,5% respectively.

c. The calculation of 'ideal' body mass by means of the formula:

$$IBM = LBM + IFM$$

where IBM = 'ideal' body mass (kg)
LBM = lean body mass (kg)
IFM = 'ideal' fat mass (kg)

A fat rating which provided information concerning the amount of fat to be lost (designated by a negative value) or gained (designated by a positive value) in order to attain the 'ideal' body mass, was calculated by means of the formula:

$$FR = IFM - FM$$

where FR = fat rating (kg)
IFM = 'ideal' fat mass (kg)
FM = fat mass (kg)

The 'ideal' body mass and fat rating of each subject were calculated by means of a specially prepared Hewlett Packard programme.

G. Androgyny

The degree of masculinity in physique was estimated by means of the androgyny index of Tanner (1951).

$$AI = (3 \times BIACROM) - BICRIST$$

where AI = androgyny index
BIACROM = biacromial diameter (cm)
BICRIST = bicristal diameter (cm)

This index is based on the relationship of shoulder and hip width and was calculated for both female and male subjects.

In a study by Malina and Zavaleta (1976), [illegible] letic females and males had androgyny indices ranging from [illegible] nd 84 to 96 respectively.

H. Relative index of tissue asymmetry (RIA)

Wolański (1972) devised the following formula for the calculation of the relative index of asymmetry:

$$RIA = \frac{2\,(\bar{X}_R - \bar{X}_L)}{\bar{X}_R + \bar{X}_L} \cdot 100$$

where $\bar{X}_R$ = arithmetic mean of observation on the right side
$\bar{X}_L$ = arithmetic mean of observation on the left side

This formula expresses the degree of asymmetry between right and left sides of the body and direct comparisons can be made irrespective of the values being investigated.

A slight modification to this formula was made for the calculation of the relative index of tissue asymmetry.

$$RIA\ (T) = \frac{2\,(X_D - X_{ND})}{X_D + X_{ND}} \cdot 100$$

where RIA(T) = relative index of tissue asymmetry
X_D = variable on dominant side
X_{ND} = variable on non-dominant side

Dominance was determined by handedness. The right-hand side was taken as dominant in the case of right-handed players and the left-hand side as dominant in the case of left-handed players.

The RIA's of all the lean volumes and bone, muscle and skin-fat indices were determined for each subject. A positive RIA value indicated that the value on the dominant side was greater than that on the non-dominant side (D > ND). A negative RIA value indicated that the value on the non-dominant side was greater than that on the dominant side (ND > D).

I. Somatotype

The somatotype expresses physique or body build in relation to its shape and proportion. Carter (1975) defines the somatotype as a description of present morphological conformation. It is expressed in a three-numeral rating, consisting of three sequential numerals which are always recorded in the same order. Each numeral provides an evaluation of one of the three primary components of physique, which describe individual variations in human morphology and composition.

Endomorphy, the first somatotype component, refers to the relative fatness in the physique.

Mesomorphy, the second component, refers in essence to relative musculoskeletal development per unit of stature.

Ectomorphy, the third component, refers to relative leanness or linearity in the physique.

The anthropometric somatotyping method of Heath and Carter (1967) was used in the present study.

I. Anthropometric measurements

Ten measurements were required in order to determine the three somatotype components. The techniques and equipment used to take these measurements have been described in a previous section (3.5.1). The measurements were:

Body mass (kg)
Stature (cm)
Skinfolds (mm): triceps, subscapular, supra-iliac and calf skinfolds measured on the right-hand side
Bone diameters (cm): bi-epicondylar (humerus) and bicondylar (femur)
Girths (cm): calf and contracted arm

The diameters and girths were measured on both the right- and left-hand sides, but in each instance only the greater of the two measures was used (Carter, 1975).

II. Somatotype calculations

Endomorphy was determined from the sum of the triceps, subscapular and supra-iliac skinfolds. Mesomorphy was derived from the deviations of bone diameters and fat-corrected calf and contracted arm girths from designated values for the stature of the subject. Ectomorphy was obtained from a height - weight ratio (reciprocal of the ponderal index) where stature was divided by the cube root of mass.

The three component ratings constituting the Heath-Carter anthropometric somatotype were calculated by means of computer programme recommended by Carter (1975). The programme included a stature corrected endomorphic rating, but since none of the subjects was a child this was not used.

Somatotype frequencies were also plotted on somatocharts. The location of a somatotype in terms of X and Y co-ordinates on the somatochart is referred to as its somatoplot.

The somatotype dispersion distance and the somatotype dispersion index also were determined. These statistics were developed by

Ross et al (1974) and are analogous to individual and mean values in ordinary parametric statistics. They provide a more sophisticated means of analyzing somatotype data.

The somatotype dispersion distance (SDD) is the distance on the somatochart between each subject's somatoplot and the mean sample somatoplot ($\bar{S}$).

The somatotype dispersion index (SDI) is the mean somatotype dispersion distance of all the somatoplots in a sample.

Until quite recently somatotype comparisons were limited to comparisons of the individual components. While the magnitude of the individual components is of obvious importance, treatment of the components as independent variables destroys the concept of relative dominance. By means of the formulae of Ross et al (1974), somatotype differences or differences among the mean somatoplots of the four groups were determined. The t-test was utilized to compare the individual somatotype components of the groups.

3.6 PHYSIOLOGICAL OBSERVATIONS

Each member of the research team was responsible for a specific physiological assessment. All equipment was regularly calibrated and particular care was taken to ensure accuracy and to eliminate measurement and recording errors.

3.6.1 Maximal aerobic power ($\dot{V}O_2$ max)

Maximal aerobic power, or $\dot{V}O_2$ max, refers to the body's ability to utilize the greatest amount of oxygen during strenuous exercise. It was indirectly measured and assessed by means of the adjusted Åstrand-Ryhming nomogram which is shown in Figure 2 (p.121).

A frictionally braked Monark cycle ergometer was used to provide a six-minute workload. The pedal frequency was standardised at 60 revolutions per minute.

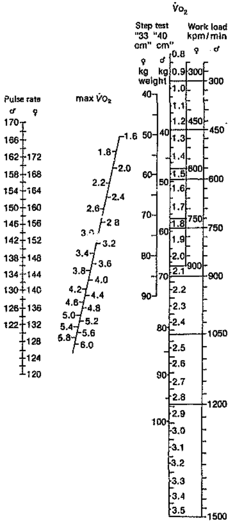

Figure 2: Adjusted Åstrand-Ryhming Nomogram
From Åstrand and Rodahl (1970)

The accuracy of predictions of $\dot{V}O_2$ max from the nomogram has been shown to depend upon the workload used, within the heart-rate range of 120 to 170 bpm (Åstrand and Rodahl, 1970). The workload (450 to 1200 kgm) was selected to induce a steady state condition in which a heart rate of between 160 and 170 beats per minute was attained. Unfortunately, not all the subjects attained heart rates within this range. A Cardionics cardiometer was used for the continuous monitoring of heart rate.

When a steady state condition was not reached within the six-minute period, the latter was prolonged for a further one or more minutes.

The saddle and handlebar heights of the cycle ergometer were adjusted to suit each subject, thus ensuring uniform mechanical efficiency.

Care was taken to ensure that the subjects had neither eaten nor participated in any form of strenuous physical activity during the two hours before testing.

Workload and oxygen consumption (ℓ/min)* were separately utilized with the attained heart rate to determine the predicted $\dot{V}O_2$ max (ℓ/min) from the nomogram. When necessary, the predicted values were corrected for age (Åstrand I., 1960). The correction factors for the respective age groups are shown in Table I.

Table I: Age correction factors for predicting maximal aerobic power

Age (yrs)	Age correction factor
15 - 24	1,10
25 - 34	1,00
35 - 39	0,87
40 - 44	0,83
45 - 49	0,78
50 - 54	0,75
55 - 59	0,71
60 - 64	0,68
65 +	0,65

From Åstrand and Rodahl (1970)

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* The techniques used to measure oxygen consumption ($\dot{V}O_2$) are described in detail in the following section (3.6.2).

The corrected absolute value was converted to millilitres and divided by the subject's body mass. This step was necessary in order to express maximal aerobic power in relative units of millilitres of oxygen per kilogram of body mass per minute (ml/kg/min). It was expressed also in millilitres of oxygen per kilogram of LBM per minute (ml/kg LBM/min).

3.6.2 Mechanical efficiency

The efficiency of human movement may be gauged by the calculating of mechanical efficiency.

$$\text{M.E. (Gross)} = \frac{\text{total external work output}}{\text{total energy input}} \cdot 100$$

At present the mechanical efficiency of tennis playing cannot be determined because there is no means of accurately measuring the total external work output.

Net mechanical efficiency is a more precise determination since a correction is made for the resting energy cost. Since exercising $\dot{V}O_2$ was determined during the Åstrand-Ryhming submaximal cycle ergometer test, only resting $\dot{V}O_2$ was required for the calculation of net mechanical efficiency. The formula used was:

$$\text{ME} = \frac{(\text{TEWO} \times 0{,}002344)}{P\dot{V}O_2 - R\dot{V}O_2} \cdot 100$$

where ME = net mechanical efficiency (%)
TEWO = total external work output (kgm/min) x pedal duration (min)

$P\dot{V}O_2$ = pedal oxygen consumption (ℓ/min STPD) x caloric value (kcal)

$R\dot{V}O_2$ = resting oxygen consumption (ℓ/min STPD) x caloric value (kcal)

0,002344 = kcal conversion factor

The non-protein respiratory quotient was calculated at rest and while the subject was pedalling from the formula:

$$RQ = \frac{CO_2}{O_2}$$

where CO_2 = *volume of carbon dioxide produced* (ℓ/min STPD)
and O_2 = volume of oxygen consumed (ℓ/min STPD)

The caloric values at rest and during pedalling were determined from the calculated RQ's and Table II.

Table II: Caloric values for non-protein R Q

R Q	Kcal/ℓO_2	R Q	Kcal/ℓO_2
0,707	4,686	0,86	4,875
0,71	4,690	0,87	4,887
0,72	4,702	0,88	4,899
0,73	4,714	0,89	4,911
0,74	4,727	0,90	4,924
0,75	4,739	0,91	4,936
0,76	4,751	0,92	4,948
0,77	4,764	0,93	4,961
0,78	4,776	0,94	4,973
0,79	4,788	0,95	4,985
0,80	4,801	0,96	4,998
0,81	4,813	0,97	5,010
0,82	4,825	0,98	5,022
0,83	4,838	0,99	5,035
0,84	4,850	1.00	5,047
0,85	4,862		

From Lusk (1928)

Oxygen consumptions during rest and exercise were assessed by the open-circuit method of indirect calorimetry (Clarke D.H., 1975).

While the subject was comfortably seated on the cycle ergometer, expired air was collected for one minute in a Collins canvas type Douglas bag by means of a three-way Otis McKerron valve. An Omega stopwatch was used for all timed periods.

During the last minute of the cycling work bout another collection of expired gas was made in a second Douglas bag. The volume and temperature of the expired air in each Douglas bag was then measured with a Collins Singer respiratory gasmeter. A Collins motor blower was used to convey the air from the Douglas bags to the gasmeter.

The oxygen concentrations(%) of the expired air were determined with a Beckman electronic oxygen analyser (Model OM14). A Beckman electronic CO_2 analyser (Model LB 2) was used to measure the concentrations (%) of carbon dioxide. Water vapour pressure (PH_2O), which depends upon the temperature of the expired air, was determined from Table III.

Table III: Values for water vapour tension at various temperatures

Temp (C)	PH_2O (mmHg)	Temp (C)	PH_2O (mmHg)
20	17,54	31	33,70
21	18,65	32	35,66
22	19,83	33	37,73
23	21,07	34	39,90
24	22,38	35	42,18
25	23,76	36	44,56
26	25,21	37	47,07
27	26,74	38	49,69
28	28,35	39	52,44
29	30,04	40	55,32
30	31,82		

From Clarke D.H. (1975)

The following series of formulae from D.H. Clarke (1975) were then used to calculate the oxygen and carbon dioxide volumes, corrected to standard temperature (0^oC) and pressure (760 mmHg), dry (STPD):

A. Volume of ventilation per minute, ambient temperature and pressure, saturated:

$$\dot{V}E(ATPS) = \dot{V}E \quad . \quad \frac{60}{ct}$$

where $\dot{V}E$ = volume of expired gas as measured

ct = collection time in seconds

60 = conversion of volume from seconds to minutes

B. The $\dot{V}E$ ATPS was converted to volume of ventilation per minute, body temperature and pressure, saturated ($\dot{V}E$ BTPS), as follows:

$$\dot{V}E\,(BTPS) = \dot{V}E\,(ATPS) \cdot \frac{310}{273 + T} \cdot \frac{P_B - PH_2O \text{ at } T}{P_B - 47}$$

where T = temperature of the expired air in degrees Celsius
P_B = barometric pressure in mm Hg
PH_2O = water-vapour tension at T

Water-vapour tension at the designated temperature (T) was obtained from appropriate tables. The value 47 is the alveolar PH_2O in mm Hg, 310 is the average respiratory tract temperature in deg K and 273 is the temperature at absolute zero in deg K.

C. The oxygen consumption per minute (BTPS) was calculated from knowledge of the proportion (fraction, F) of the oxygen and carbon dioxide expired, along with the known values of both gases in the inspired air, as follows:

$$\dot{V}O_2\ (BTPS) = \dot{V}E\ (BTPS) \cdot \frac{FIO_2\ (1 - FECO_2) - FEO_2\ (1 - FICO_2)}{(1 - FIO_2 - FICO_2)}$$

where FIO_2 = proportion of oxygen inspired (0,2093)
FEO_2 = proportion of oxygen expired
$FICO_2$ = proportion of carbon dioxide inspired (0,0003)
$FECO_2$ = proportion of carbon dioxide expired

D. The $\dot{V}O_2$ (BTPS) was converted to STPD, according to the following:

$$\dot{V}O_2\ (STPD) = \dot{V}O_2\ (BTPS) \cdot \frac{273{,}0}{310{,}0} \cdot \frac{P_B - 47}{760}$$

E. The $\dot{V}CO_2$ (BTPS) was calculated from the following formula:

$$\dot{V}CO_2\ (BTPS) = \dot{V}E\ (BTPS) \cdot \frac{FECO_2(1-FIO_2) - FICO_2(1-FEO_2)}{(1 - FIO_2 - FICO_2)}$$

F. $\dot{V}CO_2$ (STPD) was calculated as follows:

$$\dot{V}CO_2\ (STPD) = \dot{V}CO_2\ (BTPS) \cdot \frac{273{,}0}{310{,}0} \cdot \frac{P_B - 47}{760}$$

A Hewlett Packard programmable calculator (HP - 67) was used to calculate the resting and pedalling oxygen consumptions which, in turn, were utilized for the determination of net mechanical efficiency. A specially prepared programme ensured rapid results and a high degree of computational accuracy.

The efficiency of competitive singles tennis playing was also assessed by expressing the measured $\dot{V}O_2$ during play as a percentage of the predicted $\dot{V}O_2$ max.

3.6.3 Energy expenditure

Energy expenditure or cost refers to the amount of energy utilized by the body per unit of time. The absolute energy cost (gross) of competitive singles tennis playing was determined by means of the formula:

$$GEE = \dot{V}O_2 \times CV \times 4{,}183$$

where GEE = gross energy expenditure (kJ/min)
$\dot{V}O_2$ = oxygen consumption (ℓ/min STPD)
CV = caloric value (kcal)
4,183 = kJ conversion factor

A portable Kofranyi - Michaelis respirometer (dry gas meter) was carried on the subject's back and a nose clip and mouth piece were worn during the test. The subjects were requested to play as they normally would under singles match conditions for 10 minutes prior to the collecting period. This procedure was adopted to ensure sufficient physiological adaptation at the start of the collecting period which was then continued for a further 8 to 10 minutes. The respirometer, with a mass of only about 4 kilograms, placed only a slight restriction on movement about the court.

While playing, the subject inhaled atmospheric air and exhaled into the meter through a three-way valve. A small fraction of this exhaled air (0,03%) was diverted into a rubber bladder connected to the meter. After the test the total volume and temperature of the expired air were read off meters housed in the respirometer. The oxygen and carbon dioxide concentrations (%) in the sample of expired air, $\dot{V}O_2$ (ℓ/min) and caloric value (kcal) were determined with the same equipment, techniques and formulae described in the previous section (3.6.2). When the RQ was greater than 1,0 as occurred in a few cases, the caloric value was taken to be 4,85 kilocalories as recommended by Wyndham (1974).

The relative energy cost of competitive singles tennis playing was also determined by expressing the playing $\dot{V}O_2$ as a percentage of the $\dot{V}O_2$ max.

Since it was possible only to simulate match conditions, somewhat higher values could be expected under actual match circumstances as a result of the increased metabolic activity brought about by numerous psychological and physiological stresses and strains.

Surprisingly, the subjects particularly the females, were reluctant to participate in the energy cost determinations.

3.6.4 Sweat-rate

This refers to the loss of liquid from the body per unit of time by the process of sweating. The net body mass change method was used to determine sweat-rate. The formulae were:

$$SL = IBM - FBM + LI - UV - FP$$

where SL = sweat-loss (g)
IBM = initial body mass (g)
FBM = final body mass (g)
LI = liquid intake (ml)
UV = urine voided (ml)
FP = faeces passed (g)

Sweat-loss mass was converted to sweat-loss volume by means of the formula:

$$V = \frac{M}{D}$$

where V = sweat-loss volume (ml)
M = sweat-loss mass (g)
D = density of sweat = 1,003

Sweat-rate was determined by the formula:

$$SR = \frac{60}{ED} \cdot \frac{V}{1000}$$

where SR = sweat-rate (ℓ/hr)
ED = exercise duration (min)
V = sweat-loss volume (ml)

Sweat-rate determinations were made under actual match conditions and, for the purpose of meaningful comparison, sweat-rate was also expressed in litres per square metre of body surface area per hour (ℓ/m^2/hr).

The subject's initial body mass was measured immediately before competition with a Seca beam balance scale. This nude body mass was recorded to the nearest 25 grams.

Subjects who normally drank during competition were provided with 1500 millilitres of water or 'isotonic game' which is a replacement liquid.

Final nude body mass was measured directly after competition. The subject's hair and body were carefully dried before this final measurement, which also was recorded to the nearest 25 grams.

An Omega stopwatch was used to measure the total playing time.

The volume of ingested liquid was determined by subtracting the liquid returned by the subject from 1500 millilitres.

The subjects were requested not to urinate or defaecate from the time of the initial body mass measurement to the final measurement after the match since this would necessitate careful collection and measurement of the urine voided and/or the faeces passed. To our great relief all the subjects were most co-operative in this respect. Whether this co-operation was due to 'natural control', 'inherent shyness' or the rigours of competitive play remained an unasked and unanswered question.

3.6.5 Static and dynamic pulmonary volumes

A Godhart expirograph EP 16000 (wet type) was used for the measurement of pulmonary volumes and capacities.

The subject wore a nose clip and mouth-piece. The mouth piece was attached to a three-way valve which was connected to the expirograph. The test was conducted with the subject in a standing position. Smoking was prohibited for at least one hour before the test and all restrictive clothing was removed as recommended by Krāl (1974).

The subject was instructed to breath normally, then to inhale maximally, to hold the breath for one to two seconds and then to exhale as rapidly and completely as possible. This procedure was practised before being recorded on the expirograph chartpaper as a spirogram.

The following static and dynamic pulmonary volumes were calculated directly from the spirogram:

A. Tidal volume (TV), or the volume of air inspired or expired during normal breathing.

B. Inspiratory reserve volume (IRV), or the maximal amount of air inspired from a normal, resting, end-inspiratory level.

C. Expiratory reserve volume (ERV), or the maximal amount of air expired from a normal, resting, end-expiratory level (De Vries 1975, Guyton 1976).
The following pulmonary capacities were derived from two or more of the measured volumes.

D. Inspiratory capacity (IC), or the maximal volume of air inspired from a resting expiratory level, was determined by the formula:

$$IC = TV + IRV$$

where IC = inspiratory capacity (ℓ)
TV = tidal volume (ℓ)
IRV = inspiratory reserve volume (ℓ)

E. Vital capacity (VC), or the maximal volume of air expelled from the lungs by forceful effort following a maximal inspiration, was calculated by the formula:

$$VC = IC + ERV$$

where VC = vital capacity (ℓ)
IC = inspiratory capacity (ℓ)
ERV = expiratory reserve volume (ℓ)

The inspiratory and vital capacities were also calculated directly from the spirogram in order to check the indirect calculations. Relative lung size was also determined by expressing vital capacity in relation to body surface area (ℓ/m^2).

F. Forced expiratory volume (FEV_1)

Respiratory function was assessed by measuring the forced expiratory volume per second or the maximum amount of air expired from the lungs in one second after a maximal inspiration (Åstrand and Rodahl, 1970). This is a measure of absolute lung power.

G. Forced expiratory volume index (FEV_1 I)

This index, which is a measure of relative lung power, was determined by the formula:

$$FEV_1I = \frac{FEV_1}{VC} \cdot 100$$

where FEV_1I = forced expiratory volume index (%)
FEV_1 = forced expiratory volume per second (ℓ)
VC = vital capacity (ℓ)

All the volumes and capacities were converted from ambient temperature and pressure saturated (ATPS), to body temperature and pressure saturated (BTPS), by the formula (Clarke D.H., 1975):

$$V_{(BTPS)} = V_{(ATPS)} \cdot \frac{P_B - PH_2O \text{ at } T}{P_B - 47} \cdot \frac{310}{273 + T}$$

where $V_{(BTPS)}$ = volume at body temperature and pressure saturated (ℓ)
$V_{(ATPS)}$ = volume at ambient temperature and pressure saturated (ℓ)
P_B = barometric pressure (mm Hg)
PH_2O = water vapour pressure (mm Hg) at T
47 = alveolar PH_2O (mm Hg)
310 = average respiratory tract temperature ($^{\circ}$K)
273 = temperature at absolute zero($^{\circ}$K)
T = ambient temperature ($^{\circ}$C)

3.6.6 Flexibility

Static flexibility, which refers to the range of motion in a joint, was measured with a Leighton flexometer (De Vries, 1975). This instrument contains a weighted 360 degree dial and a pointer, both of which move freely and independently, being controlled by gravity. Each has a separate locking device.

The flexometer was strapped to the part of the body being tested. The dial was locked when it became steady at one extreme of a prescribed movement, and the pointer was locked when it became steady at the other extreme position of the movement. From the indicator window on the flexometer, the arc through which the movement took place was read to the nearest degree (Clarke H.H., 1975).

Each flexibility test was conducted twice and when the observations differed by five degrees or less, the average was calculated. In the event of differences exceeding five degrees, the test was performed a third time and the two nearest observations were averaged.

The shoulder, elbow and wrist flexibility tests were conducted on both the right and left sides.

The following flexibility tests were conducted (after Leighton, 1966):

A. Shoulder-joint

I. Flexion - Extension

The subject stood with heels, buttocks, upper back and rear of the head in contact with the vertical section of a portable stadiometer. The flexometer was securely strapped to the lateral side of the arm just above the elbow. From the side of the body the fully extended upper limb was moved as far as possible forward and upward and then downward and backward in a vertical arc.

II. Rotation

The same body position was assumed as in the shoulder flexion and extension test. The instrument was fastened to the lateral side of the forearm just below the wrist.

The arm was abducted and held parallel with the floor while the elbow was flexed at right angles. With this position of the arm maintained throughout the movement, the forearm was moved downward and backward, and then forward, upward and backward in a vertical arc as far as possible.

B. Elbow-joint

I. Flexion - Extension

The subject assumed a squatting position and placed one arm across the corner of a table so that the elbow extended just beyond one edge and the armpit rested against the near edge. The instrument was strapped to the lateral side of the wrist. The movement involved maximal flexion and extension of the elbow.

II. Supination - Pronation

From a squatting position the subject placed the forearm across the corner of a table with the wrist projecting just beyond the table edge. The flexometer was strapped to the front of the fist. With the wrist held straight the fist was rotated maximally in a clockwise and then anticlockwise direction.

According to Leighton (1966), this test is a measure of radial-ulnar supination-pronation and is classified under elbow-joint. However, strictly speaking, it should not be classified under elbow-joint as pronation and supination are related to the superior and inferior radio-ulnar joints. The test is referred to simply as a measure of supination and pronation in this study.

C. Wrist-joint

I. Flexion - Extension

A squatting position was assumed and the subject placed the forearm across the corner of a table so that the wrist projected just beyond the edge. The flexometer was attached to the back of the hand (lateral side). The fingers were then clenched to form a fist which was moved upward (extension) and downward (flexion) in as large an arc as possible.

This test is described by Leighton (1966) as a measure of wrist ulnar-radial flexion. Since radial flexion is sometimes used for radial deviation and likewise with ulnar flexion, it is evident that this description is misleading. The test measures flexion and extension at the wrist-joint and is therefore referred to as wrist flexion and extension in this study.

D. Hip-joint

I. Flexion - Extension

The subject assumed a standing position, feet together, knees fully extended and upper limbs extended, with hands clasped above the head. The instrument was strapped to the right side of the hip region at umbilicus height. The subject was instructed to bend forward and backward as far as possible, without moving the feet or flexing the knees.

II. Abduction

The flexometer was attached to the back of the right leg just above the heel. From a standing position, with feet together, knees extended and arms at the sides, the subject moved the right lower limb laterally (abduction) as far as possible. The knees were kept extended, the trunk vertical and the feet parallel throughout the movement.

Leighton (1966) describes this test as a measure of hip adduction and abduction. Since it is possible to adduct beyond the stationary limb to the opposite side, the test is, in fact, a measure of hip abduction and not adduction and is referred to as such in this study.

E. Trunk flexion - extension

The position of the body and the prescribed movement were exactly the same as in the test of hip flexion-extension. The position of the flexometer, however, was different. It was strapped to the right side of the chest just below the armpit at nipple height.

Since the prescribed movement involves trunk and hip flexion and extension, the reading obtained for the hip flexion and extension test must be subtracted from the trunk and hip reading in order to obtain the actual measurement of trunk flexion and extension.

$$\mathrm{TFE} = \mathrm{T + HFE} - \mathrm{HFE}$$

where TFE = trunk flexion and extension (°)
T+HFE = trunk and hip flexion and extension (°)
HFE = hip flexion and extension (°)

F. Trunk lateral flexion

The body position used in the hip abduction test was assumed. The flexometer was strapped to the centre of the back at nipple height. The prescribed movements involved bending sideways to the left and right as far as possible without leaning forwards or backwards. The feet were kept flat on the floor and the knees fully extended throughout the movement.

G. Relative index of flexibility asymmetry

The relative index of shoulder, elbow and wrist flexibility asymmetry was determined by means of the formula:

$$\text{RIA (F)} = \frac{2(X_D - X_{ND})}{X_D + X_{ND}}$$

where RIA (F) = relative index of flexibility asymmetry
X_D = flexibility variable on dominant side
X_{ND} = flexibility variable on non-dominant side

As in the case of the relative index of tissue asymmetry, dominance was determined by handedness.

3.6.7 Ocular dominance

Although normal vision is binocular, involving the use of both eyes, there is usually one eye, referred to as the directing and controlling eye, which is predominantly used (Benton et al., 1985).

Ocular dominance was assessed by means of the binocular peep-hole or hole-in-card test described by Hurtt et al (1972). A hardboard card (30 cm x 20 cm) with a small central hole, six millimetres in diameter, was held in both hands at arm's length. The subject was positioned six metres from a flashlight and instructed to raise the card so that the light could be seen through the central hole with both eyes.

The subject was right-eyed dominant if the light could no longer be seen after the right eye was covered. If the light disappeared when the left eye was covered, left-eyed dominance was indicated. The test was conducted twice on each subject.

3.6.8 Eye-limb concordance/discordance

Having assessed handedness (upper-limb dominance) and ocular dominance, eye-limb concordance/discordance, expressed as either crossed laterality or unilaterality, was determined for each subject. The subjects were also questioned about their groundstroke proficiency to determine the possible relationship between backhand and forehand drive proficiency and eye-limb concordance/discordance.

3.7 BIOCHEMICAL OBSERVATIONS

Blood specimens were taken immediately before and after competition in order to determine blood glucose, lactate and electrolyte changes induced by competitive tennis playing.

Four-millilitre samples of venous blood were hypodermically withdrawn from a superficial forearm vein by a qualified nursing sister.

The specially prepared blood samples were stored in ice and analysed within ten hours by the Industrial Hygiene Division of the Chamber of Mines.

3.7.1 Blood glucose

A disposable capillary pipette containing 50 microlitres (µℓ) whole blood was emptied into 500 microlitres premeasured ice-cold perchloric acid (0,3 normal). This solution was used for the deproteinization of the blood (Tfelt-Hansen and Siggard-Andersen, 1971). The sample was then centrifuged and the blood glucose concentration (mg/100 ml) determined by means of enzymatic spectrophotometric methods, based on the Biochemica Test Combinations from Boehringer Mannheim (Jooste et al., 1976).

3.7.2 Lactate

A disposable capillary pipette containing 50 microlitres whole blood was emptied into 250 microlitres premeasured ice-cold perchloric acid (0,6 normal). After being centrifuged, the supernatant was analysed for lactate concentration (m moles/ℓ) by means of spectrophotometric methods. The Boehringer Mannheim kit for lactate was used.

3.7.3 Electrolytes

The remaining whole blood was placed in a non-heparinised tube and stored in ice, where it was allowed to coagulate. After being centrifuged, the serum was analysed to determine the following electrolytes:

A. Sodium concentration (mEq/ℓ) was determined by means of a flame photometer.

B. Calcium and magnesium concentrations (mEq/ℓ) were measured with an atomic absorption spectrophotometer.

C. Chloride concentration (mEq/ℓ) was determined by means of a chloride titrator.

In contrast to the pre-competition drawing of blood which resulted in little or no pain, the post-competition withdrawals of blood were painful and in some cases considerable discomfort was experienced. The explanation for this phenomenon lies in the fact that exercise induces a greater muscle tonus which, in turn, increases the sensitivity of the receptors in the surrounding cutaneous and subcutaneous tissue.

3.8 STATISTICAL APPROACH

The computer programme used for the statistical analyses included the Biomedical Data Package (BMDP - P Series 1977), the Statistical Package for Social Sciences (SPSS) and specially prepared Fortran Somatotyping programmes (Carter, 1975).

The BMDP programmes which were used for the large majority of the analyses, are particularly suited to the analysis of morphological, physiological and biochemical data. A Fortran sub-programme was used to convert paired right and left morphological and physiological variables to dominant and non-dominant variables. Dominance was determined by handedness.

The computations were done by an I.B.M. 370 model 158 computer at the University of the Witwatersrand.

3.8.1 Univariate statistics

The BMDP 1D programme was used to compute the following univariate statistics: mean, standard deviation, standard error of the mean, coefficient of variation, the smallest and largest values with their respective z-scores, range and the total frequency.

The median, mode, variance, first and third quartiles, interquartile range, skewness and kurtosis were computed using the BMDP 2D programme.

Histograms and cumulative percentage tables also were provided by this programme. Cumulative percentage graphs or ogives were constructed for a number of selected variables.

A. Formulae

$\bar{X} = \Sigma Xj/n$ = Mean

$S = \left[\Sigma (Xj - \bar{X})^2 / (n - 1)\right]^{\frac{1}{2}}$ = standard deviation

$S_{\bar{X}} = \frac{s}{\sqrt{n}}$ = standard error of the mean

$g_1 = \Sigma (Xj - \bar{X})^3 / (NS^3)$ = Skewness

$g_2 = \Sigma (Xj - \bar{X})^4 / (NS^4) - 3$ = Kurtosis

SE $g_1 = (6/n)^{\frac{1}{2}}$ = Standard error of skewness

SE $g_2 = (24/n)^{\frac{1}{2}}$ = Standard error of kurtosis

3.8.2 Correlations

The SPSS Pearson correlation pairwise deletion programme was utilized for the computation of simple correlation matrices. These basic correlations do not, of course, consider the possible influence of other related factors. Pairwise deletion was used since this method, in contrast to the listwise method, does not require an equal number of cases (n) and utilizes all the available data. The equivalent BMDP programme was not used because levels of significance were omitted in the print-out and would have had to be separately calculated.

A. Formula

Product - moment correlation coefficient

$$r = \frac{\Sigma (X_j - \bar{X})\ (Y_j - \bar{Y})}{\left[\Sigma (X_j - \bar{X})^2\ (Y_j - \bar{Y})^2\right]^{\frac{1}{2}}}$$

3.8.3 Analysis of variance and covariance

A two-way analysis of variance was conducted with the BMDP 2V programme to determine the differences among the means (cell) of the variables in the four groups at the 5 and 1 percent levels of confidence or significance. The two-way analysis was utilized because of the two main factors involved, namely proficiency (professional and amateur) and sex (male and female). Note the fact that the group sizes were unequal. When significant interactions were indicated ($p < 0,05$ or $p < 0,01$), use was made of Bonferroni's Least Significant Difference (LSD) test in order to determine differences in the means among the groups.

The programme (BMDP 2V) also conducted an analysis of covariance. In this analysis, the adjusted means of selected variables in the four groups were compared in two-way tables, while certain other selected variables or covariates were held constant. The selection of the covariates was based on theoretical justification. Differences at the 5 and 1 percent levels of significance were determined. When significant interactions were indicated, Bonferroni's Least Significant Difference test was utilized. The formulae were:

Two-way analysis model:

$$Yijk = \mu + \alpha_i + B_j + (\alpha B)ij + E_{ijk}$$

where α_i = proficiency effect

B_j = sex effect

αBij = interaction between proficiency and sex

Bonferroni's test:

$$LSD_{Bonf} = t_{\frac{\alpha}{2k}} \cdot \sqrt{MSE \left(\frac{1}{n_1} + \frac{1}{n_2}\right)}$$

where LSD_{Bonf} = Bonferroni's Least Significant Difference test

α = 0,05

k = 4

MSE = mean square error

n_1 and n_2 = sizes of the two samples

3.8.4 t-test

The 'Student' t-test was utilized to compare the somatotype component ratings of professional and amateur players. The t-values and levels of significance (2-tailed) were determined by means of Hewlett Packard t-statistic and t-distribution programmes. The formula was:

$$t = \frac{\bar{X} - \bar{Y}}{\sqrt{\frac{\{X_i^2 - n_1\bar{X}^2 + \{Y_i^2 - n_2\bar{Y}^2}{n_1 + n_2 - 2} \cdot \left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

where t = t-value; $\bar{X}$ and $\bar{Y}$ = means of the two samples;
X_i and Y_i = sum of the deviations in the two samples;
and n_1 and n_2 = sizes of the two samples.

The 'Student' t-test was used also to compare the morphological and physiological data of the professional players and sedentary subjects. Levels of significance (2-tailed) were determined by means of a Hewlett-Packard t-distribution programme. The formula was:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}}$$

where t = t-value; df = $n_1 + n_2 - 2$; $\bar{X}_1$ and $\bar{X}_2$ = means of the two samples; S_1 and S_2 = standard deviations of the two samples; n_1 and n_2 = sizes of the two samples.

3.8.5 Non-parametric statistics

A. Two-way contingency table

The chi-squared test was used to test the null hypothesis that proficiency was independent of the following: levels of representation, handedness, ocular dominance and eye-limb concordance/discordance. Having determined the chi-square statistic (χ^2), a Hewlett Packard chi-square distribution programme was utilized to either accept (H_0) or reject (H_1) the null hypothesis at the 5 and 1 percent levels of confidence.

B. Formula

$$\chi^2 = \sum \left[\frac{(O_{ij} - E_{ij})^2}{E_{ij}} \right]$$

where O_{ij} = observed number in the (ij) cell

E_{ij} = expected (theoretical) number in (ij) cell

$E_{ij} = \frac{R_i \; C_j}{n}$

where R_i = total of the ith row

C_j = total of the jth column

n = grand total

3.8.6 Linear regression

Bivariate scatter plots and simple linear regression equations were calculated by means of the BMDP 6D programme.

The following statistics were presented with each graph: correlation coefficient (r), residual mean square (RMS) and regression equations and lines of the two variables (X and Y). The standard error of the estimate ($S_E = \sqrt{RMS}$) was calculated and presented instead of the residual mean square because it is expressed in the units of the dependent variable and, is therefore, more easily interpreted.

One variable could be predicted from another, with either the regression equation or the regression line.

The BMDP 6D programme did not include confidence bands. Confidence functions were separately calculated in order to determine 95% confidence bands for the regression surfaces.

A. Formulae

I. Confidence bands

$$PAL(Y) = (a+bX) + \left(\sqrt{RMS} \times \sqrt{2}t_{0,05;n-2}\right) \cdot \sqrt{\frac{1}{n} + \frac{(X-\bar{X})^2}{(n-1)(SD_X)^2}}$$

$$PBL(Y) = (a+bX) - \left(\sqrt{RMS} \times \sqrt{2}t_{0,05;n-2}\right) \cdot \sqrt{\frac{1}{n} + \frac{(X-\bar{X})^2}{(n-1)(SD_X)^2}}$$

where PAL(Y) and PBL(Y) = point above and below the Y regression line

RMS = residual mean square

X = X variable

$\bar{X}$ = mean of the X variable

SD_X = standard deviation of X variable

II. Regression model

$$Y = B_0 + B_1 X_1 + \ldots\ldots\ldots + B_p X_p + e$$

where Y = dependent variable

X = independent variable

In the case of simple linear regression, X_1 was the only independent variable in the model.

3.6.7 Multivariate statistics

A. Stepwise regression was conducted to construct multiple linear regression equations, which could be utilized to predict a variable from a subset of other selected variables. The BMDP 2R programme was utilized for this purpose. Although this prediction is more accurate than the prediction by means of simple linear regression equations, it is not as practical and often requires lengthy calculations.

B. Stepwise discriminant analysis was conducted to determine a subset of variables that maximised differences between the groups. The BMDP 7M forward stepping programme was utilized for the analysis.

A plotting function included in the programme provided a good visual representation of group differences.

A classification table in which the subjects were classified as professional or amateur players was also included in the analyses.

The analysis was not conducted simultaneously with all observations because of incomplete records, resulting from subjects not having completed the entire test and measurement battery and because of the small sample (group) sizes in relation to the number of observations. The morphological, physiological and biochemical variables were analysed separately. The variables found to be important in distinguishing among the groups were combined and a final stepwise discriminant analysis was performed.

C. Factor analysis, in which the initial factor extraction was by means of the maximum likelihood method (maximum likelihood factor analysis), was conducted by means of the BMDP 4M programme. When the correlation matrix was singular, the analysis was repeated after certain variables, specified by the programme, had been removed.

The analysis was conducted in order to summarise a large number of variables by means of a few variables (factors).

As with the stepwise discriminant analysis, the factor analysis was not conducted simultaneously on all the observations. The basic morphological and physiological variables were analysed separately.

I. Formula

The factor analysis model:

$$Zj = aj_1\ f_1 + aj_2\ f_2 + \ldots\ldots\ldots\ldots + ajmfm + Uj$$

where Z_j = *the jth standardised variable*
m = number of factors common to all variables
Uj = the factor unique to variable Zj
aj_1 = factor loadings
f_1 = common factors

3.8.8 Somatotype analyses

The following specially prepared Fortran computer programmes were used for the somatotype analyses (Carter, 1975):

A. Stype programme was used for the computation of the three anthropometric somatotype component ratings.

B. Somatograph programme was utilized to draw somatocharts and plot the frequencies of somatotypes (somatoplots).

C. SDI programme was used to calculate the somatotype dispersion distance (SDD) and the somatotype dispersion index (SDI).

D. Programme formulae (after Ross et al., 1974).

I. Mean somatotype

$$\bar{S}^{\ast} = \frac{\sum_{i=1}^{n} I_i}{n} \quad \frac{\sum_{i=1}^{n} II_i}{n} \quad \frac{\sum_{i=1}^{n} III_i}{n}$$

where $\bar{S}$ = mean somatotype (3 digit rating)

n = number of cases in sample

*Each of the three somatotype components were independently treated.

II. Somatotype dispersion distance

$$SDD = \sqrt{3(X_1 - X_2)^2 + (Y_1 - Y_2)^2}$$

where SDD = somatotype dispersion distance in Y axis units

3 = constant which converts X into Y units when it is under the square root sign

(X_1, Y_1) and (X_2, Y_2) = co-ordinates of any two somatoplots

III. Somatotype dispersion index

$$SDI = \frac{\sum_{i=1}^{n} SDD_i}{n}$$

where SDI = somatotype dispersion index

SDD = sum of the somatotype dispersion distances in a sample

n = number of cases in the sample

IV. Somatotype dispersion variance

$$SDV = \frac{\sum_{i=1}^{n} (SDD_i - SDI)^2}{n - 1}$$

where SDV = somatotype dispersion variance

SDD = individual somatotype dispersion distances

SDI = somatotype dispersion index (mean of SDD_i values)

V. Dispersion standard deviation

$$DSD = \sqrt{SDV}$$

where DSD = dispersion standard deviation

SDV = somatotype dispersion variance

E. Somatotype comparisons

Somatotype (somatoplot) differences among the four groups were determined by the formulae of Ross et al (1974), an HP 67 programmable calculator and Hewlett Packard F-and t-distribution programmes.

I. F - ratio

The F - ratio formula was utilized to assess whether somatotype dispersion variances between two groups differed significantly.

$$F = \frac{SDV_1}{SDV_2}$$

where F = ratio of observed somatotype dispersion variance

SDV_1 = somatotype dispersion variance with the greater magnitude

SDV_2 = somatotype dispersion variance with the lesser magnitude

Using $n_1 - 1$ and $n_2 - 1$ degrees of freedom, the obtained F - value was tested for significance by means of a Hewlett Packard F - distribution programme.

II. t - ratio (equal somatotype variance)

Since all the F - values were found to be insignificant, the t - value was determined by the formula:

$$t = \frac{SDD_{\bar{1} - \bar{2}}}{\sqrt{\dfrac{n_1 SDV_1 + n_2 SDV_2}{n_1 + n_2 - 2} \cdot \left(\dfrac{1}{n_1} + \dfrac{1}{n_2}\right)}}$$

where t = t - value

$SDD_{\bar{1} - \bar{2}}$ = somatotype dispersion distance between the mean somatoplots $\bar{S}_1$ and $\bar{S}_2$

SDV_1 and SDV_2 = somatotype dispersion variance of 2 samples
n_1 and n_2 = number of cases in 2 samples

$\mathrm{SDD}_{\bar{1}-\bar{2}}$ was calculated from the formula:

$$\mathrm{SDD}_{\bar{1}-\bar{2}} = \sqrt{3(X_1 - X_2)^2 + (Y_1 - Y_2)^2}$$

where $X_1\ Y_1$ = co-ordinates of $\bar{S}_1$
$X_2\ Y_2$ = co-ordinates of $\bar{S}_2$

Using $n_1 + n_2 - 2$ degrees of freedom, the obtained t - value was examined (two-tailed test) for significance by means of a Hewlett Packard t-distribution programme.

3.9 SUMMARY

Fifty-six professional and 48 amateur tennis players were studied during the 1977 South African Open Tennis Championships. The test battery, comprised of 208 variables, was completed by most of the subjects. The battery included questionnaire, anthropometric, somatotypological, physiological and biochemical variables. Personal, tennis and medical history data were obtained by means of oral questionnaires.

Mass, height, diameter, girth and skinfold measurements were taken with standardised, calibrated anthropometric equipment. The basic anthropometric data were used to obtain the following: limb and segment lengths; length, diameter and girth indices; androgyny and body surface area, lean volume, bone, muscle and skin-fat indices; absolute and relative body fat; lean and 'ideal' body mass; and the Heath-Carter anthropometric somatotype.

The following physiological variables were assessed: $\dot{V}O_2$ max (Åstrand-Ryhming nomogram); mechanical efficiency of cycling and tennis playing; absolute and relative energy cost of singles tennis playing; sweat-rate; static and dynamic pulmonary volumes; static flexibility; and eye-limb concordance/discordance. The biochemical observations included pre- and post-match blood glucose, lactate and electrolyte (Na, Ca, Mg and Cl) concentrations.

The Biomedical Data Package (BMDP) was utilized for the computation of the univariate statistics as well as for the variance, covariance, linear regression, stepwise regression, stepwise discriminant and factor analyses. The Statistical Package for Social Sciences (SPSS) was used for the computation of product-moment correlation matrices. Specially prepared Fortran computer programmes were utilized for the somatotype analyses.

CHAPTER 4

PRESENTATION OF THE DATA

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The questionnaire, morphological, physiological and biochemical data of the present study are presented in this chapter. The important results and trends of each major sub-section are singled out, briefly summarised and presented with the relevant tables and/or figures.

In Tables X to XXI, XXIII to XXV, XXVII to XXIX, XXXVI to XXXIX and Figures 3 to 3, 16 to 18, the following abbreviations are used for the four groups: MP = male professionals, MA = male amateurs, FP = female professionals and FA = female amateurs. Page numbers of the tables and figures cited in the text are included. This ensures quick and ready access to the relevant tables and figures.

4.1 QUESTIONNAIRE

The frequencies and percentage frequencies of the data obtained by means of oral questionnaires are presented in Tables IV to IX.

4.1.1 Nationality

As can be seen from Table IV (p.154), the male professionals comprised representatives of seven nationalities with, the U.S.A., British and South African nationalities most prominently represented. The female professionals comprised nationals of six different countries with the British, German and South African nationalities most prominently represented.

The amateur subjects represented six nationalities: three nationalities in the case of the males and three in the case of the females. The majority of the amateur subjects were South Africans.

4.1.2 Tennis representation

The relationship between the level of tennis representation and proficiency is shown in Table V (p.155). From this contingency table, ich contains frequencies and percentage frequencies, it is evident that there was a significant relationship between the level of representation and proficiency ($p < 0,001$).

4.1.3 Occupation

Past and present occupations are shown in Table VI (p.156). A higher percentage of female professionals, 27,3 percent as compared to the male figure of 17,6 percent, were involved in coaching. The position was reversed among the amateurs where 45,5 percent of the males and 26,7 percent of the females were coaches.

All the subjects had attended or were attending school and 26,5 percent of the male professionals and 18,2 percent of the female professionals had attended university or college.

4.1.4 Leisure-time physical activities

Physical activities conducted by subjects during their leisure-time are presented in Table VII (p.157).

The male professionals' favourite leisure activity was idleness, followed by golf and soccer. The female professionals' favourite leisure-time activity was swimming, followed by athletics and squash. A relatively high percentage of professionals, particularly the females, played tennis in their leisure-time.

4.1.5 Physical training programmes

The subjects' past and present physical training programmes are shown in Table VIII (p.158).

Long-distance or endurance running was the favourite form of training for all the groups.

A high percentage of professionals, 26,5 percent of the males and 27,3 percent of the females, did not participate in any type of training programme other than their tennis practice sessions.

From Table VIII it is evident that progressive resistance and flexibility training are not so high on the subjects' list of priorities.

4.1.6 Injury

Data on past injuries sustained by the subjects are presented in Table IX (p.159).

The fractures, dislocations and muscle ruptures did not occur during tennis participation but at some other time during the subjects' lives.

The number of fractures among male professionals and female amateurs was surprisingly high.

A relatively high percentage of players, in particular the female professionals (40,9 percent), sustained sprains while playing tennis. The ankle and shoulder joints were most commonly involved.

'Tennis elbow' occurred rarely except in the female amateurs.

4.1.7 Tennis participation

The tennis participation data are shown in Table X (p.160). The professionals did not commence playing at a significantly younger age than the amateurs. It is evident that there was a large variation in the starting age of the professionals. The female professionals' mean starting age of 10,8 years was the lowest of the four groups.

Although the mean number of years played was greater among the professionals than among the amateurs, the differences were not statistically significant.

Ogives or cumulative percentages of the number of years played in the four groups are shown in Figure 3 (p.161). The years played range from 3 to 41 years. Cumulative curves not only reflect the progressive development of a variable in each group, but also provide a good visual indication of group differences and ranges.

As expected, the professionals spent more time playing tennis than the amateurs, both in terms of hours per week and total number of hours played ($p < 0,05$).

The average number of full-time years that male and female professionals spent playing tennis were 5,3 and 5,0 respectively, while the means for male and female amateurs were 3,9 and 3,3 respectively. One full-time year comprised an average eight-hour day, five times per week with twenty-eight working days' *leave per annum*.

The total energy cost or expenditure of tennis playing in the males was found to be 27,3 and 11,1 million kilojoules for the professionals and amateurs respectively. These means differed significantly at the five percent level of confidence.

Table IV: Nationality of tennis players

	Male professionals (n = 34)		Male amateurs (n = 33)		Female professionals (n = 22)		Female amateurs (n = 15)	
	f	%f	f	%f	f	%f	f	%f
Australia	1	2,9	-	-	-	-	-	-
Britain	5	14,7	-	-	6	27,3	1	6,7
Czechoslovakia	3	8,8	-	-	-	-	-	-
France	-	-	3	9,1	1	4,5	-	-
Germany	-	-	-	-	2	9,1	-	-
Holland	1	2,9	-	-	-	-	-	-
New Zealand	1	2,9	-	-	1	4,5	-	-
South Africa	13	38,2	27	81,8	11	50,0	13	86,7
U. S. A.	10	29,4	3	9,1	1	4,5	1	6,7

Table V: Contingency table depicting the relationship between tennis proficiency and level of representation

	Representation								χ^2	Level of sig (%)
	International		National		Provincial		Club			
	f	%f	f	%f	f	%f	f	%f		
Male professionals	18	52.9	12	35,3	4	11,8	-	-	47,19	0,1
Male amateurs	-	-	2	6,1	17	51,5	14	42,4		
Female professionals	19	86,4	2	9,1	1	4,5	-	-	28,39	0,1
Female amateurs	-	-	3	20,0	7	46,7	5	33,3		

Table VI: Past and present occupations of tennis players

Occupations	Male professionals (n = 34)				Male amateurs (n = 33)				Female professionals (n = 22)				Female amateurs (n = 15)			
	Past		Present		Past		Present		Past		Present		Past		Present	
	f	%f	f	%f	f	%f	f	%f	f			%f	f	%f	f	%f
Full-time tennis playing	29	85,3	28	82,4	-	-	-	-	16		[illegible]	72,7	-	-	-	-
Full-time tennis playing + coaching	13	38,2	6	17,6	-	-	-	-	6	27,3	6	27,3	-	-	-	-
Full-time tennis coaching	-	-	-	-	4	21,1	15	45,5	-	-	-	-	2	13,3	4	26,7
Education (lecturing or teaching)	-	-	-	-	3	9,1	2	6,1	1	4,5	-	-	2	13,3	-	-
School pupil	34	100,0	-	-	33	100,0	5	15,2	22	100,0	-	-	15	100,0	5	33,3
University or college student	9	26,5	-	-	12	36,4	3	9,1	4	18,2	-	-	6	40,0	4	26,7
Commerce	1	2,9	-	-	10	30,3	9	27,3	1	4,5	-	-	1	6,7	-	-

Table VII: *Leisure-time physical activities of tennis players*

Activities	Male professionals (n = 34)		Male amateurs (n = 33)		Female professionals (n = 22)		Female amateurs (n = 15)	
	f	%*f*	*f*	%*f*	*f*	%*f*	*f*	%*f*
Athletics	6	17,6	5	15,2	9	40,9	4	26,7
Golf	9	26,5	4	12,1	5	22,7	1	6,7
Hockey	1	2,9	-	-	6	27,3	1	6,7
Long-distance running	3	8,8	2	6,1	5	22,7	1	6,7
No physical activity besides tennis	10	29,4	4	12,1	1	4,5	2	13,3
Snow skiing	4	11,8	3	9,1	1	4,5	-	-
Soccer	8	23,5	8	24,2	-	-	-	-
Squash	4	11,8	5	15,2	8	36,4	1	6,7
Swimming	6	17,6	3	9,1	10	45,5	5	33,3
Tennis	6	17,6	19	57,6	6	27,3	8	53,3
Water skiing	2	5,9	1	3,0	1	4,5	1	6,7

Table VIII: Past and present physical training programmes of tennis players

Training programmes	Male professionals (n = 34)				Male amateurs (n = 33)				Female professionals (n = 22)				Female amateurs (n = 15)			
	Past		Present		Past		Present		Past		Present		Past		Present	
	f	%f	f	%f	f	%f	f	%f	f	%f	f	%f	f	%f	f	%f
Bicycling	-	-	1	2,9	-	-	-	-	-	-	-	-	-	-	-	-
Circuit training	5	14,7	8	23,5	8	24,2	7	21,2	7	31,8	10	45,5	4	26,7	6	40,0
Endurance running	10	29,4	20	58,8	11	33,3	18	54,5	12	54,5	12	54,5	3	20,0	6	40,0
Flexibility	1	2,9	3	8,8	-	-	1	3,0	1	4,5	1	4,5	1	6,7	1	6,7
Interval training	4	11,8	6	17,6	3	9,1	2	6,1	7	31,8	6	27,3	-	-	-	-
Light progressive resistance	8	23,5	3	8,8	8	24,2	3	9,1	4	18,2	1	4,5	-	-	1	6,7
No training besides tennis	14	41,2	9	26,5	11	33,3	11	33,3	3	13,6	6	27,3	8	53,3	4	26,7
Skipping	4	11,8	8	23,5	2	6,1	6	18,2	6	27,3	7	31,8	2	13,3	5	33,3
Yoga	-	-	2	5,9	-	-	-	-	-	-	1	4,5	1	6,7	1	6,7

Table IX: Past injuries sustained by tennis players

Injuries	Male professionals (n = 34)		Male amateurs (n = 33)		Female professionals (n = 22)		Female amateurs (n = 15)	
	f	%f	f	%f	f	%f	f	%f
Chronic backache★	5	14,7	3	9,1	2	9,1	4	26,7
Dislocation	2	5,9	1	3,0	2	9,1	-	-
Fracture	14	41,2	8	24,2	4	18,2	6	40,0
Knee cartilage tear ★	3	8,8	-	-	1	4,5	1	6,7
Muscle rupture	4	11,8	6	18,2	7	31,8	1	6,7
No injury	4	11,8	9	27,3	5	22,7	3	20,0
Sprain★	12	35,3	8	24,2	9	40,9	3	20,0
'Tennis elbow'★	2	5,9	3	9,1	2	9,1	3	20,0

★Injuries resulting from tennis participation

Table X: Tennis participation of professional and amateur players : Time and Energy

	X̄				Sx̄				CV				n			
	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA
Present age (yrs)	27,1	23,8	24,1	24,9	0,99	0,82	1,03	3,47	21,4	18,2	20,0	54,0	34	28	22	15
Starting age (yrs)	11,8	12,3	10,8	13,1	0,45	0,66	0,41	1,99	22,2	28,8	17,9	58,7	34	29	22	15
Yrs played	14,8	11,9	12,9	11,8	0,79	1,10	1,00	2,31	31,1	48,9	36,4	75,9	34	28	22	15
Hrs/week	16,4	12,6	15,8	12,5	1,28	1,65	1,80	2,32	43,7	65,5	52,2	66,9	34	25	21	13
	↑___5___	↑	↑___5___	↑												
Wks/year	46,8	48,3	46,1	48,5	0,85	1,15	1,16	1,57	10,6	11,9	11,5	10,8	34	25	21	11
Total hrs (1000x)	10,0	7,2	9,3	6,2	0,81	1,34	1,25	1,56	47,6	93,3	27,3	83,9	34	25	21	11
	↑___5___	↑	↑___5___	↑												
Full-time years (8 hrs/day)	5,3	3,9	5,0	3,3	0,44	0,72	0,67	0,84	47,8	93,5	62,2	83,9	34	25	21	11
	↑___5___	↑	↑___5___	↑												
Total energy cost (kJ) (1000000x)	27,3	11,1	-	-	3,35	4,23	-	-	17,4	100,6	-	-	2	7	0	1
	↑___5___	↑														

Means connected by arrows differ significantly at the percentage levels indicated.

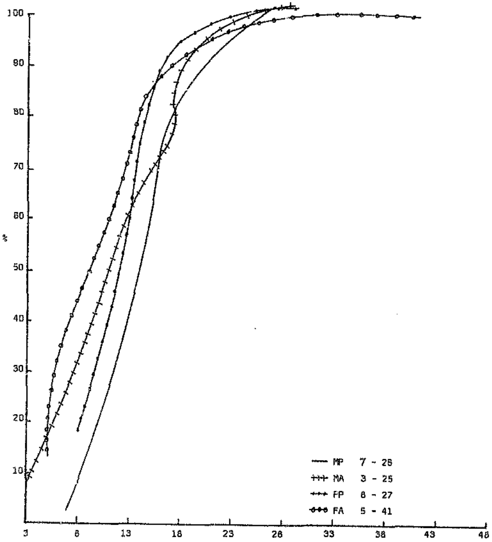


Figure 3: Cumulative percentages of years played in tennis players

4.2 BASIC ANTHROPOMETRIC MEASUREMENTS AND INDICES

Statistics of the basic anthropometric measurements and indices are presented in Tables XI to XV. They include the means ($\bar{X}$), significant differences among the four groups, standard errors of the mean ($S\bar{X}$) and coefficients of variation (CV). The numbers of cases (n) are also shown. Means found to differ significantly at the 5 and 1 percent levels of significance are connected by arrows.

4.2.1 Body mass, body surface area,[☆] androgyny[☆] and interpupillary distance

The statistics of these observations are shown in Table XI (p.165). The professionals were heavier (mass) and larger (BSA) than the amateurs ($p < 0{,}01$). The males were predictably heavier, larger and had higher androgyny indices than the females ($p < 0{,}01$).

Interpupillary distance differences among the groups were small with the exception of the amateurs, where the males were found to have a significantly *larger interpupillary distance than the females at the 5 percent* level. Cumulative percentages of interpupillary distance and androgyny in the four groups are shown in Figures 4 (p.166) and 5 (p.167) respectively. Interpupillary distances ranged from 52 to 68 millimetres, while androgyny indices ranged from 66 to 99.

4.2.2 Lengths and length indices

From Table XII (p.168) it is evident that the professionals and amateurs did not differ significantly in stature, absolute heights or relative lengths. Although the absolute upper limb and segment lengths are not included in Table XII,[✡] differences between the professionals and amateurs were also found to be non-significant.

The males were characterised by greater heights than the females ($p < 0{,}01$), with the exception of trochanterion height in the amateurs, where the difference was non-significant. The males had a significantly greater absolute upper limb length than the females but these differences were eliminated when upper limb length was expressed relatively (% of stature).

[☆] Derived anthropometric measurement. [✡] It was felt that the absolute lengths which could be easily determined from the mean data in Table XII were of lesser importance than the relative lengths.

4.2.3 Diameters and diameter indices

As can be seen from Table XIII (p.169), the male and female professionals had significantly larger biacromial, bitrochanteric and wrist diameters than the amateurs. The male professionals also had larger bicondylar (femur) and ankle diameters than the male amateurs ($p < 0,05$).

Predictably, the males were found to have significantly larger biacromial, bi-iliac, bitrochanteric, bi-epicondylar (humerus), bicondylar (femur), ankle and wrist diameters than the females.

Differences in relative biacromial and bi-iliac diameters (expressed as a percentage of stature) among the four groups were not significant. As expected, bi-iliac diameter expressed as a percentage of biacromial diameter was greater in the females at the one percent level of confidence.

4.2.4 Girths and girth indices

From Table XIV (p.170) it can be seen that the professionals had greater upper and lower limb segment girths than the amateurs, at the one percent level of confidence (calf = $p < 0,02$).

As expected, the males had significantly larger absolute girths than the females ($p < 0,01$). However, when the girths were expressed relatively this was not the case and, in fact, the female professionals had the largest relative thigh and calf girths of the four groups.

The female professionals had significantly larger thigh girths than the male professionals and the female amateurs ($p < 0,05$) and significantly larger calf girths than female amateurs at the five percent level.

4.2.5 Skinfolds

As can be seen from Table XV (p.171), skinfold differences between the professionals and amateurs were small. As anticipated, the males had smaller biceps, triceps and calf skinfolds than the females ($p < 0,01$). However, subscapular and supra-iliac skinfold differences between the sexes did not follow the expected pattern and were not statistically significant. The female amateurs' mean supra-iliac skinfold of

6,0 millimetres was the lowest of the four groups. Their mean subscapular skinfold of 8,7 millimetres was also smaller than the 9,0 millimetres of the male amateurs.

The high coefficients of variation indicate considerable variation in skinfold measurements among the tennis players.

Table XI: Body mass, surface area, androgyny and interpupillary distance of tennis players

	$\bar{x}$				$S\bar{x}$				CV				n			
	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA
Body mass (kg)	76,5	69,9	60,7	55,4	1,25	2,06	1,38	1,30	9,4	15,6	10,4	8,1	33	28	21	12
	↑—1—	—↑	↑—1—	—↑												
	↑—1—	——	—↑													
		↑——	——	—1—↑												
Body surface area (m^2)	2,0	1,9	1,7	1,6	0,01	0,03	0,02	0,02	5,8	9,7	5,9	5,2	33	28	21	12
	↑—1—	—↑	↑—1—	—↑												
	↑—1—	——	—↑													
		↑——	——	—1—↑												
Androgyny	90,6	90,2	82,3	78,8	0,96	1,76	1,27	1,50	6,1	10,5	6,7	6,3	33	28	19	11
	↑—1—	——	—↑													
		↑——	——	—1—↑												
Interpupillary distance (mm)	58,6	59,5	57,5	55,3	0,54	0,82	0,82	0,45	5,2	7,0	6,5	2,8	32	26	21	12
		↑——	——	—5—↑												

Means connected by arrows differ significantly at the percentage levels indicated.

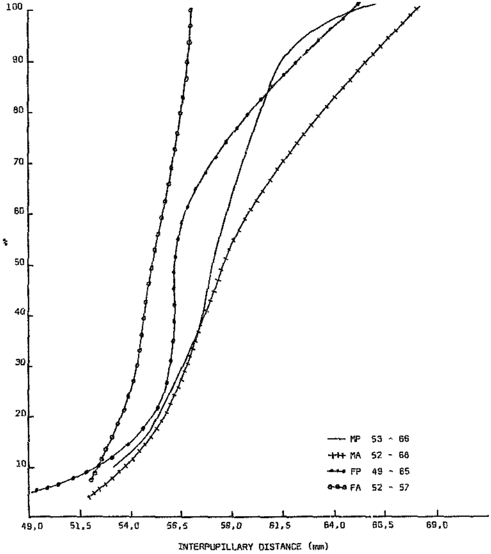


Figure 4: Cumulative percentages of interpupillary distance in tennis players

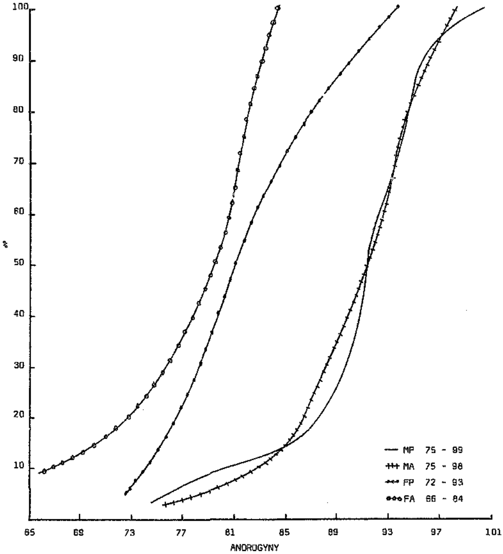


Figure 5: Cumulative percentages of androgyny in tennis players

Table XII: Lengths (cm) and length indices of tennis players

	$\bar{x}$				$S\hat{x}$				CV				n			
	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA
Stature	182,8	178,5	167,3	167,9	1,07	1,59	1,07	1,52	3,4	4,7	2,9	3,1	33	28	21	12
	↑ 1		↑													
		↑		1 ↑												
Acromiale Ht	149,3	145,2	136,7	137,5	1,06	1,48	0,97	1,01	4,1	5,4	3,3	2,4	33	28	21	11
	↑ 1		↑													
		↑		1 ↑												
Trochanterion Ht	96,1	94,2	89,8	93,2	1,08	1,[illegible]6	1,06	1,53	6,4	6,5	5,4	5,5	33	28	21	11
	↑		↑													
Dactylion Ht	67,5	65,1	62,5	63,5	0,84	0,[illegible]	0,92	0,75	7,2	7,6	6,8	3,9	33	28	21	11
	↑ 1		↑													
		↑		1 ↑												
Radiale Ht	114,5	111,4	105,5	106,8	0,98	1,31	0,81	1,05	4,9	6,2	3,9	3,3	33	28	21	11
	↑ 1		↑													
		↑		1 ↑												
Stylion Ht	88,6	84,3	82,1	82,5	0,81	1,89	0,72	0,83	5,3	11,9	4,0	3,3	33	28	21	11
	↑ 1		↑													
		↑		1 ↑												
Tibiale Ht	49,8	49,7	45,0	47,1	0,61	1,44	0,50	0,70	7,1	15,3	5,1	4,9	33	28	21	11
	↑ 1		↑													
		↑		1 ↑												
Relative U. Limb length	45,1	44,6	44,3	44,1	0,46	0,29	0,52	0,44	5,9	3,5	5,3	3,3	33	28	21	11
Relative L. Limb length	51,7	52,7	53,7	55,3	0,82	0,36	0,44	0,99	9,1	3,8	3,7	5,9	33	28	21	11
	↑ 1		↑													
		↑		1 ↑												
Relative thigh length	25,4	25,8	26,7	27,4	0,44	1,11	0,36	1,18	10,0	22,0	8,1	14,3	33	28	21	11
Relative fore-arm length	14,2	16,8	14,8	16,4	0,27	1,69	0,91	1,88	11,1	53,3	28,4	37,9	33	28	21	11
Relative arm length	19,0	18,9	18,7	18,3	0,25	0,23	0,17	0,35	7,7	6,3	4,3	6,3	33	28	21	11
	↑ 5		↑													
		↑		5 ↑												
Forearm-arm ratio	0,75	0,78	0,76	0,79	0,02	0,02	0,02	0,03	[illegible]	14,2	11,4	13,9	33	28	21	11

Means connected by arrows differ significantly at the percentage levels shown.

Table XIII: Diameters (cm) and diameter indices of tennis players

	$\bar{X}$				$S_{\bar{x}}$				CV				n			
	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA
Biacromial	38,7	39,1	38,2	35,2	0,29	0,39	0,40	0,48	4,2	5,3	4,8	4,5	33	28	20	11
	5		5													
	1															
		1														
Bi-iliac	26,5	27,2	26,5	26,6	0,46	0,42	0,71	0,40	8,2	8,2	11,9	4,8	33	28	20	11
	5															
		5														
Bitrochanteric	32,6	31,2	30,3	29,3	0,32	0,54	0,22	0,70	5,6	9,1	3,2	8,0	33	28	20	11
	2		2													
	1															
		1														
AP Chest	20,1	19,5	-	-	0,25	0,30	-	-	7,1	8,0	-	-	33	28	0	0
Bi-epicondylar (humerus)*	7,3	7,0	6,2	6,2	0,06	0,08	0,11	0,11	4,7	6,4	7,6	5,6	33	28	20	11
	1															
		1														
	5															
Bicondylar (femur)*	9,9	9,6	8,9	9,1	0,05	0,09	0,13	0,13	2,9	4,7	3,0	4,8	33	28	20	11
	5	5														
Wrist*	6,0	5,7	5,2	5,0	0,04	0,07	0,06	0,07	4,2	6,7	5,4	4,4	33	28	20	11
	1		1													
	1															
		1														
	5															
Ankle*	7,3	6,9	6,3	6,5	0,05	0,06	0,08	0,08	4,1	4,9	5,8	4,3	33	28	20	11
	5	5														
Relative biacromial diameter (%)	21,7	21,9	21,8	20,8	0,15	0,18	0,17	0,26	3,9	4,3	3,5	4,0	33	28	20	11
Relative bi-iliac diameter (%)	15,6	15,2	15,8	15,9	0,27	0,19	0,42	0,27	9,8	6,5	12,0	5,5	33	28	20	11
Step hum % U.L.	8,9	8,8	8,4	8,3	0,08	0,11	0,18	0,17	5,5	6,5	8,8	6,7	33	28	20	11
	1															
		1														
Bicon fem % L.L.	10,4	10,2	9,9	9,8	0,12	0,11	0,14	0,18	6,4	5,7	8,4	6,3	33	28	20	11
	1															
		1														
Hum/fem ratio	0,74	0,73	0,70	0,86	0,01	0,01	0,01	0,01	7,6	6,1	5,8	3,6	33	28	20	11
	1															
		1														
Bi-il % Biacromial	71,6	69,5	73,4	76,3	1,31	0,90	1,80	1,62	10,5	6,8	11,5	7,0	33	28	20	11
	1															
		1														
Relative AP chest diameter (%)	11,0	10,6	-			4	-	-	7,5	6,8	-	-	33	28	0	0

* Dominant value (handedness). Means connecte iffer significantly at the percentage levels indicated.

Table XIV: Girths (cm) and girth indices of tennis players

	$\bar{X}$				$S\bar{x}$				CV				n			
	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA
Uncontracted arm★	29,4	28,0	26,4	24,3	0,30	0,52	0,40	0,47	5,8	9,9	6,6	6,3	33	28	19	11
	MP ←1→ MA MP ←1→ FP	MA ←1→ FA	FP ←1→ FA													
Contracted arm★	32,1	31,0	28,6	26,6	0,30	0,56	0,37	0,45	5,4	9,5	5,6	5,6	33	28	19	11
	MP ←1→ MA MP ←1→ FP	MA ←1→ FA	FP ←1→ FA													
Forearm★	28,5	27,6	25,1	24,0	0,19	0,37	0,29	0,33	3,9	7,1	5,1	4,6	33	28	19	11
	MP ←1→ MA MP ←1→ FP	MA ←1→ FA	FP ←1→ FA													
Calf★	36,9	35,9	35,4	33,4	0,55	0,45	0,44	0,86	8,5	6,6	5,4	8,6	33	28	19	11
	MP ←2→ MA MP ←1→ FP	MA ←1→ FA	FP ←2→ FA													
Thigh (R) (cm)	56,7	54,0	56,0	52,7	0,48	0,83	1,01	1,03	4,8	8,1	7,9	6,5	33	28	19	11
	MP ←1→ MA		FP ←1→ FA													
Chest (cm)	94,9	92,2	-	-	0,97	1,35	-	-	5,9	7,8	-	-	33	28	0	0
Forearm % UL	31,8	32,0	31,4	32,7	0,61	0,62	0,48	0,80	11,1	10,3	7,0	8,1	33	28	21	11
Thigh % LL	59,2	57,4	62,4	56,7	0,70	0,66	1,28	1,13	6,8	6,1	8,9	6,6	33	28	19	11
	MP ←5→ FP		FP ←5→ FA													
Calf % LL	38,5	38,3	39,4	36,0	0,67	0,49	0,57	1,10	10,0	6,7	6,3	10,2	33	28	19	11
			FP ←5→ FA													
Relative chest girth (%)	52,0	51,6	-	-	0,59	0,53	-	-	6,6	5,5	-	-	33	28	0	0

Means connected by arrows differ significantly at the percentage levels indicated.

★ Dominant value (handedness).

Table XV: Skinfolds (mm) of tennis players

	$\bar{X}$				$S\bar{x}$				CV				n			
	MP	MA	FP	FA		MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA
Biceps*	3,6	3,6	6,0	5,9	0,16	0,14	0,62	0,95	25,3	20,8	44,8	53,2	33	28	19	11
	↑ 1		↑													
		↑		1 ↑												
Triceps*	6,7	6,2	12,2	10,6	0,34	0,33	0,91	1,04	29,0	28,4	32,5	32,5	33	28	19	11
	↑ 1		↑													
		↑		1 ↑												
Subscapular	[illegible]	[illegible]	[illegible]	6,7	0,38	0,50	0,92	0,50	25,3	29,5	39,8	17,9	33	28	19	11
Supra-iliac	[illegible]	7,7	8,3	6,0	0,73	1,24	0,90	0,53	60,8	85,2	46,8	29,4	33	28	19	11
Calf*	6,0	6,6	14,2	12,3	0,31	0,39	1,89	1,26	29,8	31,7	57,9	34,1	33	28	19	11
	↑ 1		↑													
		↑		1 ↑												

Means connected by arrows differ significantly at the percentage levels indicated.

* Dominant value.

4.3 DERIVED ANTHROPOMETRIC MEASUREMENTS

The means, significant differences, standard errors and coefficients of variation of the derived anthropometric measurements are shown in Tables XVI to XXI. Coefficients of variation for the RIA values in Tables XVI to XIX have not been included since this statistic is not defined for negative values. Means found to differ significantly at the 5 and 1 percent levels are connected by arrows.

4.3.1 Dominant limb and segment lean volumes and RIA's

Statistics of the dominant limb and segment lean volumes and relative indices of asymmetry are presented in Table XVI (p.176). The professional players had significantly larger mean lean volumes in the upper limb, arm and lower limb than the amateur players ($p < 0,01$). As could be expected, lean volumes were larger in the limbs and segments of the males than in those of the females at the 1 percent level of confidence. Although large variations in lean volume were observed in the four groups, the amateurs tended to have the highest coefficients of variation.

Differences in mean lean volume RIA were not significant between the sexes, with the exception of the lower limb, where the male amateurs and the female professionals had significantly greater RIA's ($p < 0,04$). The professional players had significantly greater lean volume RIA's than the amateurs in the upper limb and arm ($p < 0,05$). The female professionals and the male amateurs had significantly greater forearm RIA's. The highest RIA's in all four groups were found in the forearm as can be seen from Table XVI.

Cumulative percentages of dominant upper limb and forearm lean volumes in the four groups are shown in Figures 6 (p 177) and 7 (p.178) respectively. Upper limb lean volumes ranged from 2100 to 6600 cubic centimetres, while forearm lean volumes ranged from 800 to 3400 cubic centimetres.

4.3.2 Dominant limb and segment bone indices and RIA's

Dominant limb and segment bone indices (determined by expressing bone mass as a percentage of body mass) did not differ significantly between the professional and amateur players with the exception of lower limb indices, where the female amateurs recorded a larger index than the female professionals at the 5 percent level (Table XVII, p.179). Differences in upper limb bone index, in which bone area (cross-sectional) was expressed as a percentage of body surface area (upper limb BSA), were also statistically non-significant.

Male-female differences, at the 1 percent level of significance were found to favour the males in all measures with the exception of the lower limb. The difference in lower limb bone index between the professionals was significant at the 5 percent level (in favour of the males) but the difference between the amateurs was not significant.

The only significant bone RIA differences were found in the forearm and favoured the professionals. It is clear from Table XVII that in all four groups the largest RIA values were found in the forearm.

Cumulative percentages of dominant upper limb bone index in the four groups are presented in Figure 8 (p.180). Bone indices ranged from 0,41 to 0,86 percent.

4.3.3 Dominant limb and segment muscle indices and RIA's

From Table XVIII (p.181) it is evident that the professionals and amateurs had similar muscle indices with the exception of those for the *upper limb (BSA), where* the professionals had statistically greater indices than the amateurs at the 1 percent level of confidence.

The males had larger muscle indices than the females ($p < 0,01$) with the exception of those for the lower limb, where the females had a larger relative muscle mass than the males. However, differences were not statistically significant.

Significant muscle RIA differences between the professionals and amateurs were found in the upper limb and arm where the professionals had greater mean RIA's ($p < 0,05$). The female professionals also had a larger mean forearm RIA than the female amateurs ($p < 0,05$).

The female professionals had significantly greater mean muscle RIA values in the forearm and lower limb than the male professionals ($p < 0,05$), while the male amateurs had larger mean values in the forearm and lower limb than the female amateurs ($p < 0,05$).

As in the case of lean volume and bone index,the highest mean RIA values for all four groups were recorded in the forearm.

Ogives depicting cumulative percentages of the upper limb muscle index are displayed in Figure 9 (p.182). Values ranged from 4,1 to 7,5 percent.

4.3.4 Dominant limb and segment skin-fat indices and RIA's

Mean skin-fat indices of the professionals and amateurs did not differ significantly. (Table XIX, p.183). The female professionals had slightly higher mean indices than the female amateurs.

The males had smaller mean skin-fat indices than the females at the one percent level of significance.

No significant RIA differences amongst the four groups were found. The positive upper limb, arm and forearm RIA values indicated that there was more adipose tissue in the dominant than in the non-dominant limb-segments.

Ogives of the dominant upper limb skin-fat indices of the four groups are shown in Figure 10 (p.184). Indices ranged from 0,5 to 2,2 percent.

4.3.5 Body composition

Percentage body fat, fat mass and fat rating differences between the professionals and amateurs were small and statistically non-significant, as can be seen from Table XX (p.185).

The lean and 'ideal' body masses of the professionals were on average larger than those of the amateurs ($p < 0,01$).

Predictably, the males were found to have smaller body fat percentages and fat masses and larger lean and 'ideal' body masses than the females at the one percent level of significance.

Fat rating differences between the sexes were statistically non-significant. The female professionals' negative fat rating of 3,0 kg, indicating a loss of 3,0 kg of fat for the attainment of 'ideal' body mass, was the highest of the four groups.

As can be seen from Table XX, percentage body fat and fat mass varied greatly among the tennis players.

Cumulative percentages of percentage body fat (ranging from 7 to 31 percent), lean body mass (ranging from 41 to 80 kilograms) and 'ideal' body mass (ranging from 45 to 89 kilograms) are presented in Figures 11 (p.186), 12 (p.187) and 13 (p.188) respectively.

4.3.6 Somatotype

Somatotype component, dispersion and somatoplot statistics are presented in Table XXI (p.189). Although differences between the male professionals and amateurs in respect of the three somatotype components were statistically non-significant, the female professionals had higher mesomorphic ratings ($p < 0,06$) and lower ectomorphic ratings ($p < 0,01$) than the female amateurs.

The somatotypes (somatoplots) of the male professionals and amateurs differed at the 6 percent level of significance, while those of the female professionals and amateurs differed at the 0,1 percent level of significance.

From Table XXI (p.189) it is clear that the amateurs had smaller somatotype dispersion indices (SDI) than the professionals. Somatotype distributions on the somatogram of the males and females are shown in Figures 14 (p.190) and 15 (p.191) respectively.

Table XVI: Dominant limb and segment lean volumes (cm^3 x 1000) and RIA's of tennis players

	$\bar{X}$				$S_{\bar{x}}$				CV				n			
	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA
Upper limb	5,02	4,52	3,30	2,93	0,12	0,19	0,09	0,11	13,3	22,3	11,3	12,8	33	28	19	11
	└─ 1	─┘	└─ 1	─┘												
	└─ 1	──	─┘													
		└──	──	1 ─┘												
RIA	9,9	6,8	13,5	7,9	1.31	1,22	1,54	2,86	-	-	-	-	33	28	19	11
	└─ 5	─┘	└─ 5	─┘												
Arm	2,13	1,91	1,39	1,21	0,04	0,08	0,03	0,05	11,9	22,8	9,9	12,7	33	28	19	11
	└─ 1	─┘	└─ 1	─┘												
	└─ 1	──	─┘													
		└──	──	1 ─┘												
RIA	9,9	6,8	13,5	7,9	1,31	1,22	1,54	2,88	-	-	-	-	33	28	19	11
	└─ 5	─┘	└─ 5	─┘												
Forearm	1,50	1.48	0,83	0,80	0,04	0,09	0,03	0,05	16,5	33,0	15,6	17,8	33	28	19	11
	└─ 1	──	─┘													
		└──	──	1 ─┘												
RIA	15,7	17.2	21,3	11.2	1,05	1,28	1.31	1,87	-	-	-	-	33	28	19	11
	└─ 1	─┘	└─ 1	─┘												
Lower limb	15,50	13,93	12,41	11,46	0,36	0,50	0,38	0,49	13,2	19,0	13,5	14,0	33	28	19	11
	└─ 1	─┘	└─ 1	─┘												
	└─ 1	──	─┘													
		└──	──	1 ─┘												
RIA	0,85	0,99	-0,87	0,34	0,28	0,32	1,04	0,73	-	-	-	-	33	28	19	11
	└─ 4	──	─┘													
		└──	──	4 ─┘												

Means connected by arrows differ significantly at the percentage levels shown.

RIA = relative index of asymmetry between dominant (D) and non-dominant (ND) values (+ RIA = D > ND, - RIA = ND > D).

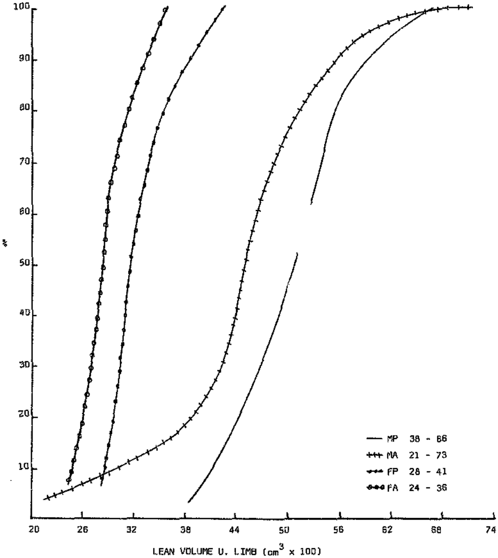


Figure 6: Cumulative percentages of dominant upper limb lean volume in tennis players

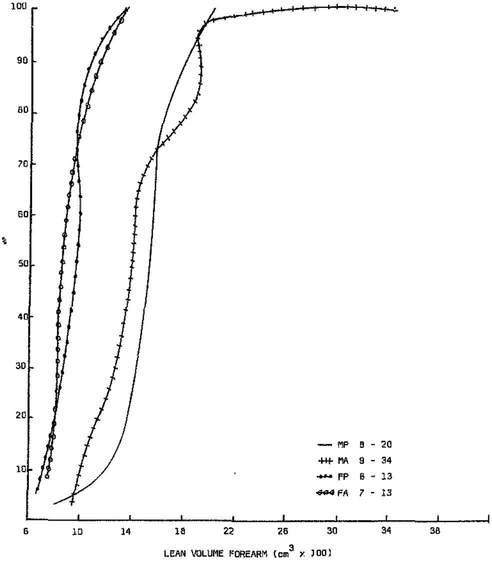


Figure 7: Cumulative percentages of dominant forearm lean volume in tennis players

Table XVII: Dominant limb and segment bone indices and *RIA's of tennis players*

	$\bar{X}$				$S\bar{x}$				CV				n			
	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA
Upper limb	0,66	0,65	0,55	0,59	0,01	0,01	0,02	0,02	9,1	8,2	14,5	11,9	33	28	19	11
	↑___1___	_______	↑													
		↑_______	_______	1___↑												
RIA	6,9	5,3	5,4	5,6	0,95	1.13	1,15	2,22	-	-	-	-	33	28	19	11
Upper limb (BSA)	0,02	0,02	0,01	0,01	,0003	,0004	,0008	,0007	7,5	10,8	28,1	22,1	33	28	19	11
	↑___1___	_______	↑													
		↑_______	_______	1___↑												
RIA	6,9	5,3	5,4	5,8	0,95	1.13	1,15	2,22	-	-	-	-	33	28	19	11
Arm	0,28	0,28	0,23	0,25	0,01	0,01	0,01	0,01	10,7	14,3	17,4	16,0	33	28	19	11
	↑___1___	_______	↑													
		↑_______	_______	1___↑												
RIA	6,9	5,3	5,4	5,8	0,95	1.13	1,15	2,22	-	-	-	-	33	28	19	11
Forearm	0,14	0,15	0,12	0,13	0,003	0,01	0,004	0,003	14,4	26,7	16,7	7,7	33	28	19	11
	↑___1___	_______	↑													
		↑_______	_______	1___↑												
RIA	10,1	8,5	16,0	9,1	0,96	2,09	1,40	1,80	-	-	-	-	33	28	19	11
	↑___2___	↑	↑___2___	↑												
Lower limb	1,07	1,07	0,98	1,15	0,01	0,02	0,03	0,03	7,5	10,3	11,2	8,7	33	28	19	11
	↑___5___	_______	↑													
			↑___5___	↑												
RIA	-0,20	0,71	-1.42	0,34	0,85	0,72	0,63	1.32	-	-	-	-	33	28	19	11

Means connected by arrows differ significantly at the percentage levels indicated.
RIA = relative index of asymmetry between dominant (D) and non-dominant (ND) value (+ RIA = D > ND, - RIA = ND > D).

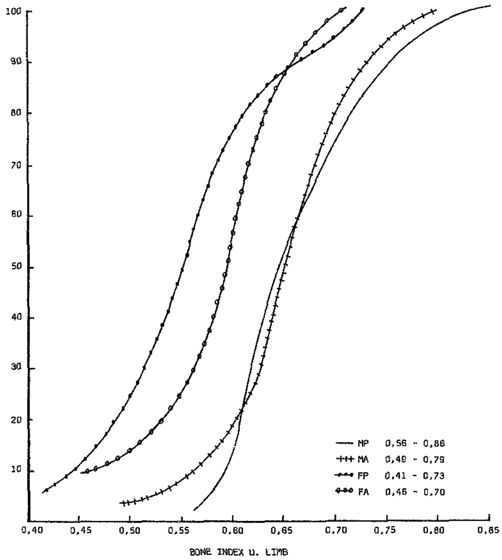


Figure 8: Cumulative percentages of dominant upper limb bone index in tennis players

Table XVIII: Dominent limb and segment muscle indices and RIA's of tennis players

	X̄				Sx̄				CV				n			
	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA
Upper limb	6,10	5,84	5,00	4,77	0,11	0,12	0,11	0,13	10,3	10,9	9,2	9,2	33	28	19	11
	↑	1	↑													
		↑	1	↑												
RIA	10,1	9,1	14,2	8,2	1,40	1,32	1,70	3,1	-	-	-	-	33	28	19	11
	↑ 5	↑	↑ 5	↑												
Upper limb (BSA)	0,32	0,31	0,30	0,27	0,01	0,01	0,01	0,01	10,5	13,2	10,7	10,4	33	28	19	11
	↑ 1	↑	↑ 1	↑												
	↑	1	↑													
		↑	1	↑												
RIA	9,5	8,2	11,4	7,7	1,37	1,20	1,41	2,34	-	-	-	-	33	28	19	11
Arm	2,60	2,51	2,11	1,98	0,05	0,05	0,04	0,08	10,0	11,5	7,8	10,6	33	28	19	11
	↑	1	↑													
		↑	1	↑												
RIA	10,1	9,1	14,2	8,2	1,40	1,32	1,70	3,1	-	-	-	-	33	28	19	11
	↑ 5	↑	↑ 5	↑												
Forearm	1,87	2,01	1,43	1,50	0,05	0,11	0,05	0,07	14,4	29,9	15,4	16,0	33	28	19	11
	↑	1	↑													
		↑	1	↑												
RIA	18,0	17,7	21,6	11,3	1,08	1,30	1,33	2,00	-	-	-	-	33	28	19	11
	↑	5	↑													
			↑ 5	↑												
		↑	5	↑												
Lower limb	18,5	19,1	19,7	19,7	0,34	0,23	0,83	0,82	8,9	6,3	13,8	13,8	33	28	19	11
RIA	0,90	1,01	-0,98	0,34	0,79	0,34	1,09	0,77	-	-	-	-	33	28	19	11
	↑	5	↑													
		↑	5	↑												

Means connected by arrows differ significantly at the percentage levels indicated.
RIA = relative index of asymmetry between dominant (D) and non-dominant (ND) value [+ RIA = D > ND, - RIA = ND > D].

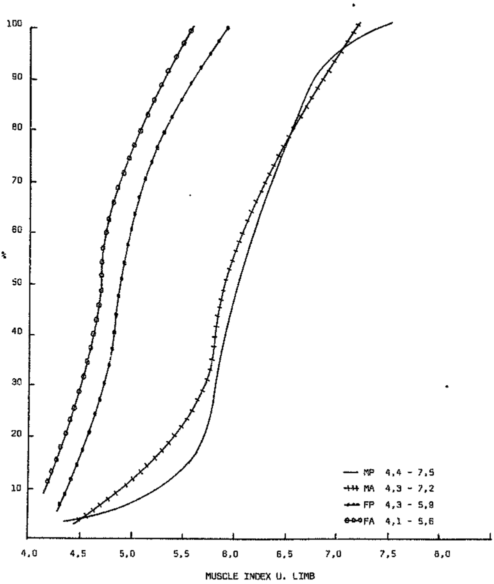


Figure 9: Cumulative percentages of dominant upper limb muscle index in tennis players

Table XIX: Dominant limb and segment skin-fat indices and RIA's of tennis players

	$\bar{X}$				$S\bar{x}$				CV				n			
	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA
Upper limb	0,70	0,68	1,23	1,15	0,03	0,03	0,09	0,10	21,4	23,5	32,5	27,8	33	28	19	11
	↑	1	↑													
		↑		1 ↑												
RIA	4,7	1,1	1,5	6,2	1,82	1,59	2,06	4,18	-	-	-	-	33	28	19	11
Upper limb (BSA)	0,04	0,04	0,07	0,06	,002	,002	,010	,010	25,0	25,0	42,9	33,3	33	28	19	11
	↑	1	↑													
		↑		1 ↑												
RIA	4,6	0,8	6,9	6,1	1,85	1,63	6,67	4,35	-		-	-	33	28	19	11
Arm	0,30	0,28	0,52	0,48	0,01	0,01	0,04	0,04	23,3	24,1	32,7	29,2	33	28	19	11
	↑	1	↑													
		↑		1 ↑												
RIA	4,7	1,1	1,5	6,2	1,82	1,59	2,06	4,18	-	-	-	-	33	28	19	11
Forearm	0,22	0,23	0,36	0,36	0,01	0,02	0,02	0,03	22,7	39,1	25,0	25,0	33	28	19	11
RIA	7,6	5,2	5,1	7,7	1,61	1,56	2,05	4,70	-	-	-	-	33	28	19	11
Lower limb	1,55	1,76	3,89	3,76	0,08	0,11	0,48	0,34	29,7	31,8	54,2	30,1	33	28	19	11
	↑	1	↑													
		↑		1 ↑												
RIA	-3,6	-1,7	1,4	-0,5	1,85	2,04	3,68	2,06	-	-	-	-	33	28	18	11

Means connected by arrows differ significantly at the percentage levels indicated.
RIA = relative index of asymmetry between dominant (D) and non-dominant (ND) value (+ RIA = D > ND, - RIA = ND > D).

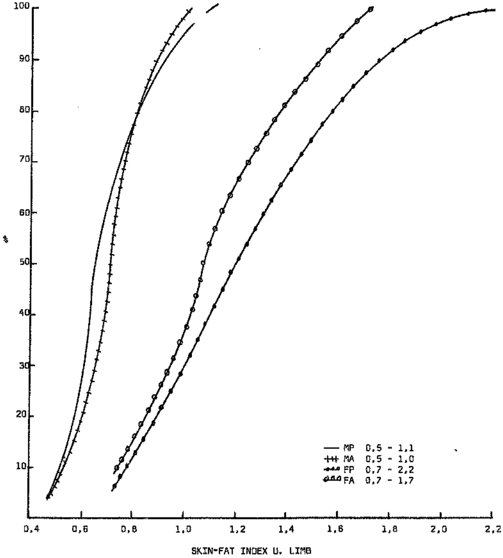


Figure 10: Cumulative percentages of dominant upper limb skin-fat index in tennis players

Table XX: Body composition of tennis players

	$\bar{X}$				$S\bar{x}$				CV				n			
	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA
Percentage body fat (relative)	11,8	12,0	22,1	20,5	0,55	0,62	1,06	0,85	26,6	27,7	20,9	13,7	33	28	19	11
Fat mass (kg) (absolute)	9,0	8,4	13,7	11,6	0,52	0,72	0,92	0,71	32,8	45,4	29,3	20,3	33	28	19	11
Lean body mass (kg)	67,4	60,2	47,8	44,3	0,99	2,00	0,84	0,69	8,5	17,6	7,7	5,2	33	28	19	11
'Ideal' body mass (kg)*	74,7	68,0	58,3	54,2	1,11	2,01	1,05	0,88	8,5	15,4	7,9	5,4	33	28	19	11
Fat rating (kg)**	-1,8	-2,0	-3,0	-1,8	0,45	0,52	0,73	0,51	—	—	—	—	33	28	19	11

Means connected by arrows differ significantly at the percentage levels shown.

*'Ideal' body fat = 9,5% (male) and 17,5% (female).

**Negative sign = fat mass loss for 'ideal' body mass.

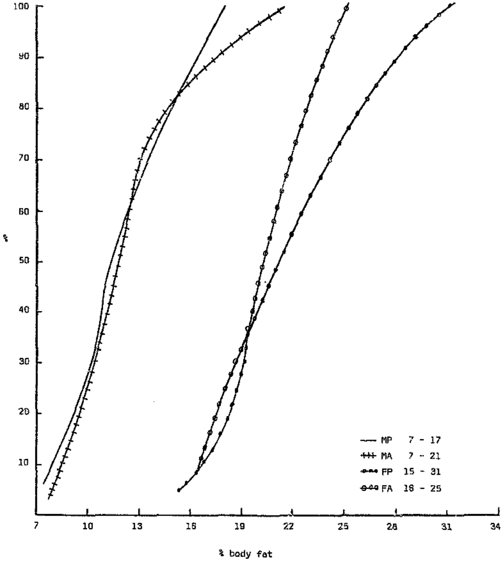


Figure 11: Cumulative percentages of percentage body fat in tennis players

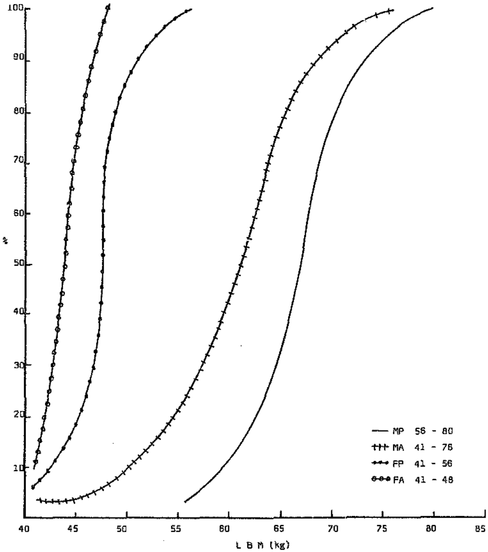


Figure 12: Cumulative percentages of lean body mass in tennis players

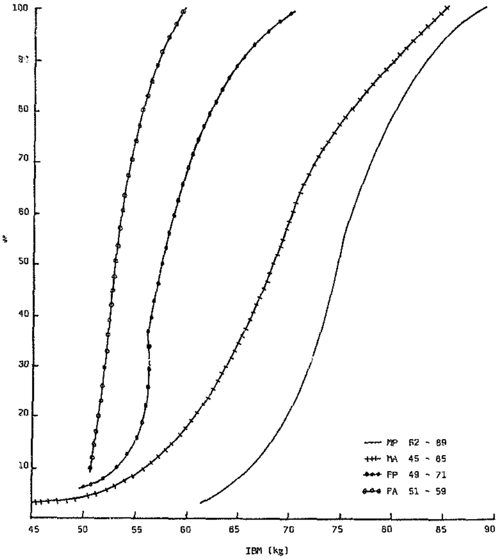
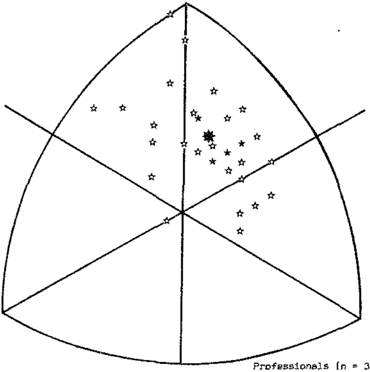


Figure 13: Cumulative percentages of 'ideal' body mass in tennis players

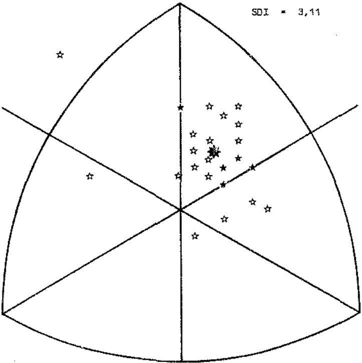
Table XXI: Somatotype components, dispersion and somatoplots of tennis players

	$\bar{X}$				$S\bar{x}$				CV				n			
	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA
Endomorphy	2,2	2,2	3,1	2,6	0,16	0,20	0,29	0,24	41,4	46,8	39,6	29,8	33	28	19	11
	↑	1	↑													
Mesomorphy	4,6	4,3	3,9	3,2	0,17	0,18	0,23	0,29	21,7	22,3	24,8	28,3	33	28	19	11
			↑ 6	↑												
	↑	2	↑													
Ectomorphy	3,0	3,2	2,6	3,6	0,15	0,14	0,20	0,24	29,2	22,9	32,6	20,3	33	28	19	11
			↑ 1	↑												
Somatoplot X co-ordinate	0,8	1,0	-0,5	1,1	0,25	0,29	0,45	0,36	-	-	-	-	33	28	19	11
	↕ 6	↕	↕ ,1	↕												
Y co-ordinate	4,1	3,2	2,1	0,2	0,46	0,44	0,54	0,85	-	-	-	-	33	28	19	11
	↑↑	1	↑↑													
	MP				MA				FP				FA			
Somatotype dispersion index (SDI)	3,11				2,74				3,54				2,80			

Means connected by arrows differ significantly at the percentage levels indicated.

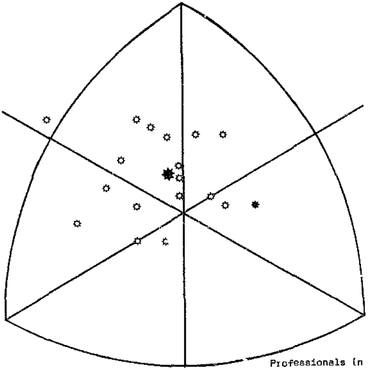


Professionals (n = 33)
SDI = 3,11



Amateurs (n = 28)
SDI = 2,74

Figure 14: Somatotype distributions of male tennis players
(✷ = mean, ☆ = 1 somatoplot, ★ = 2 somatoplots)



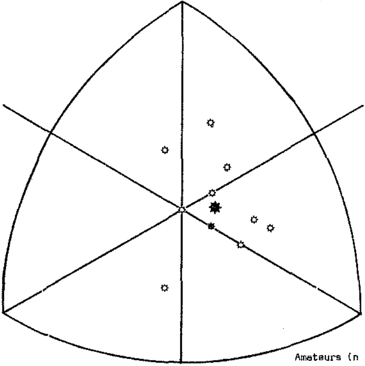


Figure 15: Somatotype distributions of female tennis players
(✸ = mean, ✡ = 1 somatoplot, ✱ = 2 somatoplots)

4.4 PHYSIOLOGICAL OBSERVATIONS

Statistics of the physiological tests and measurements are presented in Tables XXIII to XXVI and include means, significant differences, standard errors and coefficients of variation. Since the coefficient of variation is not defined for negative values, this statistic has been excluded for RIA values in Table XXV. Means that differed significantly at the five and one percent levels are connected by arrows.

Recordings of environmental conditions in terms of ambient temperature (dry bulb), relative humidity and barometric pressure during the eleven-day data collection period, are shown in Table XXII (p.195). These data were required for a number of the physiological assessments. The average morning and afternoon ambient temperature ranged from 16,0 to 30,0 degrees Celsius, while relative humidity varied from 12,5 to 84,0 percent. Barometric pressure fluctuations were between 626 and 629 mm Hg.

4.4.1 Maximal aerobic power, mechanical efficiency, energy cost and sweat-rate

The professional players had higher absolute $\dot{V}O_2$ max values than the amateurs at the one percent level of significance (Table XXIII, p.196). However, when $\dot{V}O_2$ max was expressed relatively, differences between the professionals and amateurs were statistically non-significant.

Predictably, the males had greater mean values for absolute $\dot{V}O_2$ max than the females ($p < 0,01$). The females had larger mean values for relative $\dot{V}O_2$ max (ml/kg/min) than the males, as is evident from Table XXIII. Ogives of $\dot{V}O_2$ max (ml/kg/min) are shown in Figure 16 (p.197) and, as can be seen, values ranged from 31 to 85 ml/kg/min.

When $\dot{V}O_2$ max was expressed in millilitres of oxygen per kilogram of lean body mass per min (ml/kg LBM/min), the females had higher values than the males ($p < 0,01$). The female professionals' value of 71,6 ml/kg LBM/min was exceptionally high.

From Table XXIII it is evident that differences in mechanical efficiency and energy cost of tennis playing among the four groups were statistically non-significant.

The males had higher mean absolute sweat-rates (ℓ/hr) than the females ($p < 0,03$) but differences in the mean relative sweat-rates ($ℓ/m^2/hr$) between the sexes were found to be statistically non-significant. Considerable variation in sweat-rate was evident in all four groups. Ogives of sweat-rate for the four groups are shown in Figure 17 (p.198). Sweat-rates ranged from 0,48 to 2,15 litres per hour.

4.4.2 Static and dynamic pulmonary volumes

It is apparent from Table XXIV (p.199) that the professional players had larger static and dynamic pulmonary volumes than the amateur players ($p < 0,01$), with the exception of tidal volume and FEV_1I, where differences were not statistically significant.

As expected, the males were found to have larger values than the females at the one percent level of significance for all the pulmonary measures (tidal volume at the three percent level) with the exception of FEV_1I, where differences were non-significant. Generally, the females had smaller variations in static and dynamic pulmonary volumes than the males. Cumulative percentages of FEV_1 are shown in Figure 18 (p.200). Values ranged from 2,6 to 6,8 litre per second.

4.4.3 Static flexibility and RIA's

Although the professional players had greater flexibility than the amateur players in most joints, only trunk flexion-extension differences (in favour of the professionals) were found in both sexes to be statistically significant at the one percent level (Table XXV, p.201). Generally, the highest measures of flexibility were recorded in the shoulder flexion-extension test.

The females had greater supination-pronation ($p < 0,01$), hip flexion-extension ($p < 0,01$) and hip abduction ($p < 0,05$) than the males. The males, in turn, had greater trunk flexion-extension than the females at the one percent level of significance.

Differences in RIA values among the groups were insignificant and the high frequency of negative RIA values indicated that, in most of the tests, the non-dominant joint had greater flexibility than the dominant joint.

4.4.4 Ocular-dominance, handedness and eye-limb concordance/discordance

The relationship between tennis proficiency, ocular dominance, handedness and eye-limb concordance/discordance is shown in Table XXVI (p.202). Frequencies and percentage frequencies of the four groups are also included.

Although percentage frequencies of right-and left-eyed dominance were exactly the same among the players as a whole, the majority of the males were left-eyed (54,2 percent), while the majority of the females were right-eyed (57,6 percent). Right-eyed dominance was significantly related to proficiency in the females but not in the males.

The large majority of the players were right-handed, 82,1 percent of the males and 89,2 percent of the females. Handedness or upper limb dominance and proficiency were found to be independent of one another.

The majority of the subjects were unilateral (55,4 percent). In respect of the professional players, 53,1 percent of the males and 71,4 percent of the females were unilateral. Unilaterality was significantly related to proficiency in the females but not in the males as can be seen from Table XXVI.

Table XXII: Ambient temperature, relative humidity and barometric pressure during the eleven-day tennis study

Day	Ambient temperature (°C)	Relative humidity (%)	Barometric pressure (mm Hg)
1	30,0	36,0	629
2	26,8	47,0	629
3	30,0	36,0	628
4	23,5	48,0	628
5	23,5	59,5	629
6	16,0	84,0	629
7	28,5	48,0	628
8	17,8	29,3	626
9	17,0	26,0	629
10	18,0	20,0	628
11	20,5	12,5	629
$\bar{X}$	22,9	40,6	628,4
SD	5,4	20,0	0,9
S$\bar{x}$	1,6	6,0	0,3
CV	23,6	49,3	0,1

Table XXIII: Maximal aerobic power, mechanical efficiency, energy cost and sweat-rate of tennis players

	$\bar{x}$				$S_{\bar{x}}$				CV				n			
	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA
$\dot{V}O_2$ max (ℓ/min)	3,8	3,4	3,4	2,9	0,14	0,12	0,24	0,24	20,1	17,4	27,6	26,5	31	24	16	10
	↑ 1	↑	↑ 1	↑												
	↑ 1		↑													
		↑ 1		↑												
$\dot{V}O_2$ max (mℓ/kg/min)	50,0	48,8	56,6	51,4	1,56	1,88	3,49	3,75	17,3	18,9	24,7	23,0	31	24	16	10
$\dot{V}O_2$ max (mℓ/LBM/min)	56,8	55,6	71,6	64,9	1,77	2,00	4,31	4,95	17,4	17,6	24,1	24,1	31	24	16	10
	↑ 1		↑													
		↑ 1		↑												
Mechanical efficiency (Net %)	30,1	27,5	27,8	29,5	1,40	1,44	0,96	1,86	25,5	25,1	13,4	18,9	30	23	15	9
Energy cost (kJ/min)	36,8	35,4	-	26,8	4,90	2,95	-	-	18,8	23,6	-	-	2	8	0	1
$\dot{V}O_2$ % $\dot{V}O_2$ max	39,4	51,6	-	42,3	9,30	4,67	-	-	33,4	24,0	-	-	2	7	0	1
Sweat-rate (ℓ/hr)	1,3	1,2	0,8	0,9	0,10	0,09	0,26	0,13	30,6	30,1	61,9	29,5	14	13	4	5
	↑ 3		↑													
		↑ 3		↑												
Sweat-rate/ BSA (ℓ/m^2/hr)	0,67	0,66	0,51	0,53	0,05	0,05	0,15	0,08	29,9	25,8	56,9	28,3	14	12	4	4

Means connected by arrows differ significantly at the percentage levels shown.

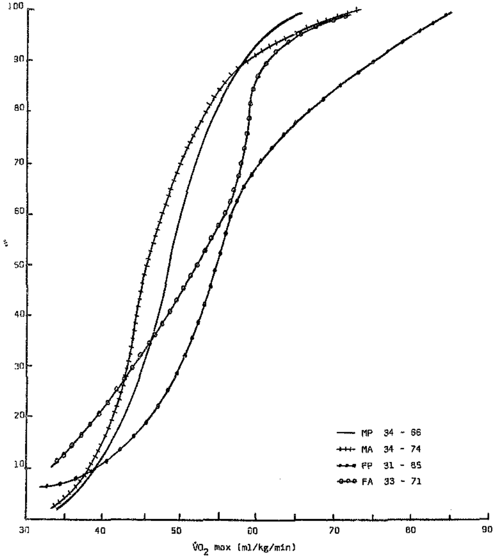
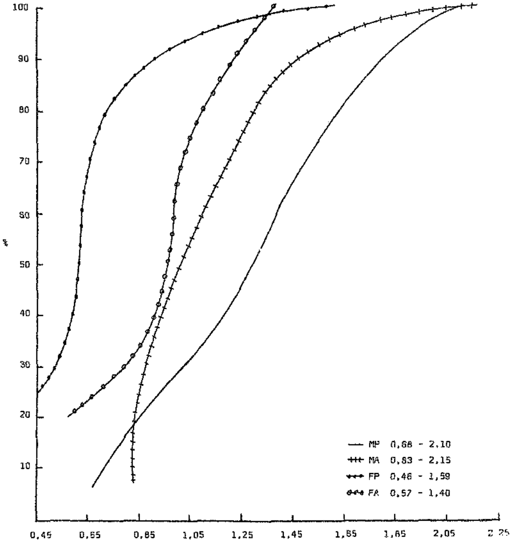


Figure 16: Cumulative percentages of maximal aerobic power in tennis players



<u>Figure 17</u>: Cumulative percentages of sweat-rate in tennis players

Table XXIV: Static and dynamic pulmonary volumes (ℓ) of tennis players

	$\bar{X}$				$S\bar{x}$				CV				n			
	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA
Tidal volume	0,93	0,95	0,80	0,73	0,06	0,06	0,05	0,08	35,8	33,9	24,0	29,1	30	26	14	7
Inspiratory reserve volume	3,0	2,6	2,1	1,7	0,10	0,03	0,09	0,10	18,7	16,7	17,1	15,5	30	26	14	7
Expiratory reserve volume	2,0	1,8	1,4	1,1	0,08	0,10	0,10	0,06	24,0	27,4	25,5	14,1	30	26	14	7
Inspiratory capacity	3,9	3,6	2,9	2,5	0,09	0,12	0,08	0,08	12,2	16,6	10,7	8,4	30	26	14	7
Vital capacity	5,9	5,3	4,2	3,5	0,15	0,17	0,10	0,09	13,6	16,0	8,5	7,0	30	26	14	7
Vital capacity/BSA (ℓ/m²)	3,0	2,8	2,5	2,2	0,06	0,06	0,05	0,08	11,5	10,6	7,8	9,1	29	25	14	7
Forced expiratory volume (ℓ/sec)	5,1	4,6	3,7	3,2	0,13	0,13	0,09	0,09	13,6	15,1	8,9	7,1	30	26	14	7
FEV_1I (%)	85,7	85,9	85,9	91,6	1,41	1,18	2,06	1,11	9,0	7,0	9,0	3,2	30	26	14	7

Means connected by arrows differ significantly at the percentage levels indicated.

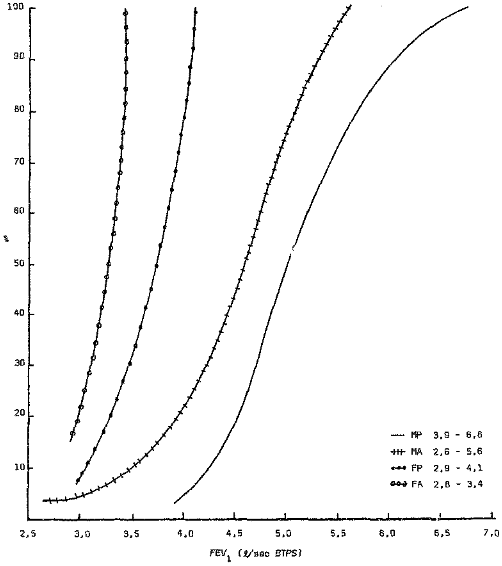


Figure 18: Cumulative percentages of forced expiratory volume in tennis players

Table XXV: Static flexibility (°) and RIA's of tennis players

	$\bar{X}$				$S_{\bar{x}}$				CV				n			
	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA
Shoulder flexion-extension*	202,9	203,1	204,4	189,1	4,08	3,12	5,23	8,83	11,2	8,0	10,2	15,5	31	27	16	11
RIA	-3,4	-1,5	0,8	-9,5	2,72	1,68	2,57	5,64	-	-	-	-	31	27	16	11
Shoulder rotation*	168,1	164,4	168,9	162,7	2,86	2,27	3,35	5,67	9,6	7,2	8,2	11,6	32	27	17	11
RIA	-0,80	-2,49	-0,81	-0,22	1,79	2,17	2,32	5,70	-	-	-	-	31	27	17	11
Elbow flexion-extension*	165,7	161,0	172,8	165,5	2,66	2,73	3,49	4,70	8,9	8,8	8,3	9,4	31	27	17	11
RIA	-1,2	-1,1	1,5	1,2	1,60	1,58	1,94	2,36	-	-	-	-	31	27	17	11
Supination -pronation*	190,6	186,7	225,7	208,9	8,39	6,24	7,40	6,84	23,7	17,4	13,5	10,9	29	27	17	11
	↑	1	↑													
		↑	1	↑												
RIA	-9,5	-9,3	-8,3	-9,4	2,80	3,81	2,66	3,14	-	-	-	-	29	27	17	11
Wrist flexion-extension*	93,8	91,8	100,9	88,7	5,24	4,93	4,71	2,95	30,6	27,9	19,2	11,0	30	27	17	11
RIA	-9,1	-5,3	-0,7	-5,8	3,68	2,52	3,56	2,80	-	-	-	-	30	27	17	11
Hip flexion-extension	116,1	112,6	139,7	140,4	3,10	3,00	5,42	4,80	14,9	13,8	15,5	10,9	31	27	16	11
	↑	1	↑													
		↑	1	↑												
Hip abduction	51,6	50,4	63,6	54,5	2,27	1,73	8,00	3,18	-	-	-	-	31	27	16	11
	↑	5	↑													
		↑	5	↑												
Trunk flexion-extension	68,8	57,6	56,0	48,6	3,06	3,03	4,60	4,27	24,4	26,8	30,7	29,1	31	26	15	11
	↑ 1	↑	↑ 1	↑												
	↑	1	↑													
		↑	1	↑												
Trunk lateral flexion	109,8	111,0	123,1	105,2	2,50	4,87	4,20	3,64	-	-	-	-	31	27	16	11

* Dominant value (handedness). Means connected by arrows *differ significantly at the percentage* levels indicated.
RIA = relative index of asymmetry between dominant (D) and non-dominant (ND) value (+ RIA = D > ND, - RIA = ND > D).

Table XXVI: Contingency table depicting the relationship between tennis proficiency, ocular dominance, handedness and eye-limb concordance/discordance

	Ocular dominance				χ^2	Handedness				χ^2	Eye-limb concordance/ discordance				χ^2
	Right-eyed		Left-eyed			Right-handed		Left-handed			Unilateral		Crossed lateral		
	f	%f	f	%f		f	%f	f	%f		f	%f	f	%f	
Male professionals	13	40,6	19	59,4	0,74	27	79,4	7	20,6	0,34	17	53,1	15	46,9	0,03
Male amateurs	14	51,9	13	48,1		28	84,8	5	15,2		15	55,6	12	44,4	
Male total	27	45,8	32	54,2		55	82,1	12	17,9		32	54,2	27	45,8	
Female professionals	15	71,4	6	28,6	4,54*	21	95,5	1	4,5	2,21	15	71,4	6	28,6	4,5*
Female amateurs	4	33,3	8	66,7		12	80,0	3	20,0		4	33,3	8	66,7	
Female total	19	57,6	14	42,4		33	89,2	4	10,8		19	57,6	14	42,4	
Professionals (male + female)	28	52,8	25	47,2	0,40	48	85,7	8	14,3	2,00	32	60,4	21	39,6	1,24
Amateurs (male + female)	18	46,2	21	53,8		40	83,3	8	16,7		19	48,7	20	51,3	
Professional + amateur total	46	50,0	46	50,0		88	84,6	16	15,4		51	55,4	41	44,6	

* $p < 0,05$

4.5 BIOCHEMICAL OBSERVATIONS

The pre- and post-match glucose, lactate and electrolyte concentrations are shown in Table XXVII (p.204). Differences among the group means were non-significant for all the measures with the exception of the females' pre-match sodium concentrations, which were significantly higher than the males ($p < 0,05$).

Comparisons between the pre- and post-match concentrations within each of the four groups showed that sodium concentrations in the male and female professionals differed significantly in favour of the post-match values at the 6 and 8 percent levels respectively.[✱] Blood glucose concentrations in both the male groups differed significantly in favour of the post-match values at the 7 percent level of confidence. Low post-match lactate concentrations were recorded for all the groups.

The post-match values were greater than the pre-match values for all the measures except magnesium. The male professionals' post-match magnesium concentration was larger than the pre-match value as can be seen from Table XXVII.

[✱] A significance of up to 10 percent is generally acceptable in biochemical studies since the heterogeneity in human beings results in large standard deviations and standard errors of the mean. As a result of of the large variation, it is difficult to detect differences at the 5 and 1 percent levels of significance.

Table XXVII: Pre- and post-match glucose, lactate and electrolyte concentrations in tennis players

	$\bar{X}$				$S_{\bar{x}}$				CV				n			
	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA	MP	MA	FP	FA
Glucose 1 (mg %)	85,4	80,3	92,0	83,2	4,72	4,42	4,63	-	15,6	15,1	10,1	-	8	12	4	1
	↕— 7	↕— 7														
2	108,1	89,8	92,2	92,4	11,73	2,60	8,36	-	28,7	10,0	18,1	-	7	12	4	1
Lactate 1 (m moles/ℓ)	1,8	2,0	1,8	1,6	0,17	0,26	0,25	-	26,3	44,0	27,0	-	8	12	4	1
	↕— 10															
2	2,6	2,1	2,3	2,1	0,45	0,33	0,70	-	46,4	53,0	60,0	-	7	12	4	1
Calcium 1 (mEq/ℓ)	4,9	5,2	4,8	4,7	0,10	0,34	0,14	-	6,0	22,9	5,7	-	8	12	4	1
2	5,0	5,2	4,9	4,8	0,12	0,37	0,13	-	6,4	24,3	5,5	-	7	12	4	1
Sodium 1 (mEq/ℓ)	136,1	136,8	138,5	142,3	0,83	0,75	1,02	-	1,7	1,6	1,5	-	8	11	4	1
	↑— 5 —	———	—↑ ↕— 8													
	↕— 6	↑———	——— 5 —	—↕												
2	140,7	138,4	141,3	144,0	1,05	1,86	1,16	-	2,0	4,5	1,6	-	7	11	4	1
Magnesium 1 (mEq/ℓ)	2,0	2,2	2,1	1,9	0,07	0,17	0,10	-	10,2	25,6	9,1	-	8	12	4	1
2	2,1	2,1	2,0	1,9	0,08	0,18	0,13	-	10,0	28,5	13,3	-	7	12	4	1
Chloride 1 (mEq/ℓ)	103,4	101,2	103,6	-	2,61	1,89	2,00	-	5,1	4,9	3,3	-	4	7	3	0
2	104,8	101,7	106,2	-	2,62	1,80	1,46	-	5,0	4,7	2,4	-	4	7	3	0

Means connected by arrows differ significantly at the percentage levels indicated.

1 = pre-match concentration.

2 = post-match concentration.

4.6 ANALYSIS OF COVARIANCE

4.6.1 Morphological variables

Differences in the adjusted means of morphological variables among the four groups are shown in Table XXVIII (p.207). The covariates or variables that were held constant are shown in the centre column and adjusted means that differed significantly are connected by arrows.

Comparisons of the results of the analyses of covariance and variance indicated the following:

A. Differences and significance levels among the four groups determined by the analysis of covariance (Table XXVIII) and variance (Tables XI, XV, XVIII and XX), were found to correspond for the following variables: *body mass (stature)*[☆], *androgyny (mass and stature)*, forearm lean volume (mass, stature and stylion ht) and percentage body fat (mass and stature).

B. Differences between the professionals and amateurs, found to be significant by the analysis of variance (Tables XIII, XIV, XVI and XX) but non-significant by analysis of covariance (Table XXVIII), included the following variables: biacromial diameter (BSA), forearm and contracted arm girths (mass and stature), upper limb lean volume (mass, stature and dactylion ht), lower limb lean volume (mass, stature and trochanterion ht) and LBM (mass and stature).

C. Bi-iliac diameter (BSA) and lower limb lean volume (mass, stature and trochanterion ht) differences between the sexes in favour of the males, found to be significant by the variance analysis (Tables XIII and XVI), became non-significant when the covariance analysis was conducted (Table XXVIII).

D. Fat rating differences between the professionals and amateurs (Table XXVIII), found to be non-significant by the analysis of variance, *were significant when the analysis of covariance* was conducted. The professionals had smaller fat ratings than the amateurs ($p < 0,05$), while the males had significantly smaller ratings than the females at the one percent level when mass and stature were held constant.

[☆] Variables shown in parentheses refer to the covariate(s) used in the covariance analysis.

4.6.2 Physiological variables

Differences in the adjusted means of the physiological variables among the four groups are presented in Table XXIX (p.208). The variables or covariates are given in the centre column and the adjusted means found to differ significantly are connected by arrows.

Comparisons of the results of the analyses of covariance and variance indicated the following:

A. Differences and significance levels among the groups determined by means of the analysis of covariance (Table XXIX) and variance (Tables XXIII, XXIV and XXV), were found to correspond for the following variables: $\dot{V}O_2$ max expressed in ml/kg LBM/min (stature)*, sweat-rate (age), FEV_1I (mass, stature and age), hip flexion-extension (age), shoulder flexion-extension and rotation (upper limb lean volume), and mechanical efficiency (mass, stature and FEV_1).

B. Differences between the professionals and amateurs which were found to be statistically significant in favour of the professionals by the analysis of variance (Tables XXIII and XXIV), but non-significant by the analysis of covariance (Table XXIX), included $\dot{V}O_2$ max expressed in ℓ/min (BSA), vital capacity (BSA), and FEV_1 (mass, stature and VC).

C. From Table XXIX it can be seen that for $\dot{V}O_2$ max expressed in ℓ/min (BSA), sweat-rate (% fat and BSA) and FEV_1 (mass, stature and VC) the differences between the males and females were small and non-significant. Analysis of variance, however, indicated that differences in these variables between the sexes were statistically significant in favour of the males (Tables XXIII and XXIV).

D. For elbow flexion-extension (U.L. lean vol) and trunk lateral flexion (age), the differences between the professionals and amateurs, in favour of the professionals, were found to be significant ($p < 0,05$) by the covariance analysis (Table XXIX), but non-significant by the variance analysis (Table XXV).

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* Variables shown in parentheses refer to the covariate(s) used in the analysis of covariance.

Table XXVIII: Differences in the means of morphological variables among tennis players *utilizing analysis of covariance*

Dependant variable	Adjusted $\hat{X}$ of dependent variables				Covariate/s				
	MP	MA	FP	FA		MP	MA	FP	FA
Mass (kg)	70.4	67,8	68,8	62.8	Stature	33	28	21	12
	└── 5	──┘	└── 5	──┘					
	└── 1	──	──┘						
		└──	── 1	──┘					
Androgyny	87,6	89,5	85,7	83,1	Mass, Stature	33	28	19	11
	└── 1	──	──┘						
		└──	── 1	──┘					
Stature (cm)	177,9	177,5	171,8	175,7	Mass	33	28	21	12
	└── 5	──	──┘						
Biacromial (cm)	38,5	38,9	37,5	37,0	Body surface area	33	28	20	11
	└── 1	──	──┘						
		└──	── 1	──┘					
Bi-iliac (cm)	28,0	27,1	27,1	27,8	Body surface area	33	28	20	11
Contracted arm girth (cm)*	30,6	30,8	28,8	29,3	Mass, Stature	33	28	18	11
	└── 1	──	──┘						
		└──	── 1	──┘					
Forearm girth (cm)*	27,5	27,6	26,0	26,0	Mass, Stature	33	28	19	11
	└── 1	──	──┘						
		└──	── 1	──┘					
Upper limb lean volume (cm^3 x 1000)*	4,5	4,4	3,6	3,9	Mass, Stature, Dactylion	33	28	19	11
	└── 1	──	──┘						
		└──	── 1	──┘					
Forearm lean volume (cm^3 x 1000)*	1,3	1,4	1,2	1,3	Mass, Stature, Stylion	33	28	18	11
	└── 5	──	──┘						
		└──	── 5	──┘					
Lower limb lean volume (average) (cm^3 x 1000)	14,2	13,8	13,7	13,2	Mass, Stature, Trochan	33	28	19	11
Percentage body fat	10,3	12,0	22,8	23,5	Mass, Stature	33	28	19	11
	└── 1	──	──┘						
		└──	── 1	──┘					
Fat rating (kg; - = fat loss)	-0,53	-1,84	-3,73	-4,30	Mass, Stature	33	28	19	11
	└── 5	──┘	└── 5	──┘					
	└── 1	──	──┘						
		└──	── 1	──┘					
Lean body mass (kg)	61,8	60,3	53,6	53,3	Mass, Stature	33	28	19	11
	└── 1	──	──┘						
		└──	── 1	──┘					

* Dominant value (handedness). Means connected by arrows differ significantly at the percentage levels indicated.

Table XXIX: Differences in the means of physiological variables among tennis players utilizing analysis of covariance

Dependent variable	Adjusted $\bar{X}$ of dependent variable				Covariate/s	n			
	MP	MA	FP	FA		MP	MA	FP	FA
$\dot{V}O_2$ max (ℓ/min)	3,5	3,3	3,8	3,4	Body surface area	31	24	18	10
$\dot{V}O_2$ max(mℓ/LBM/min)	58,0	56,0	69,7	63,2	Stature	31	24	16	10
	└── 5 ──	────	──┘						
		└────	────	5 ──┘					
Sweat-rate (ℓ/hr)	1,3	1,2	0,6	0,9	Percentage body fat	14	12	4	4
Sweat-rate "	1,2	1,2	1,0	1,0	Body surface area	14	12	4	4
Sweat-rate "	1,3	1,2	0,8	1,0	Age	14	12	4	5
	└── 5 ──	────	──┘						
		└────	────	5 ──┘					
Vital capacity (ℓ)	5,5	5,3	4,7	4,3	Body surface area	29	25	14	7
	└── 1 ──	────	──┘						
		└────	────	1 ──┘					
Forced expiratory volume (ℓ/sec)	4,5	4,4	4,4	4,4	Mass, Stature, VC	29	25	14	7
FEV_1%	86,5	85,4	85,5	88,5	Mass, Stature, Age	29	25	14	7
Hip flex-ext (°)	117,0	111,9	138,7	141,1	Age	31	27	16	11
	└── 1 ──	────	──┘						
		└────	────	1 ──┘					
Elbow flex-ext (°)*	168,0	162,0	169,7	161,6	Upper limb lean volume*	30	27	17	10
	└── 5 ──	──┘	└── 5 ──	──┘					
Trunk lateral flex (°)	111,0	110,3	122,0	105,8	Age	31	27	16	11
	└── 5 ──	──┘	└── 5 ──	──┘					
Shoulder flex-ext (°)*	203,2	203,4	203,5	190,2	Upper limb lean volume*	30	27	18	10
Shoulder rotation (°)*	167,1	164,8	167,3	161,3	Upper limb lean volume*	30	27	17	10
Mechanical efficiency (%)	30,4	27,5	25,6	27,2	Mass, Stature, FEV_1	27	22	11	[illegible]

* Dominant value (handedness). Means connected by arrows differ significantly at the percentage levels indicated.

4.7 CORRELATIONS

4.7.1 Professional players

Product-moment correlations found to be significant at the one and five percent levels in the professional players, are presented in Table XXX. Those correlations considered to be of relevance to this study are singled out.

A. Structural variables

From Table XXX (p.213) it can be seen that stature and mass, stature and interpupillary distance, and mass and androgyny were significantly correlated in both the males and females.

A high correlation of 0,89 ($p < 0,01$) was found between the supra-iliac skinfold and percentage body fat in the males.

Upper limb tissue indices, expressed as percentages of body mass and body surface area, were correlated significantly ($p < 0,01$) in the male and female groups.

B. Physiological and biochemical variables

From Table XXX (p.213) it can be seen that the following variables were correlated significantly ($p < 0,05$) in the male professionals: $\dot{V}O_2$ max and mechanical efficiency, sweat-rate and post-match lactate, sweat-rate and FEV_1, and sweat-rate and post-match magnesium (negative correlation).

Shoulder flexion-extension and shoulder rotation were correlated at the one percent level of significance in this group.

C. Combined variables

In the males, $\dot{V}O_2$ max (ℓ/min) was correlated with forearm and chest girth ($p < 0,01$). In the females, $\dot{V}O_2$ max (ml/min) was correlated with upper limb muscle index (negatively with $p < 0,01$), with androgyny ($p < 0,05$) and with age (negatively with $p < 0,01$) as can be seen in Table XXX (p.213).

Percentage body fat and FEV_1I, and androgyny and post-match lactate in the males indicated significant negative correlations at the five and one percent levels respectively. FEV_1 was significantly correlated ($p < 0,01$) with both forearm girth and LBM in the males.

In the female professionals, trochanterion height, bi-iliac diameter and relative lower limb length were negatively correlated with hip flexion-extension ($p < 0,01$). Biacromial diameter, androgyny and upper limb lean volume were negatively correlated with shoulder rotation.

In the male professionals, relative upper limb length and upper limb lean volume were negatively correlated with elbow flexion-extension ($p < 0,05$) while shoulder rotation, elbow flexion-extension, supination-pronation and trunk lateral flexion indicated significant negative correlations with age (Table XXX, p.213).

The females $\dot{V}O_2$ max, expressed both absolutely and relatively, was negatively correlated with age ($p < 0,01$).

In the males, the number of years played was correlated with IRV ($p < 0,05$) while in the females, VC, FEV_1 and elbow flexion-extension were correlated significantly with the number of years played ($p < 0,05$).

4.7.2 Amateur players

Product-moment correlations found to be significant in the amateur players are shown in Table XXXI. Correlations of importance are singled out.

A. Structural variables

Stature was correlated significantly with both mass and androgyny in the males, and with mass in the females.

Forearm girth indicated significant correlations ($p < 0,01$) with bi-acromial, bi-iliac and AP chest diameters in the male amateur players.

Androgyny was correlated significantly with percentage body fat ($p < 0,01$) and BSA (negatively with $p < 0,01$) in the males.

Upper limb tissue indices, expressed as percentages of body mass and body surface area, were correlated significantly at the one percent level in both the male and female amateurs (Table XXXI p.214).

B. Physiological and biochemical variables

$\dot{V}O_2$ max was found to be correlated significantly with post-match glucose ($p < 0{,}01$) and sodium (negative with $p < 0{,}01$) concentrations, as well as with FEV_1 (negatively with $p < 0{,}01$) in the male amateurs. In the females, $\dot{V}O_2$ max (ℓ and ml) was also highly negatively correlated with FEV_1 at the 5 percent level (Table XXXI, p.214).

The males' sweat-rate was correlated significantly with their FEV_1 and VC/BSA ($p < 0{,}05$), while energy cost indicated significant correlations with post-match glucose and sodium concentrations at the 1 and 5 percent levels respectively.

Both elbow flexion-extension and supination-pronation as well as trunk lateral flexion and hip abduction were correlated at the five percent level of significance in the male amateurs.

C. Combined variables

Forearm girth in the male amateurs was found to be correlated significantly with $\dot{V}O_2$ max (ℓ) and VC, while $\dot{V}O_2$ max (ℓ) in the females was correlated with lower limb lean volume ($p < 0{,}05$).

Percentage body fat in the males was correlated significantly with sweat-rate, post-match lactate and FEV_1 at the five percent level of confidence.

In the females, shoulder rotation indicated a significant negative correlation ($p < 0{,}05$) with biacromial diameter and androgyny, while mechanical efficiency and bi-iliac diameter were also negatively correlated ($p < 0{,}05$).

Elbow flexion-extension and relative forearm length, age and $\dot{V}O_2$ max (ml), and years played and hip flexion-extension in the males were negatively correlated.

In the female amateurs, androgyny and hip abduction, age and supination-pronation, and age and stature were negatively correlated at the five percent level of significance (Table XXXI, p.214).

4.7.3 Forearm girth

Significant product-moment correlations between forearm girth and various morphological and physiological variables in the male and female groups are shown in Table XXXII (p.215). It is clear from Tables XXX, XXXI and XXXII that forearm girth was correlated highly and significantly with the majority of the basic and derived anthropometric variables, as well as with a number of the physiological variables.

Table XXX: Significant product-moment correlations in professional tennis players

Male: Variables	r	Level of sig (%)	Female: Variables	r	Level of sig (%)
Structural			Structural		
Stature - Mass	0,61	1	Stature - Mass	0,64	1
Stature - Int-pup distance	0,45	1	Stature - Int-pup distance	0,44	5
Mass - Androgyny	0,49	1	Mass - Androgyny	0,69	1
Stature - Bicon (femur)	-0,80	1	LBM - Androgyny	o,62	1
U.L. % TBL - L.L. % TBL	-0,60	1	U.L. lean vol - Androgyny	0,54	1
% fat - thigh girth	0,50	1	Bone index U.L. - Bone index (BSA)	0,85	1
% fat - Supra-iliac skinfold	0,89	1	Fat index U.L. - Fat index (BSA)	0,99	1
% fat - L.L. lean vol	0,40	5			
L.B.M. - Androgyny	0,54	1	Physiological and biochemical		
Mus index U.L. - Mus index (BSA)	0,76	1	Sweat-rate - Trunk L.F.	-0,99	1
Bone index U.L. - Bone index (BSA)	0,75	1	Sodium post - Glucose post	-0,93	5
Fat index U.L. - Fat index (BSA)	0,96	1	Mech efficiency - Trunk L.F.	0,63	1
Bone index L.L. - LBM	-0,35	5	Shoulder rotation - Glucose post	-0,95	5
Physiological and Biochemical			Combined		
$\dot{V}O_2$ max (ml) - Mech efficiency	0,39	5	$\dot{V}O_2$ max (ml) - L.L. % TBL	-0,50	5
Sweat-rate - FEV_1	0,55	5	$\dot{V}O_2$ max (ml) - Mus index U.L.	-0,59	1
FEV_1I - Lactate post	0,72	5	$\dot{V}O_2$ max (ℓ) - Androgyny	0,49	5
Sweat-rate - Lactate post	0,68	5	VC - Intpup distance	0,56	1
Sweat-rate - Magnesium post	-0,80	5	Shoulder F.E. - LBM	0,61	1
Sweat-rate - FEV_1I	0,54	5	$\dot{V}O_2$ max (ℓ) - shoulder F.E.	0,45	5
Shoulder F.E. - shoulder rotation	0,43	1	Hip F.E. - Trochan Ht	-0,61	1
Elbow F.E. - Hip F.E.	0,55	1	Hip F.E. - LBM	-0,57	1
			Biacrom - shoulder rotation	-0,49	5
Combined			Bi-iliac - Hip F.E.	-0,61	1
$\dot{V}O_2$ max (ℓ) - Forearm girth	0,58	1	Hip F.E. - L.L. % TBL	-0,58	1
$\dot{V}O_2$ max (ℓ) - chest girth	0,41	1	FEV_1 - % fat	0,53	5
VC - Androgyny	0,33	5	FEV_1I - LBM	-0,46	5
VC - Forearm girth	0,48	1	Androgyny - shoulder rotation	-0,43	5
FEV_1I - % fat	-0,36	5	U.L. lean vol - shoulder rotation	-0,55	1
FEV_1 - LBM	0,57	1	Age - $\dot{V}O_2$ max (ℓ)	-0,67	1
FEV_1 - Forearm girth	0,57	1	Age - $\dot{V}O_2$ max (ml)	-0,71	1
Andro - Lactate post	-0,98	1	Age - Glucose post	-0,95	5
L.L. lean vol - Glucose post	-0,69	1	Age - U.L. lean vol	0,54	1
Hip Abd - % fat	0,49	1	Years - VC	0,44	5
Trunk L.F. - L.L. % TBL	0,51	1	Years - FEV_1	0,44	5
Elbow F.E. - U.L. % TBL	-0,37	5	Years - Elbow F.E.	0,41	5
Elbow F.E. - U.L. lean vol	-0,37	5	Years - Shoulder F.E.	-0,51	5
Age - FEV_1I	-0,33	5			
Age - Bone index (forearm)	-0,36	5			
Age - % fat	0,42	1			
Age - Shoulder rotation	-0,33	5			
Age - Elbow F.E.	-0,53	1			
Age - Supination - pronation	-0,38	5			
Age - Trunk L.F.	-0,45	1			
Years - Elbow F.E.	-0,30	5			
Years - IRV	0,35	5			

Table XXXI: Significant product-moment correlations in amateur tennis players

Male			Female		
Variables	r	Level of sig (%)	Variables	r	Level of sig (%)
Structural			Structural		
Stature - Mass	0,70	1	Stature - Mass	0,65	1
Stature - Androgyny	0,38	5	U.L. lean vol - LBM	0,50	1
Biacrom - % fat	0,50	1	Mus index U.L. - Mus index (BSA)	0,67	1
Biacrom - Forearm girth	0,59	1	Bone index U.L. - Bone index (BSA)	0,91	1
Bi-iliac-Forearm girth	0,75	1			
AP chest - Forearm girth	0,75	1	Physiological and biochemical		
Androgyny - % fat	0,47	1	$\dot{V}O_2$ max (ℓ) - FEV_1	-0,68	5
Androgyny - BSA	-0,78	1	$\dot{V}O_2$ max (ml) - FEV_1	-0,74	5
U.L. lean vol - L.L. lean vol	0,87	1	Sweat-rate - Trunk L.F.	-0,97	5
Mus index U.L. - Mus index (BSA)	0,80	1	Sweat-rate - U.L. lean vol	-0,97	5
Bone index U.L. - Bone index (BSA)	0,91	1	Shoulder F.E. - Trunk L.F.	0,51	5
Fat index U.L. - Fat index (BSA)	0,98	1	Mechan eff - IC	-0,60	5
Physiological and biochemical			Combined		
$\dot{V}O_2$ max (ℓ) - Glucose post	0,88	1	VC - thigh girth	-0,78	5
$\dot{V}O_2$ max (ml) - FEV_1	-0,50	1	VC/BSA - LBM	-0,77	5
$\dot{V}O_2$ max (ml) - Sodium post	-0,75	1	Shoulder F.E. - Mus index U.L.	0,63	5
Sweat-rate - FEV_1	0,54	5	Shoulder rotation - Biacrom	-0,55	5
Sweat-rate - VC/BSA	0,56	5	Shoulder rotation - Androgyny	-0,58	5
Sweat-rate - Glucose post	0,77	1	Mechan eff - Bi-iliac	-0,59	5
Energy - Glucose post	0,68	1	Mass - VC/BSA	-0,79	5
Energy - Sodium post	0,81	5	Stature - Hip F.E.	0,65	5
Elbow F.E. - Sup-pronation	0,37	5	Biacrom - FEV_1	0,76	5
Elbow F.E. - Trunk L.F.	0,41	5	Androgyny - Hip Abd	-0,65	5
Trunk L.F. - Hip Abd	0,47	1	Androgyny - FEV_1	0,77	5
			LBM - Trunk L.F.	0,55	5
Combined			L.L. lean vol - $\dot{V}O_2$ max (ℓ)	0,56	5
$\dot{V}O_2$ max (ℓ)-Forearm girth	0,41	5	$\dot{V}O_2$ max (ℓ) - LBM	-0,66	5
Sweat rate - % fat	0,52	5	L.L. lean vol - FEV_1	-0,74	5
Sweat-rate - Supra-il skinfold	0,78	1	Age - VC	0,70	5
Energy - L.L. % TBL	0,71	5	Age - Sup-pronation	-0,56	5
VC - Forearm girth	0,80	1	Age - Stature	-0,49	5
VC - $\dot{V}O_2$ max (ml)	-0,53	1	Age - Radiale length	-0,57	5
FEV_1 - % fat	0,35	5			
Lactate post - % fat	0,69	5			
Glucose post - % fat	0,71	5			
Elbow F.E. - Forearm length % TBL	-0,43	5			
Age - $\dot{V}O_2$ max (ml)	-0,43	5			
Age - VC	0,36	5			
Years - Hip F.E.	-0,65	1			
Years - U.L. lean vol	0,55	1			

Table XXXII: Significant product - moment correlations between forearm girth and various morphological and physiological variables in tennis players

Combined males				Combined females			
Variable	n	r	Level of sig(%)	Variable	n	r	Level of sig(%)
Age	61	0,38	1	Mass	30	0,85	
Mass	61	0,87	1	Androgyny	30	0,45	[illegible]
Interpup dist	57	0,28	5	B S A	30	0,76	1
Androgyny	61	0,30	1	Lengths✡	30	-	1
Lengths✡	61	-	1	Diameters☆	30	-	1
Diameters☆	61	-	1	Girths★	30	-	1
Girths★	61	-	1	Lean vol U.L.	30	0,69	1
Lean vol U.L.	61	0,89	1	Lean vol A	30	0,76	1
Lean vol A	61	0,85	1	Lean Vol F	30	0,45	1
Lean vol F	61	0,51	1	Lean vol L.L.	30	0,38	5
Lean vol L.L.	61	0,71	1	% body fat	30	0,56	1
% body fat	61	0,36	1	L B M	30	0,76	1
L B M	61	0,76	1	I B M	30	0,79	1
I B M	61	0,80	1	$\dot{V}O_2$ max (ℓ)	26	0,63	1
$\dot{V}O_2$ max (ℓ)	55	0,49	1	$\dot{V}O_2$ max (ml)	26	0,48	1
I R V	54	0,57	1	$\dot{V}O_2$ max (LBM)	26	0,56	1
I C	54	0,60	1	Lact post	5	-0,96	1
V C	54	0,58	1				
FEV_1	54	0,60	1				
Hip F E	57	-0,46	1				
Lact post	14	0,47	5				

✡ = stat, acrom, troch, dact, rad, styl, tib ht.

☆ = biacrom, bitroch, biil, AP chest, biep (hum), bicon (fem), wrist, ankle.

★ = arm (uncon), arm (con), chest, thigh and calf.

4.8 SIMPLE LINEAR REGRESSION FUNCTIONS

Simple linear regression functions or equations of morphological and physiological variables with standard errors (S_E), correlation coefficients (r) and significance levels are presented in Table XXXIII (p.218). Some linear regressions with regression lines and 95 percent confidence bands are shown in Figures 19 to 35.

4.8.1 Male professionals

Although a number of the correlation coefficients shown in Table XXXIII were significant at the one percent level, it is evident that the correlat[illegible]nerally quite low. Regressions of mass on age and of vital [illegible] mass, indicated the highest correlations. Regressions of st[illegible], upper limb lean volume, lower limb lean volume, $\dot{V}O_2$ max, LBM and IBM on mass are presented in Figures 19 (p.219), 20 (p.220), 21 (p.221), 22 (p.222), 27 (p.227) and 28 (p.228) respectively.

Mass accounted for 84,6 percent of the variation in LBM (Figure 27) and 86,5 percent of the variation in IBM (Figure 28). These high coefficients of determination (R^2)☆ and the narrow confidence bands confirm the accuracy of these two prediction formulae.

4.8.2 Female professionals

From Table XXXIII it is clear that regressions of $\dot{V}O_2$ max (ml) on age (50,4 percent variance) and of arm muscle index on years (43,6 percent variance) were the most promising linear prediction formulae.

Regressions of stature, androgyny, fat rating, LBM and IBM on mass are depicted in Figures 23, 24, 25, 27 and 28 respectively.

The regression of sweat-rate on stature is shown in Figure 26 without confidence bands. The latter could not be calculated owing to the small number of cases (n = 4).

Mass accounted for 53,3 percent of the variation in fat rating (Figure 25), 64,0 percent of the variation in LBM (Figure 27) and 77,4 percent of the variation in IBM (Figure 28). The latter formula could be used with a high degree of accuracy.

☆ Coefficient of determination $R^2 = (r)^2 \times 100$

4.8.3 Male amateurs

Correlation coefficients were found to be significant at the one percent level for all the regressions shown in Table XXXIII (p.218).

Lower limb lean volume on mass (86,5 percent variance) and FEV_1 on stature (85,6 percent variance) proved to be the most promising regression formulae.

Regressions of stature, LBM and IBM on mass are shown in Figures 29, 34 and 35 respectively. The close proximity of the IBM regression lines resulted in untidy overlapping of the confidence bands which were consequently omitted from Figure 35. The regression of vital capacity on stature is presented in Figure 30. Mass explained 94,1 percent of the variation in LBM (Figure 34) and 96,0 percent of the variation in IBM (Figure 35), while stature accounted for 67,2 percent of the variance in vital capacity (Figure 30).

4.8.4 Female amateurs

The most promising predictions are those of fat rating from mass (68,9 percent variance) and upper limb lean volume from mass (59,3 percent variance), as can be seen from Table XXXIII (p.218).

Regressions of stature, percentage fat, sweat-rate, LBM and IBM on mass are shown in Figures 31, 32, 33, 34 and 35 respectively. Confidence bands are not shown in Figure 33 because of the small number of cases (n = 4).

Mass could be utilized to predict the following variables with a high degree of accuracy: LBM (84,6 percent variance, Figure 34), IBM (90,3 percent variance, Figure 35) and percentage fat (62,4 percent variance, Figure 32).

Table XXXIII: Simple linear regression functions of morphological and physiological variables in tennis players

Male professionals

Dependent variable (Y)	Independent variable (X)	Equation	S_E	r	n
Mass (kg)	Age	Y = 0,6414X + 59,12	6,2	0,53	33
Androgyny	Mass	Y = 0,3791X + 61,63	4,9	0,50	33
% fat	Mass	Y = 0,1729X - 1,46	2,9	0,40	33
Fat rating	Mass	Y = -0,1702X + 11,24	2,3	-0,47	33
VC (ℓ)	Mass	Y = 0,0578X + 1,47	0,7	0,52	29
FEV$_1$ (ℓ/sec)	Stature	Y = 0,0510X - 4,35	0,6	0,45	29
Sweat-R (ℓ/hr)	Stature	Y = 0,0288X - 3,93	0,4	0,43	14
% fat	Years	Y = 0,2444X + 8,15	3,0	0,37	33
Trunk LF (°)	Age	Y = -1,0581X +138,48	12,6	-0,45	31
Mech eff (%)	% fat	Y = -1,1080X + 43,27	7,1	-0,46	29
$\dot{V}O_2$ max (ml/min)	Mech eff	Y = 0,4343X + 37,02	6,2	0,39	28

Female professionals

Dependent variable (Y)	Independent variable (X)	Equation	S_E	r	n
% fat	Mass	Y = 0,4991X - 5,38	3,7	0,82	19
UL lean vol (cm^3)☼	Mass	Y = 36,784X + 1043.3	298,9	0,63	19
LL lean vol (cm^3)☼	Mass	Y = 117,31X + 5462,0	38,0	0,56	18
Trunk LF (°)	Age	Y = -1,6982X + 162,58	15,9	-0,40	16
Mech eff (%)	Age	Y = -0,3659X + 36,26	3,5	-0,40	15
$\dot{V}O_2$ max (ml)	Mech eff	Y = 1,1676X + 15,63	13,8	0,38	15
Mech eff (%)	$\dot{V}O_2$ max(ml)	Y = 0,0076X + 22,29	3,6	0,38	15
FEV$_1$ (ℓ/sec)	Years	Y = 0,0427X - 3,09	0,3	0,44	14
UL lean vol (cm^3)☼	Years	Y =58,731X + 2578,0	311,3	0,58	19
Mus ind A	Years	Y = 0,0290X + 1,75	0.1	0,66	19
VC (ℓ)	Years	Y = 0,0478X + 3,57	0,3	0,44	14
$\dot{V}O_2$ max (ml)	Age	Y = -2,4947X + 114,54	10,2	-0,71	16
Sweat-R (ℓ/hr)	Mech eff	Y = -0,2266X + 7,64	0,3	-0,87	4
Mech eff (%)	Sweat-R	Y =-3,3405X + 32,82	1,2	-0,87	4

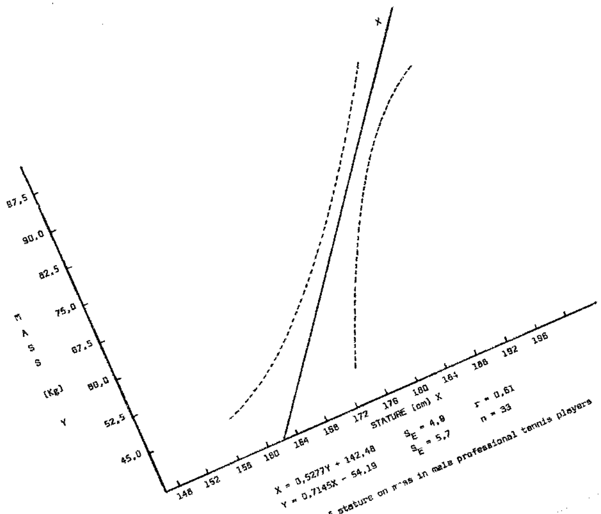
Male amateurs

Dependent variable (Y)	Independent variable (X)	Equation	S_E	r	n
Fat rating (kg)	Mass	Y = -0,1712X + 9,95	2,1	-0,68	28
% fat	Mass	Y = 0,2008X - 2,06	2,5	0,65	28
LL lean vol (cm^3)☼	Mass	Y = 207,02X - 648,45	322,7	0,83	27
$\dot{V}O_2$ max (ml/min)	Mass	Y = -0,4111X + 77,66	3,1	-0,51	24
Androgyny	Stature	Y = 0,3250X + 32,04	4,6	0,52	27
U.L. lean vol (cm^3)☼	Stature	Y + 79,404X - 9738,0	951,1	0,78	27
FEV$_1$ (ℓ/sec)	Stature	Y = 0,0665X - 7,33	0,4	0,81	25
Mus ind UL	Age	Y = 0,0984X + 3,74	0,4	0,65	26
LL lean vol (cm^3)☼	Years	Y = 102,36X + 3194,8	630,8	0,70	27

Female amateurs

Dependent variable (Y)	Independent variable (X)	Equation	S_E	r	n
Fat rating (kg)	Mass	Y = -0,3406X 17,30	1,0	-0,83	11
UL lean vol (cm^3)☼	Mass	Y = 69,342X - 970,11	253,6	0,77	11
Androgyny	Stature	Y = 0,4905X - 3,87	4,8	0,47	11
$\dot{V}O_2$ max (ℓ)	Mass	Y = 0,1195X - 3,79	0,6	o,6	10
FEV$_1$ (ℓ/sec)	Stature	Y = 0,0401X - 3,46	0,2	0,69	7
Shoulder FE (°)☼	Age	Y =-0,5787X + 212,00	17,4	-0,49	10
Mus ind A	Years	Y = 0,0100X + 1,66	0,2		11

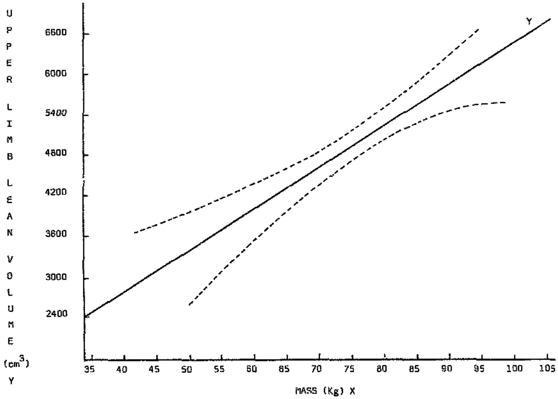
☼Dominant value (handedness). Underlined r = p (<0,01)



$X = 0{,}5277Y + 142{,}48$ $S_E = 4{,}8$ $r = 0{,}61$

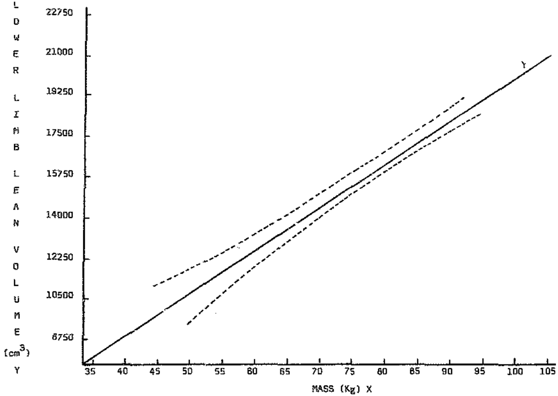
$Y = 0{,}7145X - 54{,}19$ $S_E = 5{,}7$ $n = 33$

<u>Figure 19:</u> Regression of stature on mass in male professional tennis players



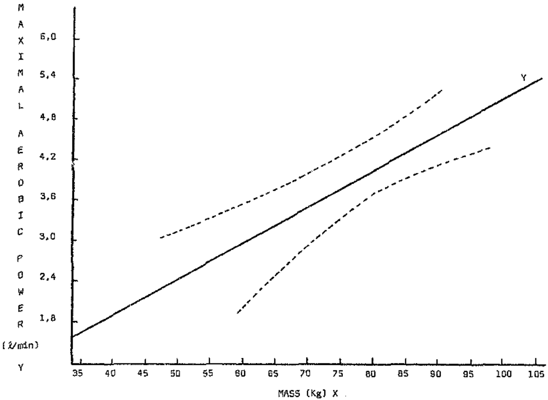
$Y = 62{,}243X + 269{,}84$ $S_E = 506{,}3$ $r = 0{,}67$ $n = 33$

Figure 20: Regression of dominant upper limb lean volume on mass in male professional tennis players



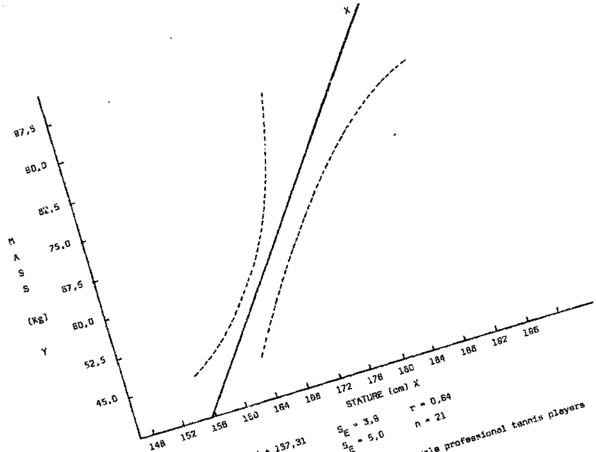
$Y = 185,65X + 1294,2 \quad S_E = 560,9 \quad r = 0,65 \quad n = 33$

Figure 21: Regression of dominant lower limb lean volume on mass in male professional tennis players



$Y = 0{,}0533X - 0{,}25 \quad S_E = 0{,}7 \quad r = 0{,}51 \quad n = 31$

Figure 22: Regression of maximal aerobic power on mass in male professional tennis players



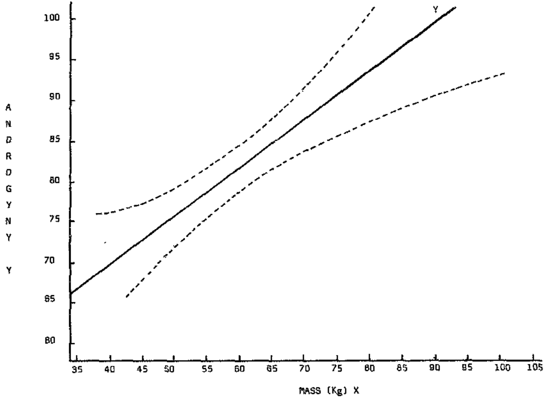
$S_E = 3,8$ $r = 0,64$

$S_E = 5,0$ $n = 21$

$X = 0,4831Y + 137,31$

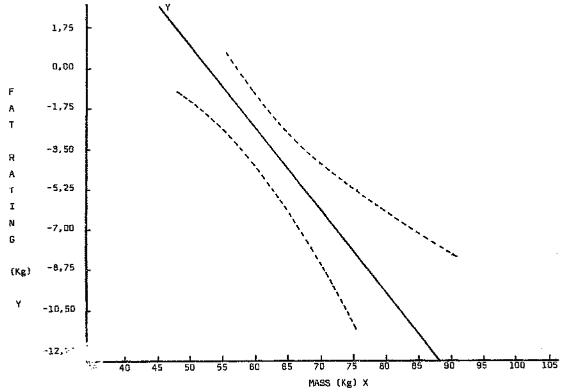
$Y = 0,8179X - 78,06$

Figure 23: Regression of stature on mass in female professional tennis players



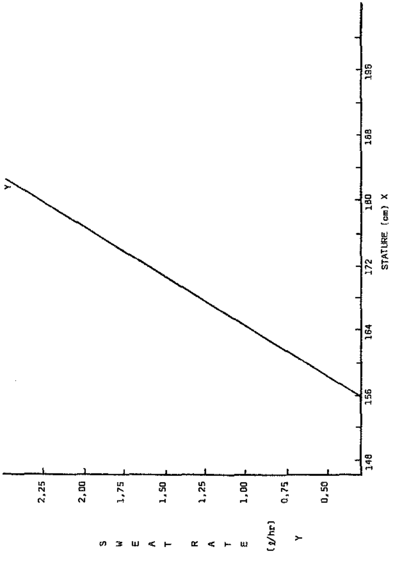
Y = 0,6007X - 45,51 S_E = 4,1 r = 0,69 n = 19

Figure 24: Regression of androgyny on mass in female professional tennis players



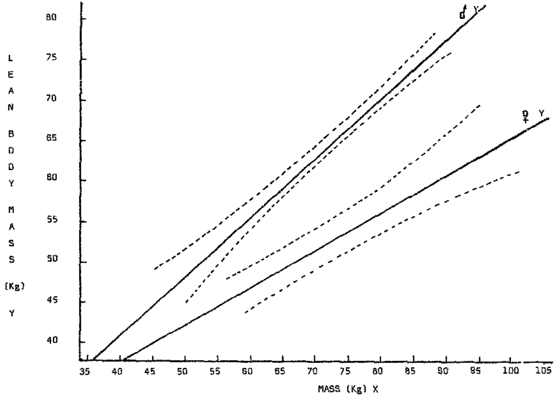
$Y = -0,3639X + 19,28 \quad S_E = 2,2 \quad r = -0,73 \quad n = 19$

Figure 25: Regression of fat rating for 'ideal' body mass on mass in female professional tennis players



$Y = 0,0813X - 12,40$ $S_E = 0,3$ $r = 0,85$ $n = 4$

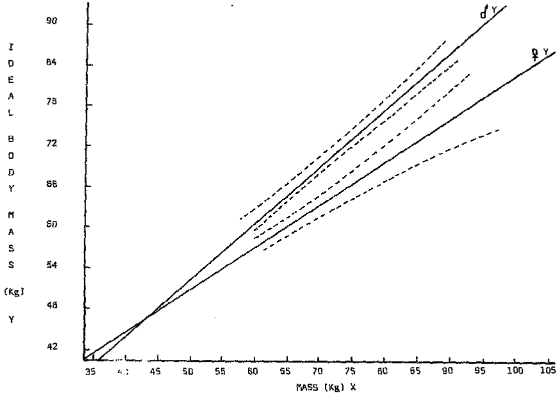
Figure 26: Regression of sweat-rate on stature in female professional tennis players



♂ $Y = 0{,}7347X + 11{,}24$ $S_E = 2{,}3$ $r = 0{,}92$ $n = 33$

♀ $Y = 0{,}4629X + 19{,}18$ $S_E = 2{,}3$ $r = 0{,}80$ $n = 19$

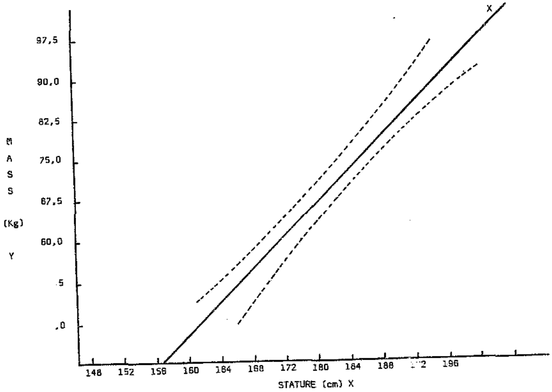
Figure 27: Regression of lean body mass on mass in professional tennis players



♂ $Y = 0{,}8291X + 11{,}28$ $S_E = 2{,}3$ $r = 0{,}93$ $n = 33$

♀ $Y = 0{,}6367X + 19{,}24$ $S_E = 2{,}2$ $r = 0{,}88$ $n = 19$

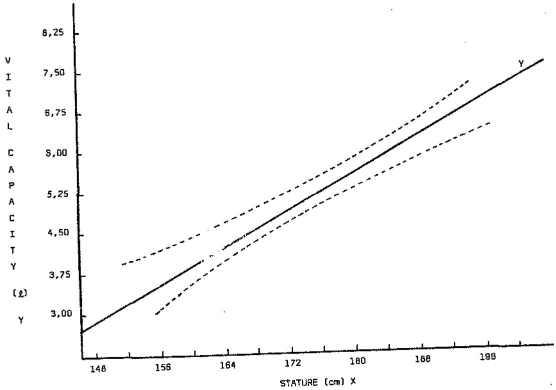
Figure 28: Regression of 'ideal' body mass on mass in professional tennis players



$X = 0,6614Y + 132,21$ $S_E = 4,4$ $r = 0,86$

$Y = 1,1056X - 127,37$ $S_E = 5,7$ $n = 28$

Figure 29: Regression of stature on mass in male amateur tennis players



$Y = 0{,}0843X - 9{,}69$ $S_E = 0{,}5$ $r = 0{,}82$ $n = 25$

Figure 30: Regression of vital capacity on stature in male amateur tennis players

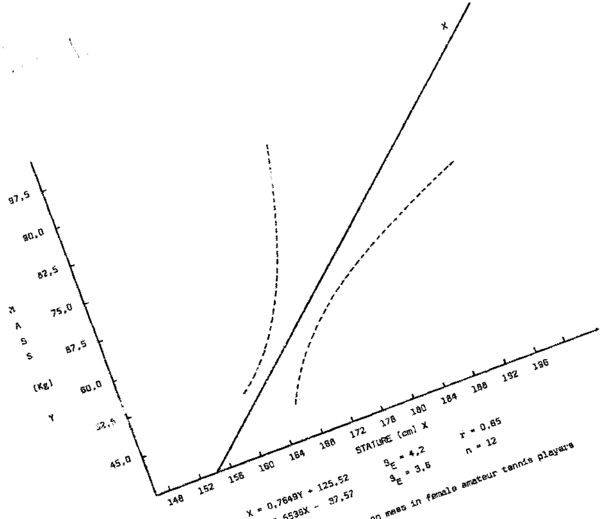
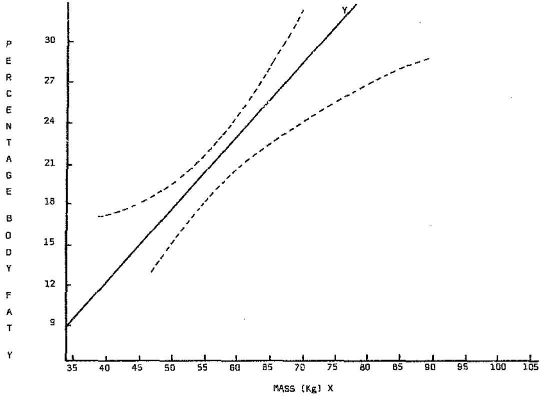
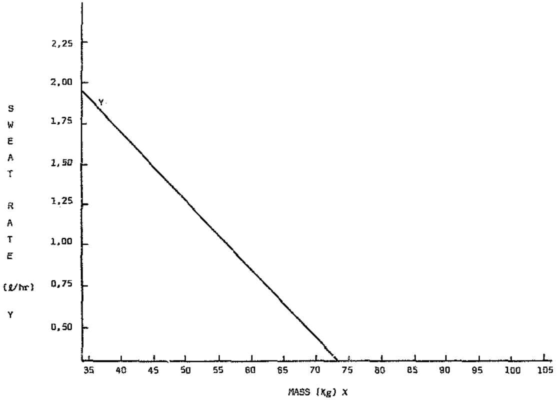


Figure 31: Regression of stature on mass in female amateur tennis players



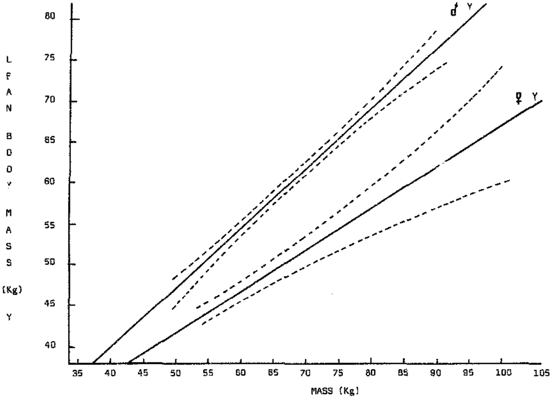
$Y = 0{,}5343X - 9{,}38$ $S_E = 1{,}8$ $r = 0{,}79$ $n = 11$

Figure 32: Regression of percentage body fat on mass in female amateur tennis players



$Y = -0{,}0424X + 3{,}40$ $S_E = 0{,}01$ $r = -0{,}87$ $n = 4$

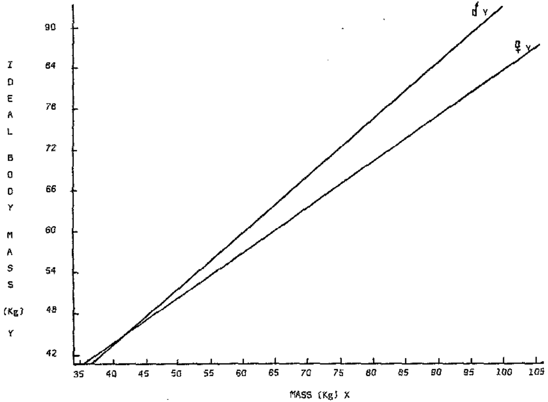
Figure 33: Regression of sweat-rate on mass in female amateur tennis players



♂ Y = 0,7351X + 9,87 S_E = 2,1 r = 0,97 n = 27

♀ Y = 0,5066X + 15,87 S_E = 0,9 r = 0,92 n = 11

Figure 34: Regression of lean body mass on mass in amateur tennis players



♂ $Y = 0{,}8305X + 9{,}82$ $S_E = 2{,}1$ $r = 0{,}98$ $n = 27$
♀ $Y = 0{,}6613X + 17{,}20$ $S_E = 1{,}0$ $r = 0{,}95$ $n = 11$

Figure.35: Regression of 'ideal' body mass on mass in amateur tennis players

4.9 MULTIPLE LINEAR REGRESSION FUNCTIONS

Multiple linear regression functions or equations of morphological and physiological variables with coefficients of variation (CV), coefficients of determination (R^2), F-values and significance levels for the professionals and amateurs are shown in Tables XXXIV and XXXV respectively.

The independent variables were selected on the basis of theoretical justification and included the following:

Morphological: BSA (size), stature, LBM (muscle mass) and body mass;

Physiological: VC, FEV_1, FEV_1I and mechanical efficiency;

Activity: Years played and hours per week; and

Age.

The most promising prediction formulae in terms of practicality and accuracy are singled out.

4.9.1 Male professionals

From Table XXXIV (p.238) it can be seen that mass and age accounted for 85,6 percent of the variation in LBM and 88,4 percent of variation in IBM. The very low coefficients of variation for these two prediction formulae were 3,3 and 2,9 percent respectively.

Prediction of LBM and IBM by means of the above-mentioned two-term equations, compared to the one-term equations shown in Figures 27 (R^2 = 84,6%) and 28 (R^2 = 86,5%), indicate that the addition of age only marginally increased the accuracy of the LBM and IBM predictions.

4.9.2 Female professionals

From Table XXXIV(p.238) it is clear that upper limb muscle index (BSA), fat mass and IBM could be accurately predicted by the use of the two- and three-term equations presented.

BSA and years played accounted for 87,2 percent of the variation in IBM (CV = 2,9%). This equation, therefore, provides a far more accurate prediction of IBM than that afforded by the use of mass only, where the variance was 77,4 percent (Figure 28).

Age and hours per week could be utilized to provide a reasonably accurate prediction of $\dot{V}O_2$ max (ml/LBM/min), the coefficients of determination and variation being 56,7 and 17,0 percent respectively.

4.9.3 Male amateurs

From Table XXXV (p.239) it may be observed that androgyny, upper and lower limb lean volumes, fat mass, LBM, IBM, VC and wrist flexion-extension could be accurately predicted from the two- and three-term equations presented.

Eighty-four percent of the variation in vital capacity was explained by stature, age and years played. The coefficient of variation for this prediction was 7,2 percent.

4.9.4 Female amateurs

Upper limb lean volume, $\dot{V}O_2$ max (ℓ/min), . shoulder flexion-extension could be assessed accurately with the prediction formulae presented in Table XXXV (p.239).

Mass and hours played per week explained 74,7 percent of upper limb lean volume variance, while mass alone explained 59,3 percent of this variation (Table XXXIII). The two-term equation, therefore, offers far greater predictive accuracy than the one-term equation.

Table XXXIV: Multiple linear regression functions of morphological and physiological variables in professional tennis players

Male professionals

Dependent variable (Y)	Equation	CV	R^2	F	Level of sig(%)	n
% fat	Y = 31,0 − 0,16 (FEV$_1$I) − 0,19 (M.Eff)	23,0	32,6	5,9	1	27
Fat mass (kg)	Y = −10,4 + 0,20 (mass) + 0,14 (age)	24,3	46,7	13,1	1	33
Fat rating (kg)	Y = 10,4 − 0,11 (mass) − 0,14 (age)	-	29,6	6,9	1	33
L.B.M. (kg)	Y = 10,4 + o,80 (mass) − 0,14 (age)	3,3	85,6	89,2	1	33
I.B.M. (kg)	Y = 10,4 + 0,90 (mass) − 0,14 (age)	2,9	88,4	114,1	1	35
U.L. lean vol (cm^3)✪	Y = −179,4 + 18,32 (hrswk) + 84,15 (mass)	9,9	48,1	13,8	1	33
Fore lean vol (cm^3)✪	Y = −128,7 + 11,11 (hrswk) + 18,8[illegible] (mass)	13,8	36,6	8,7	1	33
Mus ind U.L. (BSA)	Y = 1,03 + o,41 (BSA) − 0,01 (stat) − 0,002 (age)	9,4	46,9	8,5	1	33
$\dot{V}O_2$ max (l/min)	Y = −1,5 + 0,80 (LBM) + 0,03 (hrswk) + 0,04 (M.Eff)	14,2	46,9	7,3	1	27
$\dot{V}O_2$ max (ml/min)	Y = 27,9 + 0,43 (hrswk) + 0,57 (M.Eff)	12,6	43,7	9,3	1	27
FEV$_1$ (l/sec)	Y = −1,1 + 3,68 (BSA) − 0,04 (age)	11,2	3[illegible],9	6,5	1	29
Shoulder rotat (°)✪	Y = 209,9 − 0,76 (hrswk) − 1,94 (age) + 1,4 (yrs)	8,7	28,8	3,5	5	30
Elbow F.E. (°)✪	Y = 239,6 − 0,67 (mass) − 0,87 (age)	7,5	36,1	7,6	1	30
Hip F.E. (°)	Y = −42,5 + 250,47 (BSA) − 4,42 (mass)	12,5	37,1	8,0	1	30

Female professionals

Dependent variable (Y)	Equation	CV	R^2	F	Level of sig(%)	n
Stature (cm)	Y = 94,4 + 1,38 (LBM) + 4,23 (FEV$_1$) − 0,26 (M.Eff)	1,3	86,4	14,8	1	11
Androgyny	Y = 5,21 + 0,16 (hrswk) + 44,01 (BSA)	4,4	62,1	13,1	1	19
U.L. lean vol (cm^3)✪	Y = −1180,7 + 2251,15 (BSA) + 52,79 (yrs)	6,6	69,4	18,1	1	19
L.L. lean vol (cm^3)✪	Y = 6850,8 − 8[illegible] 13 (hrswk) + 106,70 (mass)	11,6	32,5	3,9	5	19
Mus ind UL (BSA)	Y = 1,08 + 0,004 (yrs) − 0,01 (stat) + 0,40 (BSA)	6,7	77,1	16,9	1	19
Mus ind F	Y = −4,0 + 0,08 (stat) − 2,69 (BSA)	10,5	58,4	11,2	1	19
% fat	Y = 71,6 + 0,72 (mass) − 0,56 (stat)	14,0	60,3	12,1	1	19
Fat mass (kg)	Y = 30,4 + 0,70 (mass) − 0,37 (stat) + 0.17 (yrs)	3,1	84,2	28,7	1	19
Fat rating (kg)	Y = −28,5 − 0,53 (mass) + 0,38 (stat) − 0,17 (yrs)	-	74,3	14,5	1	19
I.B.M. (kg)	Y = −13,5 + 43,61 (BSA) − 0,17 (yrs)	2,9	87,2	54,4	1	19
$\dot{V}O_2$ (ml LBM/min)	Y = 132,5 − 3,09 (age) + 0.70 (hrswk)	17,0	58,7	8,5	1	16
VC (l)	Y = 3,2 + 0,05 (yrs) + 0,02 (hrswk)	7,1	43,3	4,2	5	14
Shoulder F.E. (°)✪	Y = 79,7 + 2,61 (mass) − 2,58 (yrs)	7,4	55,0	8,0	1	16
Elbow F.E. (°)✪	Y = 348,6 + 1,60 (yrs) − 1,15 (stat)	7,3	32,2	3,3	-	17
Sup-pronation (°)✪	Y = 505,7 + 2,39 (hrswk) − 181,1 (BSA)	9,5	56,6	9,2	1	17
Trunk LF (°)	Y = 408,1 − 1,49 (stat) − 1,42 (age)	11,8	35,4	3,6	5	18
Mech eff (%)	Y = 78,1 − 0.28 (stat) − 0,32 (age)	12,2	28,[illegible]	2,4	-	15

✪ Dominant value (handedness).   INDEPENDENT VARIABLES = mass, stat, B.S.A., L.B.M., age, yrs, hrswk = (not underlined)

F to enter = 2,0

F to remove = 1,9   INDEPENDENT VARIABLES = L.B.M., VC, FEV$_1$, FEV$_1$I, hrswk, M.Eff = (underlined)

Table XXXV: Multiple linear regression functions of morphological and physiological variables in amateur tennis players

Male amateurs

Dependent variable (Y)	Equation	CV	R^2	F	Level of sig(%)	n
Stature (cm)	$Y = 129,7 + 0,18\ (LBM) + 3,63\ (VC) + 4,21\ (FEV_1)$	2,1	81,4	26,3	1	22
Androgyny	$Y = 77,9 - 5,40\ (BSA) + 0,32\ (mass)$	5,2	79,1	41,7	1	25
U.L. lean vol (cm^3)✡	$Y = 1395,3 + 96,64 (mass) - 28,10 (stat) + 53,14 (age)$	9,9	81,1	71,4	1	25
LL lean vol (cm^3)✡	$Y = -2858,8 + 35,40\ (hrswk) + 229,6\ (mass)$	7,6	88,1	81,7	1	25
Mus ind UL (BSA)	$Y = 0,6 + 0,01\ (mass) - 0,004\ (stat) + 0,002\ (yrs)$	10,0	69,2	15,7	1	25
% fat	$Y = 20,5 + 0.32\ (mass) - 0,17\ (stat)$	20,0	53,5	12,8	1	25
Fat mass (kg)	$Y = 17,9 - 0,97\ (BSA) + 0,42\ (mass) - 0,21\ (stat)$	21,4	81,6	31,1	1	25
Fat rating (kg)	$Y = -16,8 - 0,31\ (mass) + 0,20\ (stat)$	-	61,1	17,3	1	25
L.B.M. (kg)	$Y = -19,7 - 4,19\ (BSA) + 0,64\ (mass) + 0,25\ (stat)$	3,0	97,4	266,0	1	25
I.B.M. (kg)	$Y = -16,6 + 4,53 (BSA) + 0,64 (mass) + 0,18 (stat)$	2,6	97,5	271,8	1	25
$\dot{V}O_2$ max (ml)	$Y = 99,9 - 0,41\ (mass) - 1.28\ (age) + 0,67\ (yrs)$	15,8	44,4	4,8	5	22
VC (ℓ)	$Y = -13,1 + 0,09\ (stat) + 0,09\ (age) - 0,05\ (yrs)$	7,2	83,8	32,8	1	23
Shoulder rotat (°)✡	$Y = 150,6 + 0,41\ (mass) - 1,15\ (yrs)$	6,1	31,8	5,1	5	25
Wrist F E (°)✡	$Y = 50,5 + 14,89\ (BSA) + 0.80\ (yrs)$	14,8	76,0	34,7	1	25
Hip FE (°)	$Y = 167,9 + 2,45\ (BSA) - 0,64\ (mass) - 1,38\ (yrs)$	8,9	63,7	12,3	1	25
Sweat-rate (ℓ/hr)	$Y = -1,3 + 0,30\ (VC) + 0,03\ (hrswk) + 0,02\ (M.Eff)$	20,00	66,5	5,3	5	12

Female amateurs

Dependent variable (Y)	Equation	CV	R^2	F	Level of sig(%)	n
Stature	$Y = 23,6 + 7,05\ (VC) + 1,30\ (FEV_1I)$	0,3	99,4	241,6	1	6
Androgyny	$Y = -16,9 - 0,83\ (hrswk) + 0,61\ (stat)$	4,3	84,4	8,3	5	10
U.L. lean vol (cm^3)✡	$Y = -1030,3 - 29,02\ (hrswk) + 76,24\ (mass)$	7,5	74,7	10,3	1	10
Mus ind U.L. (BSA)	$Y = 0,6 + 0,007\ (mass) - 0,004\ (stat)$	7,4	72,7	9,3	5	10
Mus ind LL (average)	$Y = 84,5 - 0,38\ (stat) - 0,08\ (age)$	11,2	48,3	3,3	-	10
Forearm girth✡	$Y = 26,4 + 0,30\ (mass) - 0,12\ (stat)$	1,2	94,9	85,1	1	10
$\dot{V}O_2$ max (ℓ/min)	$Y = -5,6 + 0,30\ (LBM) + 4,90\ (VC) - 6,72\ (FEV_1)$	17,2	89,0	5,4	-	6
VC (ℓ)	$Y = 5,4 - 0,04\ (hrswk) - 0,03\ (mass)$	4,0	80,0	7,8	-	7
Shoulder FE (°)✡	$Y = 274,0 - 5,30\ (hrswk) - 1,83\ (age) + 1,68\ (Yrs)$	7,8	84,0	10,4	5	10
Sup-pronation (°)✡	$Y = 242,5 - 1,68\ (age) + 1,26\ (yrs)$	6,0	70,4	8,3	5	10
Wrist F E (°)✡	$Y = 107,3 - 0,90\ (hrswk) - 0,67\ (yrs)$	8,8	54,5	4,2	-	10

✡ Dominant value (handedness). INDEPENDENT VARIABLES = mass, stat, B.S.A., L.B.M., age, yrs, hrswk = (not underlined)

F to enter = 2,0

F to remove = 1,9 INDEPENDENT VARIABLES = L.B.M., VC, FEV$_1$, FEV$_1$I, hrswk, M.Eff = (underlined)

4.10 STEPWISE DISCRIMINANT ANALYSIS

A total of twenty stepwise discriminant analyses (forward stepping) were conducted. The basic anthropometric, derived morphological, physiological and biochemical variables were separately analysed to determine those variables[✲] that maximised differences between the professionals and amateurs, and between the males and females. These variables are presented in order of importance, in Tables XXXVI to XXXVIII with their approximate F- statistics. Also included are classification matrices or tables which provide statistical classifications of the subjects.

Variables found to be important by the initial separate stepwise discriminant analyses were then used in a final stepwise discriminant analysis to determine, from amongst the combined variables, the most significant variables that maximised differences among the groups. The results are presented in Table XXXIX.

4.10.1 Morphological variables

These comprised a number of basic and derived measurements.

A. Basic anthropometric measurements

Ankle and bicondylar diameter of the femur (males), bitrochanteric diameter and the triceps skinfold (females), ankle diameter and contracted arm girth (professionals), and biacromial diameter and the triceps skinfold (amateurs) were the most significant distinguishing variables as can be seen from Table XXXVI (p.242).

B. Derived morphological measurements

As can be seen from Table XXXVII (p.243), LBM and bicondylar diameter of the femur as a percentage of lower limb length (males), forearm girth as a percentage of upper limb length and relative lower limb length (females), lean body mass and percentage body fat (professionals), and percentage body fat and lower limb muscle index (amateurs) were found to be the most significant distinguishing variables.

4.10.2 Physiological variables

The significant distinguishing physiological variables are

[✲] The two most significant distinguishing variables and the relevant groups (brackets) are cited in the text.

presented in Table XXXVIII (p.244) and include the following: hip flexion-extension and $\dot{V}O_2$ max expressed in millilitres per kilogram lean body mass (males), FEV_1 and trunk lateral flexion (females), inspiratory capacity and hip flexion-extension (professionals) and VC/BSA and hip flexion-extension (amateurs).

4.10.3 Biochemical variables

None of the twelve biochemical variables was found to discriminate significantly between the professionals and amateurs, nor between the males and females.

4.10.4 Morphological and physiological variables

The variables found to be significant in the initial analyses, were used in a final stepwise discriminant analysis, the results of which are presented in Table XXXIX (p.245).

Ankle diameter and $\dot{V}O_2$ max, expressed in litres per min (males), lower limb lean volume and forearm girth as a percentage of upper limb length (females), lean body mass and the supra-iliac skinfold (professionals) and dactylion height and percentage body fat (amateurs) were the most significant distinguishing variables.

Histograms of canonical variables which graphically illustrate the differentiation between the male, female, professional and amateur groups, are presented in Figure 36 (p.246).

From the classification matrices shown in Table XXXIX, it is evident that subject classification by means of representation (professional or amateur) and sex (male or female) corresponded well with the statistical classification. According to the statistical classification or grouping by representation,[*] 88,9 percent of the male professionals, 95,0 percent of the male amateurs and all the female professionals and amateurs were 'correctly' classified. With regard to sex classification all the subjects were 'correctly' categorised.

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[*] Made with the aid of discriminant functions, utilizing information on the selected variables.

Table XXXVI: Stepwise discriminant analysis: basic anthropometric measurements* of tennis players

MALE		FEMALE	
Professional - Amateur		Professional - Amateur	
Variable entered	Approximate F-statistic	Variable entered	Approximate F-statistic
Ankle diameter	16,1	Bitrochanteric diameter	24,6
Bicondylar diameter (fem)	10,2	Triceps skinfold	23,6
Interpupillary distance	8,1	Thigh girth	22,3
		Biepicondylar diam (hum)	21,9
		Biceps skinfold	21,3
		Bi-iliac skinfold	20,7

Classification matrix				Classification matrix			
	MP	MA	Correct %		FP	FA	Correct %
MP	24	7	77,4	FP	18	0	100
MA	5	21	80,8	FA	0	11	100
Total	29	28	78,9	Total	18	11	100

PROFESSIONAL		AMATEUR	
Male - Female		Male - Female	
Variable entered	Approximate F-statistic	Variable entered	Approximate F-statistic
Ankle diameter	104,3	Biacromial diameter	34,1
Contracted arm girth	75,0	Triceps skinfold	33,8
Triceps skinfold	73,6	Wrist diameter	31,5
Body mass	70,1	Biepicondylar diam (hum)	27,6
Supra-iliac skinfold	59,8	Bi-iliac diameter	27,2
Radiale height	54,9	Trochanterion height	24,9

Classification matrix				Classification matrix			
	MP	FP	Correct %		MA	FA	Correct %
MP	31	0	100	MA	26	0	100
FP	0	18	100	FA	0	11	100
Total	31	18	100	Total	26	11	100

*A total of 26 basic anthropometric measurements (Tables XI to XV) were utilized in the stepwise discriminant analysis.

Table XXXVII: Stepwise discriminant analysis: derived morphological measurements* of tennis players.

MALE		FEMALE	
Professional - Amateur		Professional - Amateur	
Variable entered	Approximate F-statistic	Variable entered	Approximate F-statistic
Lean body mass	11,4	Forearm girth % U.L. length	45,9
Bicon dia (fem) % L.L. length	7,2	Relative L.L. length	38,5
Bone index L.L.	6,1	Bone index U.L. (BSA)	35,9
Relative forearm length	5,6	Relative forearm length	34,7

Classification matrix				Classification matrix			
	MP	MA	Correct %		FP	FA	Correct %
MP	25	8	75,8	FP	19	0	100
MA	8	20	71,4	FA	0	11	100
Total	33	28	73,8	Total	19	11	100

PROFESSIONAL		AMATEUR	
Male - Female		Male - Female	
Variable entered	Approximate F-statistic	Variable entered	Approximate F-statistic
Lean body mass	183,5	Percentage body fat	87,8
Percentage body fat	136,7	Muscle index L.L.	81,3
Forearm-arm length ratio	98,4	Bi-il diameter % biacrom diameter	75,3
		Fat index L.L.	73,0
		Bone index U.L.	72,7

Classification matrix				Classification matrix			
	MP	FP	Correct %		MA	FA	Correct %
MP	33	0	100	MA	28	0	100
FP	0	19	100	FA	0	11	100
Total	33	19	100	Total	28	11	100

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* A total of 40 derived measurements (Tables XI to XIV and XVI to XX) were utilized in the stepwise discriminant analysis.

Table XXXVIII: Stepwise discriminant analysis: physiological measurements* of tennis players

MALE		FEMALE	
Professional - Amateur		Professional - Amateur	
Variable entered	Approximate F-statistic	Variable entered	Approximate F-statistic
Hip flexion-extension	14,4	Forced expiratory vol (FEV_1)	17,4
$\dot{V}O_2$ max (ml/kgLBM/min)	12,3	Trunk lateral flexion	14,7
Trunk flexion-extension	11,7	Hip abduction	13,2
Tidal volume	10,7	Inspiratory capacity	13,0
$\dot{V}O_2$ max (ℓ/min)	9,9	Wrist flexion-extension	12,6
		Forced expiratory vol index (FEV_1I)	12,5

Classification matrix				Classification matrix			
	MP	MA	Correct %		FP	FA	Correct %
MP	25	2	92,6	FP	10	0	100
MA	4	17	81,0	FA	0	6	100
Total	29	19	87,5	Total	10	6	100

PROFESSIONAL		*AMATEUR*	
Male - Female		Male - Female	
Variable entered	Approximate F-statistic	Variable entered	Approximate F-statistic
Inspiratory capacity	42,9	Vital capacity/BSA	20,6
Hip flexion-extension	25,1	Hip flexion-extension	13,0
Forced expiratory vol (FEV_1)	19,1		
Shoulder rotation	16,6		

Classification matrix				Classification matrix			
	MP	FP	Correct %		MA	FA	Correct %
MP	25	2	92,6	MA	18	3	85,7
FP	*0*	*10*	*100*	*FA*	*0*	*6*	*100*
Total	25	12	94,6	Total	18	9	88,9

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* A total of 20 physiological measurements (Tables XXIII to XXV) were utilized in the stepwise discriminant analysis.

Table XXXIX: Stepwise discriminant analysis: morphological and physiological measurements* of tennis players

MALE		FEMALE	
Professional - Amateur		Professional - Amateur	
Variable entered	Approximate F-statistic	Variable entered	Approximate F-statistic
Ankle diameter	18,1	Lean volume L.L.	57,1
$\dot{V}O_2$ max (ℓ/min)	16,3	Forearm girth % U.L.	56,9
Hip flexion-extension	13,0	Bitrochanteric diameter	49,1
Trunk flexion-extension	12,7	Bone index U.L. (BSA)	39,0
		Bi-iliac diameter	30,3

Classification matrix				Classification matrix			
	MP	MA	Correct %		FP	FA	Correct %
MP	24	3	88,9	FP	12	0	100
MA	1	19	95,0	FA	0	6	100
Total	25	22	91,5	Total	12	6	100

PROFESSIONAL		AMATEUR	
Male - Female		Male - Female	
Variable entered	Approximate F-statistic	Variable entered	Approximate F-statistic
Lean body mass	122,3	Dactylion height	55,2
Supra-iliac skinfold	88,4	Percentage body fat	54,5
Percentage body fat	81,7	Bone index U.L.	49,5
Forearm-arm ratio	76,3	Bi-il dia % Biacrom dia	48,5
Contracted arm girth	73,2	Muscle index L.L.	41,4
Body mass	64,7	Body surface area	40,5

Classification matrix				Classification matrix			
	MP	FP	Correct %		MA	FA	Correct %
MP	27	0	100	MA	24	0	100
FP	0	12	100	FA	0	6	100
Total	27	12	100	Total	24	6	100

* Measurements found to be important by analyses conducted separately on the basic anthropometric, derived morphological and physiological variables were utilized in the stepwise discriminant analysis.

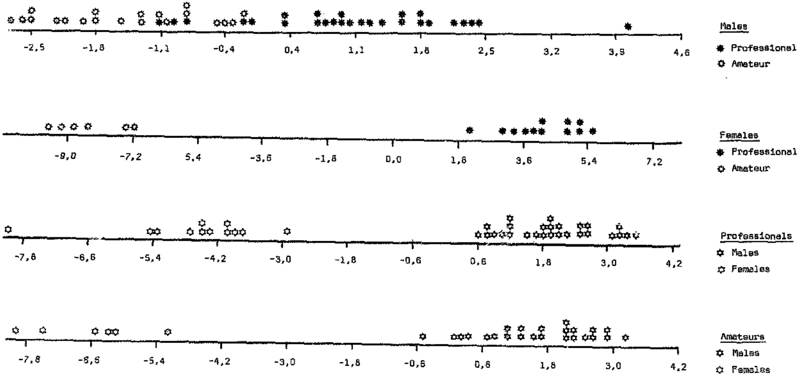

Figure 36: Histograms of canonical variables illustrating differentiation among tennis players

4.11 FACTOR ANALYSIS

The maximum likelihood factor analyses conducted separately in the male and female groups, did not provide any additional useful information. The sorted, rotated factor loadings of the males' basic morphological and physiological variables are shown in Tables XL (p.248) and XLI (p.249). In these tables the factor loading matrices are arranged so that the columns appear in decreasing order of variance explained by the factors. Loadings greater than 0,500 appear first and loadings less than 0,250 are replaced by blanks.

High factor loadings were allocated to variables measuring the same component, such as length, girth and fatness (Table XL) and pulmonary, cardio-respiratory and flexibility function (Table XLI). From these tables it is evident that the factor analyses provided results that had initially been expected.

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Table XL: Sorted factor loadings of morphological variables in male tennis players

Variables	Primary Factors							
	1	2	3	4	5	6	7	8
Acrom ht	0,909	0,273	-	-	-	-	-	-
Radi ht	0,907	0,292	-	-	-	-	-	-
Stat ht	0,901	-	-	0,284	-	-	-	-
Troch ht	0,776	-	-	-	-	-	-	-
Dact ht	0,738	-	0,282	-	-	-	-	-
Biep (hum)•	0,510	0,413	-	-	-	-	-	-
Uncont arm•	0,298	0,876	-	-	-	-	-	-
Cont arm•	0,310	0,843	-	-	-	-	-	-
Fore girth•	0,318	0,829	-	0,289	-	-	-	-
Chest girth	0,304	0,720	-	-	0,290	-	-	-
Mass	0,549	0,618	-	0,422	-	-	-	-
A.P. chest dia	-	0,556	-	-	0,316	-	-	0,394
Thigh girth	0,366	0,519	0,370	0,499	-	-	-	-
Biceps skin	-	-	C,844	-	-	-	-	-
Triceps skin	0,359	-	0,727	-	-	-	-	-
Calf skin	-	-	0,668	-	-	0,314	-	-
Supra-il skin	-	0,370	0,655	-	-	-	-	0,377
Supscap skin	-	0,367	0,576	-	-	-	0,564	-
Ankle dia•	-	-	-	0,788	0,266	-	-	-
Bicon (fem)•	0,315	0,276	-	0,784	-	-	-	-
Wrist dia•	-	0,261	-	0,579	-	-	-	-
Tib ht	0,354	-	-	-	-	0,837	-	-
Styl ht	0,568	-	-	-	-	-0,655	-	-
Calf girth•	-	0,370	0,359	0,259	-	-	-	-
Bitroch dia	0,332	-	-	-	-	-	-	-
Biacrom	0,452	0,356	-	-	-	-	0,282	-
Int-pup dist	-	-	-	-	-	-	-	-
Bi-il	-	0,265	-0,322	0,335	-	-	-	-

• Dominant value (handedness).

Table XLI: Sorted factor loadings of physiological variables in male tennis players

Variables	Primary Factors 1	2	3	4	5	6	7
ERV	0,984	-	-	-	-	-	-
VC	0,877	-	0,425	-	-	-	-
FEV_1	0,875	-	0,345	-	0,331	-	-
VC/BSA	0,773	-	0,333	0,402	-0,276	-	-
$\dot{V}O_2$ max (ml/LBM)	-	0,964	-	-	-	-	-
$\dot{V}O_2$ max (ml)	-	0,931	-	-	-	-	-
$\dot{V}O_2$ max (ℓ)	0,301	0,854	-	-0,312	-	-	-
IC	0,510	-	0,790	-	-	-	-
IRV	0,477	-	0,780	-	-	-0,347	-
Elbow F E*	-	-	-	0,643	-	-	-
Trunk LF	-	-	-	0,626	-	-	-
Hip F E	-	-	-0,309	0,520	-	-	-
FEV_1 I	-	-	-	-	0,961	-	-
TV	-	-	-	-	-	0,962	-
Mech Eff	-	-	-	-	-	-	0,643
Wrist F E*	-	-	-	-	-	-	-
Shoulder F E*	-	-	-	-	-	0,259	0,355
Hip Abd	-	-	-	-	-	-	-0,392
Trunk F E	-	-	0,298	-	-	-	-
Shoulder rot*	-	-	-	-	-	-	0,265
Sup-pron*	-	-	-	0,310	-	-	0,293

* Dominant value (handedness).

4.12 SUMMARY

4.12.1 Questionnaire

Professional tennis coaching was more popular among the female than the male professional players, while in the amateur group it was more popular among the male players.

The male professionals preferred to be idle in their leisure-time, while the female professionals preferred social swimming. A number of the professional players, particularly the females, were active squash players.

Long-distance running was the favourite form of physical training for both the professional and amateur players. A high percentage of the professionals (27%) did not participate in any type of physical training besides their tennis practice sessions.

The incidence of 'tennis elbow' among the professionals was very low (6%). Ankle and shoulder joint sprains were the injuries most frequently sustained during tennis playing.

The professional players did not commence tennis playing at a significantly younger age than the amateurs. The average male player requires about 10 000 hours or 5,3 full-time years of tennis playing in order to become an expert tennis performer. The average female, on the other hand, requires approximately 9 300 hours or 5 full-time years.

4.12.2 Basic anthropometric measurements and indices

The professionals were significantly heavier (mass) and larger (BSA) than the amateurs but stature, height and limb length differences (absolute and relative) were small. Mean androgyny indices and interpupillary distances were similar in the four groups. Significantly larger mean biacromial, bitrochanteric and wrist diameters and upper and lower limb segment girths were found in the professional players. Skinfold differences between the professional and amateur groups were small. Subscapular and supra-iliac skinfold differences between the sexes were not statistically significant.

4.12.3 Derived anthropometric measurements

The professionals had larger mean lean volumes in the upper limb, arm and lower limb than the amateur players ($p < 0,01$). Significantly greater lean volume RIA values were found in the professional groups. The largest lean volume RIA values for all four groups were found in the forearm. The mean bone, muscle and skin-fat indices of limb and limb-segments of the professionals and amateurs were fairly similar.

As in the case of lean volume, the largest bone and muscle index RIA's in all four groups were found in the forearm. The professional players had significantly greater forearm bone index and upper limb muscle index RIA's than the amateurs.

The positive upper limb, arm and forearm skin-fat RIA values indicated that there was more adipose tissue in the dominant than in the non-dominant limb-segments. Mean absolute and relative body fat values of the professionals and amateurs did not differ significantly. The professionals' lean body mass and 'ideal' body mass were significantly greater than those of the amateurs ($p < 0,01$).

Somatotype differences between the two male and two female groups were statistically significant at the 6 and 0,1 percent levels respectively. Smaller SDI's were found in the amateur than in the professional groups.

4.12.4 Physiological observations

Although the professional players had higher mean absolute VO_2 max values than the amateurs ($p < 0,01$), differences in relative $\dot{V}O_2$ max were not significant. The females had higher $\dot{V}O_2$ max values (ml/kg LBM/min) than the males ($p < 0,01$). The mean mechanical efficiency of cycling (net), energy cost of tennis playing (absolute) and sweat-rate of the professional and amateur players did not differ significantly. The professional players had significantly larger mean static and dynamic pulmonary volumes than the amateurs, with the exception of tidal volume and FEV_1I.

Static flexibility differences between the professionals and amateurs were not significant, with the exception of trunk flexion-extension, which favoured the professionals. The negative RIA values in the majority of the bilateral tests indicated greater flexibility in the non-dominant than in the dominant joints.

Ocular dominance (right-eyed) and eye-limb concordance/discordance (unilaterality) were significantly related to tennis proficiency in the females but not in the males.

4.12.5 Biochemical observations

Differences in mean pre- and post-match glucose, lactate and electrolyte concentrations among the four groups were small. Low post-match lactate concentrations were recorded in all the groups. Post-match values were greater than pre-match values for all the biochemical variables with the exception of magnesium.

Ankle diameter and $\dot{V}O_2$ max (ℓ/min) were the two most important discriminants between the male professional and amateur groups, while lower limb lean volume and forearm girth were the two most significant discriminants between the female groups.

Lean body mass and the supra-iliac skinfold were the two most important distinguishing variables between the male and female professional groups, while dactylion height and relative body fat were the most important variables discriminating between the male and female amateur groups.

CHAPTER 5

DISCUSSION

Page

CHAPTER 5

DISCUSSION

The most pertinent findings of the present investigation, as well as those of other related studies, are discussed and interpreted in this chapter.

5.1 QUESTIONNAIRE

In the study of sport champions and the subsequent establishment of 'ideal' norms, it is important that the samples be representative of the population in question. The professional groups in this study were representative since they comprised relatively large numbers of registered professional tennis players who represented a total of 9 nationalities.

The highly significant relationship between the level of tennis proficiency (professional and amateur) and representation (international, national, provincial and club) was an expected finding. However, it was interesting to discover that international or national tennis representation was not a prerequisite for success in the professional ranks. In the professional groups, 11,8 percent of the males and 4,5 percent of the females had attained only provincial representation.

An investigation of the occupations of the players revealed that the female professionals were more involved in professional tennis coaching than the males, while the reverse was true of the amateur players. This state of affairs among the professionals may be due to the fact that the available tournament prize money for female professionals is substantially less than that for males and that the females are more inclined to supplement their incomes by coaching. With regard to the amateurs, it would appear that the greater demand and higher payment for male coaches make this occupation more attractive to males.

The favourite leisure-time activity of the male professionals was idleness, followed by golf and soccer. The female professionals' preferences, in order of importance, were swimming, athletics and squash. Predictably, tennis was the amateurs' favourite leisure-time activity. Although squash may result in habit interference and reduced tennis performance (Copley, 1975c), its popularity among professional players, particularly the females, seems to indicate that little or no habit interference is experienced by proficient players who have well established tennis techniques.

Long-distance or endurance running was the favourite form of training for all the groups. It was interesting to note a marked increase in the popularity of endurance running and circuit training, which was evident from a comparison of past and present percentage frequencies. In recent years distance running has received substantial publicity, both in South Africa and abroad, and it is more than likely that this 'jogging' trend is a general one rather than a specific trend among tennis players. The facts that 26,5 and 27,3 percent of the male and female professionals, respectively, did not participate in any type of training programme other than their tennis practice sessions and that progressive resistance and flexibility training are low on the list of their priorities, illustrate the ignorance prevalent among sport participants today. Progressive resistance training develops both muscular power and endurance, while flexibility training promotes agility and is important in the prevention of muscle, tendon and ligament injuries (De Vries, 1975; Williams and Sperryn, 1976; Copley, 1979a).

Ankle and shoulder sprains were the most common type of tennis injury sustained by the professionals and the male amateurs. The female professionals in particular, appear to be prone to this injury. The incidence of 'tennis elbow' occurred far less frequently in the professional players than in the amateur players. This finding suggests that the correct technique could play a role in the prevention of this injury. According to Nirschl (1974), the incorrect execution of the backhand drive and volley contributes significantly to the development of 'tennis elbow'. In a study of 84 expert tennis players Priest et al (1977) found that 45 percent of the players had experienced symptoms of 'tennis elbow' at some time during their playing careers. Nearly all the 'tennis elbow' symptoms were experienced in one or more of the following three areas: lateral epicondyle, medial epicondyle and the groove for the ulnar nerve (cubital tunnel). Thirteen percent of the players had experienced classical 'tennis elbow'. In the present study, 7,5 percent of the professional players had experienced 'tennis elbow'. The tennis serve, which necessitates forceful extension, flexion and rotation of the trunk, is probably a major contributing cause of the chronic backache found to occur most frequently in the lumbar region.

The age of expert performers is important to the sport scientist concerned with human excellence and diversity. In many sports the age range may be quite considerable. For example, De Garay et al (1974) found an age range of four decades in Olympic weight lifters. In the present study the mean ages of the male and female professionals were 27 and 24 years respectively. These were also the mean ages of a group of expert tennis players studied by Jones et al (1977). The chronological ages at which 317 national amateur tennis championships (singles and doubles) were either won or retained in France, England and the U.S.A., ranged from 14 to 37 years (Lehman, 1938). Maximum proficiency was attained between the ages of 25 and 27 years, while 27 was found to be the optimum age. If we assume that the optimum age of 27 applied to both male and female (no mention was made of the sexual make-up in the 317 championship matches), then a comparison with the ages of the modern professional player indicates that, whereas the male player's optimum playing age has remained unchanged, the female player reaches her optimum tennis playing age approximately three years sooner than the female tennis champion of yesteryear. Professional-amateur differences in the age at which playing was first commenced were statistically non-significant. This finding contradicts the general belief that a young starting age is a prerequisite for top class tennis performance. Although the professional players spent significantly more time (hrs/wk) playing tennis than did the amateur players, differences in the total number of years played were statistically non-significant.

In the process of becoming a professional tennis player the average male spends about 10 000 hours or 5,3 full-time years on the court. This constitutes a total energy cost (gross) of approximately 27,3 million kilojoules. The average female spends approximately 9 300 hours or 5,0 full-time years on the court in order to become an expert performer.

5.2 MORPHOLOGICAL OBSERVATIONS

5.2.1 Introduction

In the discussion of the morphological observations the following approach was utilized:

A. Discussion and interpretation of the statistical differences (analysis of variance and covariance) among the four groups. Relative and absolute differences in bone, muscle, and fat measurements among the four groups are summarised in Table XLVI. In the assessment of the morphological effects of tennis playing the cross-sectional method of analysis was used. As pointed out in Chapter 1, it would be incorrect to assume that tennis playing and training over a number of years were solely responsible for the observed morphological differences between the professional and amateur players. Constitutional dissimilarities and pre-selection (prior to training) may also have been partly responsible for professional-amateur differences in morphology.

B. Visual comparisons of the mean morphological characteristics of professional tennis players and other expert sport performers. Anthropometric data, body composition variables and somatotype ratings of sportsmen and sportswomen are presented in Tables XLII, XLIII, XLIV, XLV, XLVII and XLVIII. Measurements of sedentary males and females who were similar in age to the professional tennis players, are also included in these tables as controls. The 'Student' t-test was utilized to compare the mean anthropometric data of the professional players with the mean data of the sedentary subjects.

C. Discussion and interpretation of important correlations (product-moment) and linear regression equations (simple and multiple).

D. Discussion and interpretation of the variables found to be important (stepwise discriminant analysis) in discriminating between the professionals and amateurs and between the male and female groups.

5.2.2 Body mass and body surface area

The average body mass of the male professional players was 7 kilograms higher than that of the male amateur players, while the female professionals' mean was 6 kilograms higher than that of the amateurs. When stature was held constant (covariance analysis), the professionals were still significantly heavier than the amateurs (Table XXVIII, p.207). Body surface area (BSA) was also significantly greater in the professionals. As expected, the males were heavier and larger than the females ($p < 0,01$).

From Table XLII (p.265) it can be seen that the male tennis professionals' mean body mass was 7 kilograms greater than that of sedentary males ($p<0,01$). The professional tennis players, professional cricketers and physical education students had similar body masses. It was interesting to find that only the Olympic rowers had a greater mean BSA than the male professional tennis players. As can be seen from Table XLIII (p.266), the female tennis professionals had the second largest mean body mass (Olympic canoeists were the heaviest) and the largest mean BSA. The professional and national tennis players had very similar mean body masses.

Predictably, body mass was correlated significantly with stature in all four tennis-playing groups. It was found that body mass could be used to predict accurately a number of morphological and physiological variables. The most promising regression formulae are presented and discussed under the relevant sub-sections of this chapter.

Body mass, which was considerably larger in the male professionals than in the female professionals, was an important discriminant between these two groups, while BSA, which was larger in the male amateurs than in the female amateurs ($p < 0,01$), was an important variable in distinguishing between these two groups. However, it should be noted that when use is made of multivariate statistics (stepwise discriminant analysis), a variable may be found to be an important discriminant between two groups, without these groups necessarily differing significantly in this particular variable.

5.2.3 Lengths

In contrast to body mass, the professionals' mean stature was similar to that of the amateur players, for both sexes. When body mass was held constant, stature differences remained statistically non-significant (Table XXVIII, p.207). According to the height table of

Martin and Saller (1957), the male professionals' mean stature of 182,8 centimetres falls in the category 'very tall'. The male amateurs' mean stature of 178,5 centimetres falls in the category 'tall'. Tallness appears to be an advantage in tennis playing.

Absolute height, and absolute and relative upper and lower limb and segment length differences between the professionals and amateurs were also small and statistically non-significant. The mean upper limb lengths (absolute) were comparable for the male professional (81,8 cm) and amateur (80,1 cm) players and very similar for the female professionals (74,2 cm) and amateurs (74,0 cm). These findings indicate that the greater racket-head speed and subsequent ball velocity generally attained by the professional player, is not the result of a greater upper limb or lever arm length. On the other hand, the greater racket-head speed and ball velocity which generally characterises the male player's game, is probably due partly to the male's considerably greater upper limb or lever arm length. Tangential velocity (V_T) or racket-head speed (linear) is the product of angular velocity (ω) and lever arm length (r).

Predictably, the males had greater absolute lengths than the females. However, the mean relative upper and lower limb and segment lengths of the males and females were very similar; in fact, the females had greater mean relative lower limb and thigh lengths than the males (Table XII p.168).

As can be seen from Tables XLII (p.265) and XLIII (p.266), the professional tennis players were on the average taller than most of the other groups of sport representatives. The male professionals were on average 7 centimetres taller than the sedentary males ($p < 0,01$). Only the rowers were taller than the male professionals. The mean statures of the professional and national tennis players were practically identical.

Forearm-arm ratio was an important discriminant between the male and female professional groups (>FP), while dactylion height was a highly significant discriminant between the male and female amateur groups (> MA).

5.2.4 Diameters

The male professionals had significantly larger mean biacromial, bitrochanteric, wrist, ankle and bicondylar (femur) diameters than the amateurs, while the female professionals had significantly larger mean biacromial, bitrochanteric and wrist diameters than the female amateurs. The professionals' significantly larger dominant wrist diameter may be due partly to bone hypertrophy in response to habitual racket manipulation. As expected, the males had greater bone diameters than the females.

Differences in mean interpupillary distance between the professionals and amateurs and between the male and female professionals were not significant. However, the male amateurs had a significantly larger mean interpupillary distance than the female amateurs. Stature was the only morphological characteristic that correlated significantly with interpupillary distance in the professional players.

Comparisons with other sportsmen (Table XLII, p.265) indicated that while the male professional tennis players' mean hip width was similar to the mean widths of most of the other sport representatives, their mean shoulder width was noticeably smaller. The professional female tennis players, on the other hand, had on the average, narrower hips but a similar mean shoulder width compared with other sportswomen (Table XLIII, p.266).

Ankle diameter was the most important discriminant between the male professional and amateur groups (> MP), while bitrochanteric (>FP) and bi-iliac (>FA) diameters were significant discriminants between the female professional and amateur groups. Bi-iliac diameter as a percentage of biacromial diameter was important in distinguishing between the male and female amateur groups (> FA). The evidence suggests that narrow hips may constitute a structural advantage in women's tennis.

5.2.5 Girths

The professional players had larger mean upper and lower limb segment girths than the amateurs ($p < 0,01$). Relative girth differences between the professionals and amateurs were not significant. It was interesting to find that the female professionals had the largest mean relative thigh and calf girths of the four groups. The female professionals appear to have a greater tissue mass in the lower than in the upper limb compared with the males. A similar finding was reported by Hebbelinck et al (1975) in male and female Olympic swimmers and divers.

From Table XLII (p.265) it is evident that the male professional tennis players tended to have smaller mean girths than the cricketers, rowers, Nordic skiers and wrestlers. In contrast, the female professional tennis players tended to have larger mean girths than most of the other female sport representatives (Table XLIII, p.266). The professional tennis players and sedentary subjects (male and female) had similar means for arm (uncontracted) and calf girths. However, mean forearm and thigh girths were far larger in the tennis players ($p < 0{,}01$). The evidence suggests that intensive tennis training and competition increases these girths.

Unexpectedly, forearm girth was found to be correlated highly and significantly with the majority of the basic and derived anthropometric variables as well as with various physiological variables (Table XXXII, p.215). Forearm girth was correlated particularly highly with the following variables: body mass, BSA, upper limb lean volumes, lean body mass and 'ideal' body mass. In the males, forearm girth also correlated significantly with $\dot{V}O_2$ max (ℓ/min), FEV_1, VC and relative body fat, while in the females it correlated significantly with $\dot{V}O_2$ max (absolute and relative) and relative body fat.

Forearm girth as a percentage of upper limb length was the second most important discriminant between the female professional and amateur groups (> FA). Contracted arm girth was a significant discriminant between the male and female professional groups (> MP).

5.2.6 Skinfolds

The mean skinfolds of the professional and amateur players did not differ greatly (Table XV, p.171). Predictably, the males had smaller biceps, triceps and calf skinfolds than the females ($p < 0{,}01$). However, subscapular and supra-iliac skinfold differences between the sexes were not significant. The mean supra-iliac skinfold of the female amateurs (6,0 mm) was in fact, the lowest of the four groups. Garn (1957) also reported that, although males had smaller amounts of subcutaneous fat than females, this was not applicable to the iliac crest and deltoid sites. Soft tissue X-ray techniques were used to measure the subcutaneous adipose tissue. Ageing is generally associated with increased deposits of subcutaneous adipose tissue. In males these deposits usually occur in the trunk region (the so-called 'tyre' in males), while in females the deposits occur generally in the arm, hip and thigh regions. The findings of the present study may be the result of regional differences in subcutaneous fat deposits between the sexes. These sex differences are probably genetically determined.

The mean triceps and supra-iliac skinfolds of the tennis professionals were significantly smaller than those of sedentary males ($p < 0,05$) and sedentary females ($p < 0,01$). The supra-iliac skinfold was an important discriminant between the male and female professional groups ($>$FP).

5.2.7 Androgyny

The male professional and amateur groups had very similar androgyny or masculinity indices (Figure 5, p.167). When mass and stature were held constant (covariance analysis), androgyny differences were still found to be statistically non-significant (Table XXVIII, p.207). As can be seen from Table XLII (p.265), the male professional tennis players were considerably less androgynous than the professional cricketers and the Olympic boxers, rowers and snow skiers. The androgyny indices of non-athletic college males reported by Tanner (1951) and Milne (1972) were very similar to the mean values of the male tennis players in the present study. The evidence suggests that androgyny in physique is unrelated to tennis proficiency in the male.

In contrast to the males, the female professional tennis players were clearly more androgynous than the female amateur players (Figure 5, p.167). Even with corrections for mass and stature (Table XXVIII, p.207), the professionals were still more androgynous than the amateurs. Studies by Hebbelinck <u>et al</u> (1975) and Malina and Zavaleta (1976) have indicated that a 'masculine physique' is necessary for success in sports such as hurdling, javelin throwing, diving and swimming. As can be seen from Table XLIII (p.266), the female professional tennis players were less androgynous than the Olympic gymnasts, canoeists and swimmers but very similar to national sprinters. The androgyny index of 78,9 reported by Tanner (1951) for non-athletic females was considerably lower than the index of 85,6 calculated for sedentary females from the mean data reported by Fleming et al (1964). The latter androgyny index, which was usually high, was due largely to the very narrow mean bi-iliac diameter (22,7 cm) of the subjects who appeared to be quite young. The fact that the female professionals were clearly more androgynous than the amateurs and non-athletic females (Tanner 1951) suggests that a 'masculine physique' may be an advantage to the female tennis player.

Although androgyny and mass (also LBM), and androgyny and stature, were significantly correlated in the professionals and amateurs respectively, the correlations and coefficients of determination (R^2) were too low for the accurate prediction of androgyny. The addition of BSA and hours played per week increased the accuracy with which androgyny could be predicted. However, since only two diameters are required for the calculation of the androgyny index, these multiple linear regression equations are of little practical value.

Table XLII: Mean anthropometric data of sportsmen

	Professional Tennis Players Present Study	National Tennis Players Chinn et al (1974)	Professional Cricketers Jones et al (1965)	Olympic Boxers De Garay et al (1974)	Olympic Rowers Novak et al (1978)	Olympic Nordic Skiers Sinning et al (1977)	Olympic Wrestlers Tanner (1964)	Physical Educ Students Desiprès et al (1978a)	Olympic Cyclists De Garay et al (1974)	Sedentary Caucasoids Fleming et al (1964)
Mass (kg)	76,5	77,7	77,0	80,0	88,7	71,8	72,0	76,3	68,9	70,2
Stature (cm)	182,8	183,0	176,4	179,5	189,7	179,0	172,4	177,6	174,9	175,9
B S A (m^2)	2,01	2,00*	1,94*	1,99*	2,17*	1,90*	1,85*	1,94*	1,83*	1,86*
Biacrom (cm)	39,7		41,1	42,1	43,2	41,4	40,6		39,9	38,5
Bi-iliac (cm)	28,5		28,1	29,3	30,4	28,8	28,5	34,5	28,1	27,5
Androgyny	90,6		95,2*	97,0*	99,2*	95,4*	93,3*		91,6*	88,0*
Girths (cm)										
Chest	94,9		95,1			95,9				93,6
Arm (uncon)	29,4	30,0	30,7		31,8		31,7	33,9		29,2
Forearm	28,5	28,7			30,4	27,9				24,2
Thigh	56,7		60,4		57,5	55,0	54,8			51,4
Calf	36,9		38,3		41,4	37,9		37,5		35,7
Skinfolds (mm)										
Triceps	6,7				8,0	6,8	6,9☆	8,8		8,4
Biceps	3,6				3,1		3,7☆			
Subscapuler	8,5				8,7	7,3	9,1☆	11,5		9,4
Supra-iliac	6,8				10,8	6,5	5,9☆	15,7		10,7

*Calculated from available mean data.

☆Calculated from available raw data.

<u>Table XLIII</u>: Mean anthropometric data of sportswomen

	Professional Tennis Players	National Tennis Players	Olympic Nordic Skiers	*Olympic* Gymnasts	*Olympic* Canoeists	*National* Sprinters	*Olympic* Swimmers	Sedentary Caucasoids
	Present Study	Chinn et al (1974)	Sinning et al (1977)	Novak et al (1977)	De Garay et al (1974)	Malina et al (1971)	Hebbelinck et al (1975)	Fleming et al (1964)
Mass (kg)	60,7	59,3	56,9	52,5	61,0	57,0	59,9	59,6
Stature (cm)	167,3	168,0	164,5	163,5	163,1	165,0	164,4	164,6
B S A (m^2)	1,70	1,68✿	1,62✿	1,56✿	1,66✿	1,62✿	1,65✿	1,65✿
Biacrom (cm)	36,2		35,0	36,7	38,0	36,5	37,1	36,1
Bi-iliac (cm)	26,5		27,6	25,9	27,8	27,5	27,1	22,7
Androgyny	82,3		77,4✿	84,2✿	86,2✿	82,0✿	84,2✿	85,6✿
<u>Girths</u> (cm)								
Arm (uncon)	26,4	26,0		24,7		25,0		25,5
Forearm	25,1	25,1	24,2	22,8				20,6
Thigh	56,0		56,1	48,1				49,4
Calf	35,0		35,6	34,3		36,0		34,5
<u>Skinfolds</u> (mm)								
Triceps	12,2		13,0	12,1		11,0		18,6
Biceps	6,0			4,1		6,0		
Subscapular	10,1		8,5	6,5		10,5		14,5
Supra-iliac	8,3		8,8	7,6		15,0		15,3

✿Calculated from available mean data.

5.2.8 Body composition

A. 'Ideal' body mass

As in the case of body mass, both the professionals and the males had significantly larger mean 'ideal' body masses than the amateurs and the females respectively (Table XX p.185). The 'ideal' body mass was lower than the measured body mass in all four groups. The female professionals had the largest difference and their 'ideal' mass was 3 kilograms (fat rating) lower than their measured mass. Professional and amateur tennis players had, on the average, a body mass which was between 2 and 3 kilograms heavier than the 'ideal' tennis-playing body mass.

In the assessment of the 'ideal' body mass for tennis playing, relative body fat values of 9,5 percent in the male and 17,5 percent in the female were used. These values were selected on the basis of data obtained from some of the world's leading male and female tennis players (Copley, 1976a). Competitive tennis playing necessitates rapid movement about the court and there is little doubt that the player with the least amount of fat has an advantage. The 'ideal' relative body fat values used in this study were not particularly low, in fact, values of about 7,5 percent in the male and 14,5 percent in the female, would probably be more 'desirable'. The use of these lower values instead of those utilized in the present study, would constitute a reduction of approximately 2 kilograms in the total adipose tissue mass of the professional players.

Body mass was very highly and significantly correlated with 'ideal' body mass in all four groups and the following simple linear regression equations were obtained:

		R^2 (%)
Male professionals	IBM = 0,8291 (mass) + 11,28	87
Female professionals	IBM = 0,6367 (mass) + 19,24	77
Male amateurs	IBM = 0,8305 (mass) + 9,82	96
Female amateurs	IBM = 0,6613 (mass) + 17,20	90

The 'ideal' body mass for tennis in professional and amateur players can be accurately predicted from these regression formulae or, otherwise, directly from the respective regression graphs (Figure 28, p.228, and Figure 35, p.235). BSA and 'years played' accounted for 87 percent of the variation in the IBM of the female professionals, which was 10 percent higher than that accounted for by mass alone. However, it is unlikely

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B. Lean body mass (LBM)

The mean LBM of the professionals was greater than that of the amateurs ($p < 0,01$). Differences were not significant when stature and mass were held constant. The LBM of the males was significantly greater than the females even when stature and mass were standardised (Table XXVIII p.207).

The male professional tennis players' mean LBM was similar to that of the Olympic soccer players, slightly higher than that of the Olympic sprinters and wrestlers but ± 8 kilograms greater ($p < 0,01$) than that of sedentary males (Table XLIV, p.279). The female tennis professionals' mean LBM was fairly similar to those of Olympic swimmers and Nordic skiers, and 5 kilograms greater ($p < 0,01$) than that of sedentary females (Table XLV, p.280). The evidence suggests that intensive tennis training and competition over a period of years results in an increase in mean LBM.

As in the case of 'ideal' body mass, LBM was highly and significantly correlated with body mass in all four groups. The following one-term regression equations can be used to predict the LBM of professional and amateur tennis players:

				R^2 (%)
Male professionals	LBM	=	0,7347 (mass) + 11,24	85
Female professionals	LBM	=	0,4629 (mass) + 19,18	64
Male amateurs	LBM	=	0,7351 (mass) + 9,87	94
Female amateurs	LBM	=	0,5066 (mass) + 15,97	85

It is evident from the high coefficients of determination and narrow confidence bands that either these regression equations or the regression graphs (Figure 27, p.227 and Figure 34, p.234) can be utilized to predict accurately LBM in tennis players. Since LBM prediction equations have been found to be highly population-specific (Jackson and Pollock, 1977), it is important that the appropriate formulae be used.

A stepwise discriminant analysis conducted on the derived morphological variables revealed that LBM was the most important discriminant between the male professional and amateur groups (> MP). However, when the analysis was conducted on all the measurements, LBM was not found to be an important discriminant between the two male groups. LBM was the most important variable in distinguishing between the male and female professional groups (> MP). The male professional's abilities to hit the ball harder and to move about the court more rapidly than the female are probably due in part to his greater LBM.

C. Bone measurements[☆]

I. Bone index

The mean limb and segment bone indices (relative bone masses) of the professional and amateur players were fairly similar. Predictably, bone indices were significantly higher in the males.

As may be seen from Table XLIV (p.279), the male professional tennis players had the same mean upper limb bone index as the Olympic wrestlers, but a higher index than the Olympic sprinters and javelin throwers. The upper limb bone indices of sedentary males and females (Table XLV p.280) were considerably lower than those of the tennis professionals ($p < 0,01$).

The male professionals tended to have higher mean bone index RIA values than the male amateurs, while the female professionals tended to have lower mean RIA values than the female amateurs. However, RIA differences among the groups were not significant with the exception of the forearm and lower limb (females). The professionals had significantly higher mean forearm bone index RIA values than the amateurs. The female professionals' mean RIA value (16,0) was particularly high. It should be pointed out that identical upper limb and arm RIA values (bone, muscle and skin-fat) were obtained within each of the four groups. The reasons for this were: bi-epicondyler (humerus) diameter was utilized to calculate cross-sectional bone area of both the upper limb and the arm; right and left limb and segment lengths were assumed to be equal and, tissue density constants were used. As a result, right and left side ratios remained the same.

[☆] For a discussion of lean volume see p.272.

Bone index (upper limb), determined by expressing bone mass as a percentage of body mass (formulae of Wartenweiler et al., 1974), was highly and significantly correlated in all four groups with bone index (upper limb), determined by expressing bone cross-sectional area as a percentage of body surface area (method proposed by the author). The latter method involves fewer calculations than the method of Wartenweiler et al (1974) and the evidence suggests that it may be used as an alternative method. Bone index could not be accurately predicted from any of the derived simple or multiple linear regression equations.

Upper limb bone index (BSA) was an important discriminant between the female professional and amateur groups (> FP)[✩], while the upper limb bone index was a significant discriminant between the male and female amateur groups (> MA).

11. Relative and absolute bone differences

The relative and absolute differences in bone measurements are summarised in Table XLVI (p.281). It is evident from this table that while the professionals, particularly the males, tended to have significantly larger absolute bone measurements (diameters) than the amateurs, differences in relative measures (bone index) were generally small. The facts that the highest bone RIA values in all four groups were found in the forearm and that wrist diameters and forearm bone RIA values were considerably larger in the professional players, indicate that habitual racket manipulation results in marked bone hypertrophy in the dominant forearm. Other studies on expert tennis players have revealed similar findings. Lewis (1971) found larger bone diameters and cortical thicknesses in the dominant upper limb compared with the non-dominant limb, while Priest et al (1977) reported significant hypertrophy in the radius and ulna of the playing forearm compared with the non-playing forearm. Roentgenographic techniques were used in both studies.

[✩] When expressed to two decimal places (Table XVII, p.179) no difference between the two female groups was observed. However, when expressed to four decimal places the bone index was larger in the female professionals.

D. Muscle measurements

I. Muscle index

The professionals tended to have higher mean muscle indices (relative muscle masses) than the amateurs but the differences were not statistically significant. However, differences (in favour of the professionals) in relative upper limb muscle cross-sectional area (muscle index BSA) were significant ($p < 0{,}01$). This finding and the fact that upper limb muscle index was not highly correlated with upper limb muscle index (BSA) in three of the four groups, indicate that different results may be expected when these two tissue index methods are applied to muscle tissue. In contrast, when these two tissue index methods are applied to bone tissue, similar results may be expected.

The males had higher mean relative muscle masses than the females in the upper limb, arm and forearm ($p < 0{,}01$). On the other hand, the females had larger relative muscle masses in the lower limb. Relative thigh and calf girths were found also to be larger in the females (professionals). These findings are probably due partly to the fact that the lower limbs of both sexes are subjected generally to more similar conditions of physical activity than are the upper limbs.

The male professional tennis players had a slightly higher average upper limb muscle index than the Olympic sprinters, but a considerably lower mean index than that of the Olympic javelin throwers and wrestlers (Table XLIV, p.279). The mean upper limb muscle indices of sedentary males and females were considerably lower than those of the tennis professionals (Tables XLIV, p.279 and XLV, p.280) at the 1 percent level of significance.

Mean upper limb and arm muscle index RIA's were larger in the professionals than in the amateurs ($p < 0{,}05$). The forearm muscle RIA was also larger in the female professionals ($p < 0{,}05$). Although differences were small, it was surprising to find a larger mean forearm muscle RIA in the male amateurs than in the male professionals.

Muscle index could not be accurately predicted from one-term regression equations, but the following multiple linear regression formulae do provide a relatively high degree of predictive accuracy.

		R^2(%)
Female professionals	Mus index U.L.(BSA) = 1,06+0,004 (yrs) - 0,01 (stat) + 0,40 (BSA)	77
Male amateurs	Mus index U.L.(BSA) = 0,6+0,01 (mass) - 0,004 (stat) + 0,002 (yrs)	69
Female amateurs	Mus index U.L.(BSA) = 0,6 + 0,007 (mass) - 0,004 (stat)	73

Lower limb muscle index was an important discriminant between the male and female amateur groups (> FA).

II. Lean volume

The professionals' mean upper limb, arm and lower limb lean volumes were larger than those of the amateurs ($p < 0,01$). The professionals also had larger average lean volumes in the forearm, but the differences were not significant. Predictably, the average lean volumes of the males were larger than those of the females ($p < 0,01$). Although upper and lower limb lean volume differences between the professionals and amateurs were non-significant when mass, stature and lengths (limb) were kept constant, these corrections did not alter the position in respect of the lean volume differences between the sexes (Table XXVIII, p.207), in other words, the average lean volumes were still found to be larger in the males.

Comparisons of the mean values for upper limb and segment lean volumes among expert male sport participants (Table XLIV, p.279) revealed that the male professional tennis players had larger average arm and forearm lean volumes than Olympic soccer players and a larger mean upper limb lean volume than Olympic sprinters. Since sprinting and soccer playing make little structural or functional demands on the upper limb, this is not unexpected. Olympic water polo players, swimmers and rowers had substantially larger average lean volumes of arm and forearm than the professional tennis players. Arm, forearm and upper limb lean volumes in the male professionals were considerably larger than those of sedentary males ($p < 0,01$).

On the average the female professional tennis players had a larger arm lean volume than Olympic runners. The professional tennis players and the gymnasts had the same average forearm lean volumes (Table XLV, p.280).

One would expect to find larger mean lean volumes in gymnasts who use their upper limbs extensively. Female Olympic gymnasts are often quite young (14 to 16 years) and this may explain their relatively small arm and forearm average lean volumes. The female professional tennis players had substantially larger average lean volumes of arm, forearm and upper limb than sedentary females $(p < 0.01)$.

The lean volume RIA findings were very similar to the muscle index RIA findings. As in the case of the muscle index, the largest average lean volume RIA's in all four groups were found in the forearm.

The male amateurs had significantly larger forearm lean volume RIA's than the male professionals $(p < 0.01)$. A similar finding was evident respect of the forearm muscle index RIA. An investigation of the lean volume in the non-dominant forearms of the male professionals and amateurs revealed that there were relatively larger differences (in favour of the professionals) in the non-dominant forearm compared with the differences in the dominant forearm. This finding suggests that the male professional players had more muscular forearms than the amateurs before the commencement of tennis playing and training. It seems likely that a degree of pre-selection may have been partly responsible for the observed differences in upper limb muscularity between the male professional and amateur players.

It should be pointed out that the non-dominant upper limb is not an unexercised extremity, since it is used to elevate the ball during the serve, to achieve and maintain balance during the execution of the strokes, to steady and support the racket on the backhand side prior to the forward swing and, sometimes, to execute drives and/or volleys in the case of double-handed strokes. These functions, particularly the latter one, would tend to lessen, particularly in the professionals, the structural differences between the dominant and non-dominant limbs and may provide some explanation for larger mean lean volume and muscle index RIA values in the amateur players.

The findings indicated that lean volume could not be accurately predicted by means of one-term regression equations. The following multiple regression equations were the most promising:

		R^2 (%)
Male professionals	Lean volume = -179,4 + 18,32 (hrs/wk) + 64,15 (mass) (U.L.)	48
Female professionals	Lean volume = -1160,7 + 2251,15 (BSA) + 52,79 (yrs) (U.L.)	69
Male amateurs	Lean volume = 1395,3 + 98,64 (mass) - 28,10 (stat) + 53,14 (age) (U.L.)	91
Female amateurs	Lean volume = -1030,3 - 29,02 (hrs/wk) + 76,24 (mass) (U.L.)	75

Lower limb lean volume was the most important discriminant between the female professional and amateur groups (> FP). This was not an important discriminant between the two male groups. The female professionals' greater lower limb lean volume probably enables them to move about the court more rapidl [illegible] emale amateurs.

III. Relative [illegible] bsolute muscle differences

Relative and absolute differences in muscle measurements among the groups are shown in Table XLVI (p.281). The mean girth and lean volume values were in close agreement and there is little doubt that the professional tennis player is, on the average, considerably more muscular than the amateur, while the male is considerably more muscular than the female. The professional is also relatively more muscular than the amateur, although differences here are far less pronounced. The findings indicate that habitual racket manipulation results in marked muscular hypertrophy of the dominant upper limb. The high forearm muscle index and lean volume RIA's indicate that the greatest hypertrophy occurs in the forearm. Similar findings were reported from studies conducted on tennis players by Buskirk et al (1956), Chinn et al (1974), Copley (1976a) and Priest et al (1977). From visual inspections of a large number of professional tennis players, it has become evident to the author that the structural asymmetry which generally characterises the professional player, is not restricted to the upper extremities but is clearly discernible in the musculature of the trunk (rectus abdominis, pectoralis major and trapezius) as well.

Another interesting trend evident from Table XLVI (p.281) is that the female professionals had higher mean muscle index RIA's than the males in the upper limb, arm and forearm. Under similar training or exercising conditions, muscular hypertrophy is usually less pronounced and occurs more slowly in the female than in the male (Massey et al., 1973; Noakes, 1977). According to Noakes (1977) this phenomenon is due to the lower levels of body building testosterone in the female. From the muscle index RIA findings it appears that upper limb muscular hypertrophy is relatively greater in the female than in the male professional tennis players. It is the author's contention that this phenomenon is due largely to sex differences in absolute muscular strength. Because of her smaller absolute strength (Mathews and Fox, 1976) and the fact that there is usually little difference in the mass of the rackets used (Copley, 1979a), the female utilizes a higher proportion of her maximum upper limb strength. This then would result in relatively greater muscular hypertrophy in the female professional tennis player.

E. Fat measurements

I. Skin-fat index

The mean upper and lower limb skin-fat indices (relative fat masses) of the professionals and amateurs were similar. The female professionals had slightly higher skin-fat index means than the female amateurs. As could be expected, the females had significantly larger relative fat masses than the males ($p < 0.01$).

From Table XLIV (p.279) it is evident that the male professional tennis players had on the average, relatively less upper limb fat than Olympic javelin throwers and wrestlers, but relatively more fat than Olympic sprinters. The sedentary males had a higher mean upper limb relative fat mass than the professional tennis players. The female professional tennis players had a smaller relative amount of fat in the upper limb compared with the sedentary females (Table XLV, p.280).

Differences in mean skin-fat index RIA's among the four groups were not statistically significant. It would appear that intensive racket manipulation has little effect on the amount of fat in the dominant compared with the non-dominant upper limb. This was in keeping with similar results obtained in studies conducted on tennis players by the author (Copley, 1976a) and Gwinup et al (1978). These findings, as well as those of the present study, fail to support the 'spot reduction' theory.[✪]

[✪] Reduction in the amount of adipose tissue in a specific area in response to localised training or exercise.

The positive upper limb, arm and forearm skin-fat RIA's found in all four groups indicated very clearly that there was more fat in the dominant than in the non-dominant upper limb. Although one might have expected non-significant fat differences between the dominant and non-dominant limbs, one would not have expected to find more fat in the dominant upper limb. Biceps and triceps skinfolds were consistently larger in the dominant limb. It is highly unlikely that instrument or observer error were responsible for the observed finding since calibrated Harpenden skinfold calipers were utilized for the measurements and because the two observers (the author and a senior assistant), frequently took skinfold measurements on the same subject. According to W. Ross (personal communication), muscular hypertrophy may result in reduced skin compressibility which, in turn, would have the effect of increasing skinfold caliper measurements. Since most of the players were more muscular in their dominant limbs, this appears to be a feasible explanation for the observed finding.

The upper limb skin-fat index was highly and significantly correlated with upper limb skin-fat index (BSA) in the male professional and amateur groups. When these two tissue index methods (relative mass and relative cross-sectional area) are applied to fat tissue, similar findings can be expected. Since the latter tissue index method (by relative cross-sectional area), proposed by the author, involves fewer calculations than the other method, it appears to be the more practical one to use.

As in the case of the bone index, skin-fat index could not be accurately predicted from any of the derived simple or multiple linear regression formulae.

II. Relative and absolute body fat

The mean relative and absolute body fat of the professionals and amateurs were fairly similar. Predictably the females had greater relative and absolute body fat than the males ($p < 0.01$). According to S. Terblanche (personal communication), exercise causes a marked stimulation of the female's but not the male's appetite. This is due to sexual dimorphism in hormonal response to exercise. This may partly explain the observed difference in body fat between the male and female tennis players. When mass and stature were held constant, relative body fat differences among the groups remained unaffected (Table XXVIII, p.207).

From Table XLIV (p.278) it is evident that the male professional tennis players' mean relative and absolute body fat was greater than that of all the other sport representatives with the exception of the Olympic javelin throwers and wrestlers (relative fat). However, the professionals had substantially less relative fat than sedentary males ($p < 0,01$). The female professional tennis players had the largest mean relative and absolute body fat of all the expert performers (Table XLV, p.280). They did, however, have markedly less relative ($p < 0,01$) and absolute ($p < 0,05$) body fat than sedentary females. The professional tennis players' average body fat (relative and absolute) is considerably greater than one would expect to find in athletes whose sport requires rapid displacement of the body mass for extended periods of time. The lack of specialised training programmes, and the high carbohydrate content meals served at most of the tournaments, are probably major factors contributing to this observed finding.

The accuracy with which absolute body fat (fat mass) could be predicted was considerably higher than the accuracy with which relative body fat (% fat) could be predicted in all the groups, except the female amateurs. Of course, relative body fat may be determined easily by expressing absolute fat mass as a percentage of body mass.

The following linear regression equations can be used to predict body fat with a fairly high degree of accuracy:

		R^2 (%)
Male professionals	Fat mass (kg) = -10,4 + 0,20 (mass) + 0,14 (age)	47
Female professionals	Fat mass (kg) = 30,4 + 0,70 (mass) - 0,37 (stat) + 0,17 (yrs)	84
Male amateurs	Fat mass (kg) = 17,9 - 0,97 (BSA) + 0,42 (mass) - 0,21 (stat)	82
Female amateurs	Percent fat = 0,5343 (mass) - 9,38	62

The prediction of relative body fat from mass in the female amateurs can be obtained also from the regression graph presented in Figure 32 (p.232).

Relative body fat was a very important discriminant between the male and female groups (>F). It is the author's contention that the male's ability generally to move about the court more rapidly and efficiently than the female, is due partly to his considerably lower relative body fat.

III. *Relative and absolute fat differences*

A summary of the relative and absolute differences in fat measurements among the four groups is presented in Table XLVI (p.281). It is evident from this table that the professionals tended to have larger absolute and relative fat measurements than the amateurs. Absolute and relative fat measurements were considerably larger in the females compared with the males. Fat differences between professional players and sedentary subjects seem to indicate that tennis playing may have the effect of reducing body fat. However, the insignificant differences between the professionals and amateurs in respect of relative and absolute body fat and upper limb skin-fat index RIA's, suggest that the frequency and intensity of tennis playing have little effect on absolute fat mass and local fat deposits.

TABLE XLIV: Body composition of sportsmen

	Professional Tennis Players	Olympic Water Polo Players	Olympic Swimmers	Olympic Rowers	Olympic Soccer Players	Olympic Sprinters*	Olympic Javelin Throwers*	Olympic Wrestlers*	Sedentary Caucasoids*
	Present Study	Novak et al (1976)	Novak et al (1976)	Novak et al (1978)	Novak et al (1978)	Tanner (1964)	Tanner (1964)	Tanner (1964)	Fleming et al (1964)
Lean body mass (kg)	67,4	74,8	59,3	82,2	67,3	64,5	79,0	63,3	59,6
Absolute fat (kg)	9,0	7,2	5,6	6,5	4,5	7,3	13,9	8,7	10,6
Relative fat (%)	11,8	8,8	7,5	7,3	6,2	10,2	15,0	12,1	15,1
LEAN VOLUME (cm^3 x 1000)									
Arm	2,13	2,78	2,53	2,89	2,02				1,88
Forearm	1,50	1,73	1,56	2,14	1,41				1,01
Upper limb	5,02					4,68	7,18	5,43	3,77
UPPER LIMB TISSUE INDICES (Tissue mass % body mass)									
Bone	0,66					0,62	0,58	0,66	0,51
Muscle	6,10					6,07	7,31	7,08	5,00
Skin-fat	0,70					0,81	0,94	0,77	0,80

* Calculated from available raw and mean data.

TABLE XLV: Body composition of sportswomen

	Professional Tennis Players	Olympic Runners	Olympic Swimmers	Olympic Gymnasts	College Tennis Players	Olympic Nordic Skiers	National Sprinters	Sedentary Caucasoids*
	Present Study	Novak et *at* (1977)	Novak et *al* (1977)	Novak et *al* (1977)	Katch & McArdle(1977)	Sinning et *al* (1977)	Malina et *al* (1971)	Fleming et *al* (1964)
Lean body mass (kg)	47,6	49,3	48,7	45,8	44,7	48,6	46,2*	42,5
Absolute fat (kg)	13,7	7,4	11,4	6,8	14,3*	8,3*	10,8*	17,1
Relative fat (%)	22,1	13,3	18,9	12,9	24,2	16,1	19,0	28,8
LEAN VOLUME (cm^3 x 1000)								
Arm	1,38	1,28	1,70	1,27				0,94
Forearm	0,93	0,97	1,02	0,93				0,62
Upper limb	3,30							2,07
UPPER LIMB TISSUE INDICES								
(Tissue mass & body mass)								
Bone	0,55							0,43
Muscle	5,00							3,17
Skin-fat	1,23							1,48

* Calculated from available raw and mean data.

TABLE XLVI: Relative and absolute differences in bone, muscle and fat measurements between professional and amateur and between male and female tennis players

BONE

		Relative		Absolute	
		Bone index	Bone index RIA		Diameter
Upper limb	Professional vs Amateur	MP^{+}	MP^{+}	Biepicondylar (humerus)	P^{+}
	Male vs Female	M^{++}	FA^{+}		M^{++}
Arm		FA^{+} M^{++}	MP^{+} FA^{+}	Wrist	P^{++} M^{++}
Forearm		A^{+} M^{++}	P^{++} F^{+}	Bicondylar (femur)	MP^{++} M^{++}
Lower limb		FA^{++} MP^{++}	MP^{+} FP^{+}	Ankle	MP^{++} M^{++}

MUSCLE

	Relative				Absolute	
	Muscle index	Muscle index RIA	Lean volume	Lean volume RIA		Girth
Upper limb	P^{+} M^{++}	P^{+} FP^{+}	P^{++} M^{++}	P^{++} FP^{+}	Arm (uncon)	P^{++} M^{++}
Arm	P^{+} M^{++}	P^{++} FP^{+}	P^{++} M^{++}	P^{++} FP^{+}	Arm (con)	P^{++} M^{++}
Forearm	A^{+} M^{++}	FP^{++} FP^{++}	P^{+} M^{++}	MA^{++} FP^{+}	Forearm	P^{++} M^{++}
Lower limb	MP^{+} F^{+}	MA^{+} FP^{++}	P^{++} M^{++}	MA^{+} FP^{++}	Calf	P^{++} M^{++}
					Thigh	P^{++} M^{++}

FAT

	Relative			Absolute		
	Skin-fat index	Skin-fat index RIA	Body fat % body mass	Fat mass		Skinfolds
Upper limb	P^{+} F^{++}	MP^{+} FA^{+}			Biceps	FP^{+} F^{++}
Arm	P^{+} F^{++}	MP^{+} FA^{+}			Triceps	P^{+} F^{++}
Forearm	MA^{+} F^{+}	MP^{+} MP^{+}			Subscapular	MA^{+} FP^{+}
Lower limb	MA^{+} F^{++}	MP^{+} FP^{+}			Supra-iliac	MA^{+} FP^{+}
			FP^{+} F^{++}	P^{+} F^{++}	Calf	MA^{+} F^{++}

P = Professional (male and female), A = Amateur (male and female), M = Male (professional and amateur).
F = Female (professional and amateur).
\+ The mean measurement of the group was larger than that of the opposite group but the difference was not significant
++ The mean measurement of the group was significantly larger than that of the opposite group in the proficiency (P vs A) or sex (M vs F) classifications. For example, in the calf skinfold column, the male amateurs recorded a larger mean calf skinfold than the male professionals (difference not significant) while the females recorded significantly larger mean calf skinfolds than the males.

5.2.9 Somatotype

The mean somatotypes of the male professionals (2,2 - 4,6 - 3,0) and the male amateurs (2,2 - 4,3 - 3,2) both fell in the upper right sector of the somatochart and were classified as ectu-mesomorphic (Figure 14, p.190). The mean somatotypes of the two male groups differed at the 6 percent level of significance. The male professionals were on the average, more mesomorphic and less ectomorphic than the amateur players.

The mean somatotype of the female professionals (3,1 - 3,9 - 2,6) fell in the upper left sector of the somatochart (endo-mesomorphic), while the female amateurs' mean somatotype (2,6 - 3,2 - 3,6) was located in the middle right sector and was classified as meso-ectomorphic (Figure 15, p.191). The difference between the mean somatotypes of the two female groups was highly significant ($p = 0,001$). The female professionals were more mesomorphic ($p < 0,05$) and less ectomorphic ($p < 0,01$) than the amateurs.

Surprisingly, the somatotype dispersion indices (SDI) were greater in the professional groups. One would expect the SDI (relative looseness of cluster of a number of somatoplots about their mean) to have been smaller in the more select professional groups. The most proficient professional and amateur players (male and female) tended to have relatively high mesomorphic and low endomorphic ratings. In contrast to the general belief, it appears that there are physique requirements, particularly in females, for top class tennis performance (Copley, 1979b). It would be interesting to see whether similar trends emerge from a tri-dimensional analysis of the somatotype data. As stated in the first chapter, this will be done later. Of course,physique is only one of the prerequisites for success, but deviation from the optimum physique may become a handicap to the player striving to excel.

Although comparisons of the mean somatotype components and tissue indices of the professional and amateur players appeared to indicate that intensive tennis playing may increase mesomorphy but have little effect on endomorphy, a comparison of the professional players' and sedentary subjects' mean somatotypes did not confirm this theory. Mean mesomorphic ratings were identical but the professionals had lower mean endomorphic ratings than the sedentary subjects (Table XLVII,p.284 and Table XLVIII, p.285). However, it should be pointed out that visual comparisons of mean values should be treated with caution. Both the mesomorphic and endomorphic components of the sedentary subjects reported by De Garay et al (1974) were higher than one would expect to find.

Mean somatotypes of male participants representing a wide variety of sports are shown in Table XLVII (p.284). It is evident from this table that the somatotype of professional tennis players was very similar to that of Olympic Nordic skiers reported by Sinning et al (1977). From Table XLVIII (p.285) it may be seen that the mean somatotype of the female professionals was fairly similar to that of Olympic swimmers (Hebbelinck et al., 1975).

Table XLVII: Mean somatotype ratings of sportsmen

	Professional Tennis Players Present Study	Professional Golfers Carter (1970)	Professional Cricketers Jones et al (1965)	Basketball Players Carter (1970)	Olympic Swimmers Hebbelinck et al (1975)	Olympic Nordic Skiers Sinning et al (1977)	Olympic Wrestlers Tanner (1964)	Olympic Boxers De Garay et al (1974)	Olympic Cyclists De Garay et al (1974)	Physical Educ Students Desiprès et al (1978a)	Sedentary Subjects De Garay et al (1974)
Endomorphy	2,2	4,1	3,4	2,7	2,1	2,0	2,7	2,4	1,8	3,6	3,3
Mesomorphy	4,6	5,0	4,7	4,9	5,0	4,5	5,6	6,0	5,0	5,5	4,6
Ectomorphy	3,0	2,3	2,3	3,0	2,9	3,0	2,5	1,9	2,7	2,2	2,9
Somatotype category	ecto-meso	endo-meso	endo-meso	ecto-meso	ecto-meso	ecto-meso	endo-meso	endo-meso	ecto-meso	endo-meso	endo-meso

Table XLVIII: Mean somatotype ratings of sportswomen

	Professional Tennis Players	Olympic Basketball Carter (1970)	Professional Golfers Carter (1970)	Olympic Swimmers Hebbelinck et al (1975)	Olympic Nordic Skiers Sinning et al (1977)	Olympic Canoeists De Garay et al (1974)	Physical Educ Students Carter (1970)	Club Tennis Players Desiprès et al (1978a)	National distance runners Day et al (1976)	Sedentary Subjects De Garey et al (1974)
Endomorphy	3,1	4,3	4,1	3,1	3,5	3,5	3,9	4,0	1,6	5,1
Mesomorphy	3,9	4,5	4,0	4,0	4,3	5,3	4,4	3,6	3,2	3,9
Ectomorphy	2,6	3,0	2,7	3,0	2,3	1,8	2,2	2,6	4,0	2,3
Somatotype category	endo-meso	endo-meso	meso-endo	endo-meso	endo-meso	endo-meso	endo-mero	meso-endo	meso-ecto	meso-endo

5.3 PHYSIOLOGICAL OBSERVATIONS

5.3.1 Introduction

The following approach was utilized in the discussion of the physiological observations:

A. Discussion and interpretation of the statistical differences between the professionals and amateurs and between the males and females. As in the case of the assessment of the morphological effects of tennis playing, it cannot be automatically assumed that intensive tennis playing over a period of years was solely responsible for the observed physiological differences between the professional and amateur players. These differences may have been due partly also to constitutional dissimilarities and a degree of pre-selection.

B. Visual comparisons of the mean physiological characteristics of professional tennis players and other world class sport performers. $\dot{V}O_2$ max and vital capacity values of sportsmen and sportswomen are presented in Tables XLIX (p.290) and L (p.296). Mean values of sedentary males and females are included in these tables as controls. The 'Student' t-test was used to determine differences in the means of the professional players and sedentary subjects.

C. Discussion and interpretation of important correlations, linear regression equations and discriminants (stepwise discriminant analysis).

5.3.2 Maximal aerobic power

The male tennis players and professionals of both sexes had significantly larger mean absolute $\dot{V}O_2$ max values (ℓ/min) than the females and amateurs respectively. However, differences in relative $\dot{V}O_2$ max (ml/kg/min) were small. An unexpected finding was that the females had higher relative $\dot{V}O_2$ max values than the males. Although sex differences in $\dot{V}O_2$ max (ml/kg/min) were not significant, differences in $\dot{V}O_2$ max (ml/kg LBM/min) were significant ($p < 0{,}01$). Most published reports have shown that men generally have substantially higher $\dot{V}O_2$ max values (absolute and relative) than women (e.g. Saltin and Åstrand, 1967; Åstrand and Rodahl, 1970; Wilmore and Brown, 1974; Costill, 1979).

Since females have a much smaller lean body mass than males, one would expect male-female differences in $\dot{V}O_2$ max, expressed in millilitres per kilogram lean body mass, to be less pronounced than differences in $\dot{V}O_2$ max expressed in millilitres per kilogram body mass.

The Åstrand-Ryhming nomogram tends to underestimate the $\dot{V}O_2$ max of the unconditioned subjects and to overestimate that of conditioned subjects (Åstrand and Rodahl, 1970; Thiart et al., 1978) but it is highly unlikely that its use in the present study would have resulted in an overestimation of $\dot{V}O_2$ max in the female tennis players and an underestimation in the males. The female players had high absolute $\dot{V}O_2$ max values and small gross and lean body masses compared with the males and this may partly explain the females' higher relative $\dot{V}O_2$ max.

A number of players had $\dot{V}O_2$ max values in excess of 70 ml/kg/min. An exceptionally high value of 85 ml/kg/min was found in one female professional. This subject had been a leading British cross-country runner prior to becoming a tennis professional. Since she was highly conditioned, it is possible that the predicted $\dot{V}O_2$ max was an overestimation of her true $\dot{V}O_2$ max.

A comparison of the means and coefficients of variation obtained when workload and $\dot{V}O_2$ were separately utilized to predict $\dot{V}O_2$ max from the Åstrand-Ryhming nomogram, indicated practically identical values within each of the four groups. In contrast, Shephard (1966) reported that the use of workload compared with $\dot{V}O_2$ in the Åstrand-Ryhming nomogram substantially increased the variance of the predicted $\dot{V}O_2$ max. He subsequently recommended the use of $\dot{V}O_2$. However, it should be pointed out that Shephard's study was conducted on sedentary subjects. The evidence suggests that while $\dot{V}O_2$ is probably preferable to workload for the prediction of $\dot{V}O_2$ max in sedentary subjects, either one may be used for conditioned subjects. When the $\dot{V}O_2$ max of conditioned subjects is predicted from the Åstrand-Ryhming nomogram, there appears to be little point in utilizing $\dot{V}O_2$, which is both [illegible] and time-consuming to measure, when workload, which is [illegible]d, can be utilized with the same degree of predictive accuracy.

Mean absolute and relative $\dot{V}O_2$ max values of male and female sports participants are shown in Table XLIX (p.290). The male professional tennis players and Olympic soccer players had similar values. It was interesting that national table tennis players had the same absolute $\dot{V}O_2$ max as professional tennis players but a higher relative $\dot{V}O_2$ max. Although the mean absolute $\dot{V}O_2$ max of sedentary males was significantly lower than that of male professional tennis players ($p < 0,05$), their relative $\dot{V}O_2$ max was only slightly lower than that of the tennis professionals.

Ball games do not place heavy demands on aerobic power since short periods of high intensity activity are frequently interrupted by periods of reduced tempo or rest (Åstrand and Rodahl, 1970). Mathews and Fox (1976) state that only 30 percent of the energy for tennis is derived from aerobic metabolism, while the remaining 70 percent is anaerobically obtained. It was surprising, therefore, to discover that the average female professional tennis player had a very high $\dot{V}O_2$ max, comparably to that of national swimmers and runners (Table XLIX, p.290).

The female professionals had a markedly higher $\dot{V}O_2$ max (absolute and relative) than sedentary females ($p < 0,01$). The evidence suggests that while a high $\dot{V}O_2$ max is not a prerequisite for success in men's tennis, it is a prerequisite for success in women's tennis. Women's tennis is generally characterised by longer rallies and lower work intensities with more emphasis on aerobic metabolism than men's tennis, which generally involves shorter rallies and higher work intensities with the emphasis on anaerobic metabolism. These differences in functional demands of men's and women's tennis may provide an explanation for the present findings.

$\dot{V}O_2$ max (absolute and relative) was highly and significantly negatively correlated with age in the female professionals. This confirms the general observation of a reduced $\dot{V}O_2$ max with ageing (Jooste <u>et al.</u>,1975).

The most promising regression equations for the prediction of $\dot{V}O_2$ max were:

		R^2 (%)
Male professionals	$\dot{V}O_2$ max (ℓ/min) = 0,0533 (mass) - 0,25	26
Female professionals	$\dot{V}O_2$ max (ml/kg LBM/min) = 132,5 - 3,09 (age) + 0,70 (hrswk)	57

		R^2 (%)
Male amateurs	$\dot{V}O_2$ max = 99,9 - 0,41 (mass) - 1,28 (age) + 0,67 (yrs) (ml/kg/min)	44
Female amateurs	$\dot{V}O_2$ max = 0,1195 (mass) - 3,79 (ℓ/min)	46

It is evident from these regression formulas that $\dot{V}O_2$ max could not be predicted accurately from gross body mass or lean body mass in any of the four groups. Although submaximal $\dot{V}O_2$ can be accurately predicted from gross body mass (van der Walt et al., 1978), there are discrepancies in the literature as to the accuracy with which $\dot{V}O_2$ max may be predicted from gross body mass and LBM. Buskirk and Taylor (1957) reported that body mass accounted for only 40 percent of the variation in $\dot{V}O_2$ max. Similar coefficients of determination (R^2) were found in the present study. In contrast, Wyndham and Heyns (1969) and van der Walt et al (1978) reported considerably higher coefficients of determination for the prediction of $\dot{V}O_2$ max from body mass. The latter workers are of the opinion that somatotype plays an important role in the prediction of $\dot{V}O_2$ max from body mass and that the discrepancies in the reported data are due mainly to somatotype differences in the various authors' samples.

$\dot{V}O_2$ max (ℓ/min and ml/kg LBM/min) was an important discriminant between the male professional and amateur groups (> MP). This finding indicates that a high $\dot{V}O_2$ max is an advantage in men's tennis, in spite of the fact that it does not appear to be a prerequisite for the attainment of high levels of tennis proficiency.

TABLE XLIX: Mean maximal aerobic power of sports participants

MALE

	Professional Tennis Players Present Study	Olympic *Water Polo* Players Novak et al (1978)	Olympic *Swimmers* Novak et al (1978)	Olympic *Soccer* Players Novak et al (1978)	Olympic *Rowers* Novak et al (1978)	National *Weight* Trainers Fahey et al (1975)	National *Table Tennis* Players Saltin & Åstrand (1967)	Sedentary *Caucasoids* Saltin & Åstrand (1967)
Absolute $\dot{V}O_2$ max (ℓ/min)	3,8	4,9	4,3	3,8	5,5	4,6	3,6	3,1
Relative $\dot{V}O_2$ max (ml/kg/min)	50,0	61,4	57,9	53,2	62,2	48,8	59,0	43,5

FEMALE

	Professional Tennis Players Present Study	National Cross-country Skiers Saltin & Åstrand (1967)	National Swimmers Saltin & Åstrand (1967)	National Sprinters Saltin & Åstrand (1967)	National Table Tennis Players Saltin & Åstrand (1967)	National Fencers Saltin & Åstrand (1967)	Sedentary Caucasoids Saltin & Åstrand (1967)
Absolute $\dot{V}O_2$ max (ℓ/min)	3,4	3,8	3,2	3,1	2,4	2,4	2,2
Relative $\dot{V}O_2$ max (ml/kg/min)	56,6	63,0	57,5	55,0	44,0	43,5	39,0

5.3.3 Mechanical efficiency

Although the male professionals recorded the highest mean net cycling mechanical efficiency (30,1%), differences among the four groups were not statistically significant. Even when body mass, stature and pulmonary function (FEV_1) were held constant, mechanical efficiency differences among the groups were still found to be non-significant. These findings indicate relatively similar physiological responses to submaximal cycling in the four groups.

The mean mechanical efficiency values of all four groups were higher than the mean value of 23,5 percent for a group of sedentary adults (Åstrand I., 1960) and 25,0 percent for a group of athletes (Di Prampero et al., 1976). However, Gaesser and Brooks (1975) have pointed out that, unless cycling work rates are standardised, comparisons of mechanical efficiency should be treated with caution.

When the efficiency of tennis playing is assessed by $\dot{V}O_2$ during play being expressed as a percentage of $\dot{V}O_2$ max, the male professional on the average used only 39 percent of his $\dot{V}O_2$ max, while the male amateur utilized 52 percent of his $\dot{V}O_2$ max. This method of assessing efficiency in tennis players is preferable to the determination of the mechanical efficiency of cycling. Unfortunately, reliable statistical analyses and interpretations of tennis playing efficiency were not possible because of the small number of observations.

In the professional players, mechanical efficiency was correlated significantly with $\dot{V}O_2$ max (ml/kg/min). Although the correlation was not high, this finding supports the contention that mechanical efficiency may be used to gauge cardio-respiratory fitness.

A wide pelvis has the effect of reducing the mechanical efficiency of running because of the greater hip muscle involvement (Mathews and Fox, 1976). In the present study bi-iliac diameter and mechanical efficiency were negatively correlated in the female amateurs ($p < 0,05$). This finding suggests that the efficiency of cycling may be influenced also by pelvic width.

Sweat-rate accounted for 76 percent of the variation in mechanical efficiency in the female professionals. The one-term regression equation that may be used to predict mechanical efficiency with a fairly high degree of accuracy is:

Female professionals $\quad ME\ (net) = -3,3405\ (sweat\text{-}rate) + 32,82 \quad S_E = 1,2$

5.3.4 Energy cost

Unfortunately, only 11 subjects were willing to participate in the energy cost determinations. The fear of having to breathe through the portable respirometer and the fact that the duration of the test was relatively long (20 to 30 minutes), were probably the main reasons for the general reluctance of players. Reliable statistical analyses and interpretations were not possible because of the small number of cases involved.

The difference in gross, absolute energy cost between the two male groups was very small. The mean energy cost of 36 kJ/min for the male players in the present study was slightly higher than the value of 28 kJ/min found by Skubic and Hodgkins (1967) and the value of 30 kJ/min reported by D.H. Clarke (1975). These absolute energy cost differences may be the result of differences in tennis proficiency. Generally, the proficient tennis performer plays a more aggressive attacking game than the less proficient performer. Attacking tennis is characterised by repeated, rapid net approaches which require far more physical effort than a defensive baseline game. The energy cost of singles tennis and badminton playing are very similar (± 30 kJ/min). Squash playing is far more strenuous with a mean energy cost of about 64 kilojoules per minute (Passmore and Durnin, 1955). Unfortunately, most of the energy cost tables in the literature are published without reference to subject numbers, standard deviations, proficiency levels or whether gross or net values are being presented. This greatly hinders comparisons of the reported values.

While the absolute energy cost of singles playing was very similar in the male professional and amateur groups, it was evident that the relative cost of playing ($\dot{V}O_2$ % $\dot{V}O_2$ max), was far lower in the professional group (39%) than in the amateur group (52%). The inverse relationship between relative energy cost and proficiency in swimming (Karpovich and Millman, 1947) and in handball (Banister et al., 1964), appears to be applicable also to the sport of tennis. Interestingly, the relative energy cost of singles tennis playing in the male professional, is very similar to that of the manual labourer who is allowed to set his own working pace (Åstrand I., 1967).

5.3.5 Sweat-rate

The mean absolute (ℓ/hr) and relative (ℓ/m^2/hr) sweat-rates of the professional and amateur players were very similar. The males had significantly higher absolute sweat-rates than the females ($p < 0,03$). Relative sweat-rates also were higher in the males. The female hormone luteotrophin (LTH), which reduces the loss of liquid from the body, is largely responsible for the females' lower sweat-rate (personal communication from S. Terblanche). When relative or percentage body fat was held constant, sweat-rate differences (absolute) between the sexes were not significant (Table XXIX, p.208). This indicates that sweat-rate is influenced by the amount of adipose tissue.

The mean relative sweat-rate of the male professional tennis players (0,67ℓ/m^2/hr) was lower than that of world class marathon runners (0,89 ℓ/m^2/hr),✡ but slightly higher than that of well trained heat acclimatised subjects (0,52 ℓ/m^2/hr).■ The sweat-rates of the tennis players are fairly high when one considers that competitive playing often exceeds 4 hours per day. In a match lasting 120 minutes, the male professional and amateur players would lose on the average 1,95 and 1,80 litres of liquid respectively. This constitutes a liquid-loss of 2,6 percent of the total body mass of the males.✶ In female professionals and amateurs the liquid-losses would constitute on the average 2,0 and 2,4 percent of the body masses respectively.✶ It is obvious from these data that competitive tennis playing may result in marked dehydration.

According to Hayward et al (1978), the rate of cooling is a function of BSA. The large BSA's of the professional players (♂ = 2,02 m^2 and ♀ = 1,70 m^2) indicate a high rate of cooling and efficient thermoregulation during exposure to heat.

✡ Calculated from data reported by Costill (1979).

■ Calculated from data reported by Jooste and Strydom (1978).

✶ Calculated from mean data the present study.

Sweat-rate in the males could not be accurately predicted by means of either simple or multiple linear regression equations. However, in the females the following one-term regression equations appeared to be the most promising:

		R^2 (%)
Female professionals	Sweat-rate = 0,0813 (stat) - 12,40 (ℓ/hr)	72
Female amateurs	Sweat-rate =-0,0424 (mass) + 3,40 (ℓ/hr)	76

As these regression formulae were derived from data obtained from small samples (4 professionals and 4 amateurs), they should be treated with caution. The fact that sweat-rate (FA) was negatively correlated with body mass was surprising since heavier persons usually have greater sweat-rates (Åstrand and Rodahl, 1970).

5.3.6 Static and dynamic pulmonary volumes

The professional players had significantly larger mean absolute (VC) and relative lung sizes (VC/BSA), IRV, ERV, IC and absolute lung power (FEV_1) than the amateurs. Differences in TV and relative lung power (FEV_1I) were small and non-significant. Predictably, the males had significantly larger dynamic and static volumes than the females, with the exception of relative lung power where differences were small. The females tended to have slightly greater relative lung power than the males.

As can be seen from Table L (p.296), the male professional tennis players had a noticeably smaller average VC than soccer players, swimmers and track athletes but a larger VC than the sedentary males. In respect of the females, the Olympic swimmers were characterised by the largest mean VC. The female tennis players and runners had similar mean VC's. The mean VC of sedentary females was considerably smaller than that of professional tennis players ($p < 0,05$).

It was surprising to find that FEV_1 was significantly negatively correlated with $\dot{V}O_2$ max in the amateur players, as a positive correlation was expected. However, it should be noted that although the correlations were significant, they were not high.

The accuracy with which VC and FEV_1 could be predicted was considerably higher in the amateur groups. The most promising regression formulae were:

		R^2 (%)
Male professionals	$FEV_1 = -1,1 + 3,68\ (BSA) - 0,04\ (age)$	33
Female professionals	$VC = 3,2 + 0,05\ (yrs) + 0,02\ (hrswk)$	43
Male amateurs	$VC = -13,1 + 0,09(stat) + 0,09\ (age) - 0,05\ (yrs)$	84
Female amateurs	$VC = 5,4 - 0,04\ (hrswk) - 0,03\ (mass)$	80

The following one-term regression equati[illegible] the estimation of VC from stature in male amateurs also provided [illegible] igh degree of predictive accuracy:

Male amateurs $VC = 0,0843\ (stat) - 9,69$ $R^2 = 67$

The regression line of this equation with 95 percent confidence bands is shown in Figure 30 (p.230).

Tidal volume was an important physiological discriminant between the two male groups (> MA), while FEV_1 and IC were important physiological discriminants between the two female groups (> FP). IC and FEV_1 were significant physiological discriminants between the two professional groups (> MP), while relative lung size (VC/BSA) was an important discriminant between the two amateur groups (> MA). The evidence suggests that a large FEV_1, IC and relative lung size (VC/BSA) are advantages in tennis and that competitive tennis playing over a period of years has beneficial effects on both the structure and function of the respiratory system.

TABLE L: Mean vital capacity of sports participants

MALE

	Professional Tennis Players Present Study	Soccer Players Novak et al (1968)	Swimmers Novak et al (1968)	Track Athletes Novak et al (1968)	Gymnasts Novak et al (1968)	Sedentary Subjects Comroe et al (1962)
Vital capacity (ℓ)	5,9	6,8	6,9	6,3	5,8	4,8

FEMALE

	Professional Tennis Players Present Study	Olympic Runners Novak et al (1977)	Olympic Swimmers Novak et al (1977)	Olympic Gymnasts Novak et al (1977)	Sedentary Subjects Comroe et al (1962)
Vital capacity (ℓ)	4,2	4,3	4,9	3,9	3,2

5.3.7 Flexibility

Only trunk flexion-extension appears to be increased by intensive tennis training and competition. This is probably the result of habitual bending and twisting of the trunk during the tennis service. In contrast to this finding, the negative RIA values for most of the bilateral flexibility tests indicate that tennis playing actually reduces joint mobility in the upper limb. This was particularly evident in the supination-pronation test where the highest negative RIA values were recorded in all four groups. A similar finding was reported by Chinn et al (1974) in a study of international and national tennis players. Supination-pronation and shoulder rotation were found to be significantly reduced in the playing limb compared with the non-playing limb. According to these workers, fibrotic changes in the capsule and ligaments, resulting from repeated microtraumata over years of intensive tennis training and competition, may have the effect of reducing joint mobility in the dominant upper limb. Although these fibrotic changes serve to maintain overall stability of the joint structure by decreasing capsular distensibility, they prevent the full range of internal rotation.

Soft tissues, particularly muscle tissue, can have a significant effect on joint mobility (De Vries, 1975). In a study by Braune and Flugel (1882) on cadavers, it was found that supination-pronation was significantly affected by the forearm musculature which became wedged between the ulna and radius during pronation of the forearm. The male tennis player's significantly lower supination-pronation, compared with the female's, is probably the direct result of his significantly greater forearm muscle mass. Elbow flexion-extension also appears to be affected by upper limb musculature. Professional-amateur differences in elbow flexion-extension were not statistically significant. However, when upper limb lean volume, which was greater in the professionals ($p < 0,01$), was held constant (Table XXIX, p.208), it was found that the professionals had significantly greater elbow flexion-extension than the amateurs ($p < 0,05$). Intra-muscular changes resulting directly from upper limb muscle hypertrophy may also be partly responsible for a reduction in joint mobility. Muscle hypertrophy increases intra-muscular tension or muscle tone and also causes relative shortening of the muscle, since the increase in fibre cross-sectional area is proportionally greater than the increase in fibre length.

A number of static flexibility tests were significantly negatively correlated with age which indicates reduced joint mobility with ageing. This was particularly evident in the male professionals.

The low correlations and coefficients of determination among the various measures of static flexibility confirm the observation made by Holland (1968) that the measurement of one of several body joints cannot be used to predict accurately the range of motion in other joints.

The following multiple linear regression equations were found to offer the greatest predictive accuracy of static flexibility:

Amateurs		R^2 (%)
Females	Shoulder FE = 274 - 5,3 (hrswk) - 1,83 (age) + 1,68 (yrs)	84
Males	Wrist FE = 50,5 + 14,89 (BSA) + 0,8 (yrs)	76
Professionals		
Females	Sup-pron = 505,7 + 2,39 (hrswk) - 191,1 (BSA)	57
Males	Hip FE = -42,5 + 250,47 (BSA) - 4,42 (mass)	37

In the stepwise discriminant analysis conducted with all the variables (morphological and physiological), hip and trunk flexion-extension were found to be highly important discriminators between the male professional and amateur groups (> MP). The male professionals' greater hip joint mobility probably results in a more mechanically efficient serving action than that of amateur players. The importance of mechanical efficiency in tennis is related to the duration of play. Although lateral flexion of the trunk and hip abduction were found to be important in discriminating between the female professional and amateur groups when the analysis was conducted with only the physiological variables, they were not important discriminants when the analysis was conducted simultaneously with all the variables, morphological and physiological.

5.3.8 Vision

The small professional-amateur differences in interpupillary distance indicate that this linear measurement is not related to proficiency in tennis. It would be interesting to determine whether interpupillary distance and depth perception are related.

The majority of individuals are right-handed, a fact substantiated by the present findings in which 84,6 percent of the players were right-handed. No such definite trend is apparent in respect of ocular dominance. Duke-Elder (1939) reported that 64,0 percent of the adult population were right-eyed. In the present study, right- and left-eyed percentages among the players, both professionals and amateurs were approximately equal. The majority of male players were left-eyed (54,2 percent), while most females were right-eyed (57,6 percent). This finding suggests slight sexual dimorphism in ocular dominance. In this study right-eyed dominance was significantly related to tennis proficiency in the females but not in the males. It appears that ocular dominance is more important to the female tennis player than to the male player.

Studies by Adams (1965) and Whiting and Hendry (1968) have indicated that expert sport performers are predominantly unilateral. Similar findings are evident from this study where the majority of the male (53,1 percent) and the female (71,4 percent) professional tennis players were unilateral. One may not assume that unilaterality and ball game proficiency are necessarily related. Such an assumption would be feasible only if there were an equal number of crossed lateral and unilateral subjects in the general population, which does not appear to be the case. From a study conducted on a large cross section of the general population, Hildreth (1949) reported that between 60 to 80 percent of the subjects were unilateral. In the present study, 55,4 percent of all the players (professional plus amateur) were unilateral. It would appear that unilaterality is more common than crossed laterality in both sport participants and sedentary persons.

The relationship between eye-limb concordance/discordance and proficiency in ball games can be determined only by assessing and comparing eye-limb concordance/discordance in performers of varying levels of proficiency within a particular sport type. This approach was utilized in the present study. By means of Chi-square analysis (contingency table), it was found that unilateral female tennis players were generally more proficient than crossed lateral players. Unilateral baseball batters were also found to be more proficient than crossed lateral batters in a study by Adams (1965). Tennis proficiency was not related to eye-limb concordance/discordance in the male tennis players. As in the case of eye dominance, eye-limb concordance/discordance appears to be more important to the female tennis player than to the male player. The majority of professional players (60,4%) were unilateral and the evidence suggests that unilaterality is preferable to crossed laterality. Eye and limb dominance are usually congenital and in this respect therefore, good female tennis players appear to be born rather than made.

An interesting observation was made regarding stroke proficiency and eye-limb concordance/discordance. Most unilateral players rated themselves more proficient on the forehand side compared to the backhand, while most crossed lateral players were of the opinion that they were better on the backhand side compared to the forehand. From this observation it would appear that when the dominant or controlling eye is on the same side as that on which the ball is struck, greater groundstroke proficiency is achieved. This observation is substantiated by Lund (1932) and Fink (1938), who found that the highest degree of co-ordination was achieved when the dominant or directing eye was on the same side as the dominant hand.

The claim is often made that left-handed tennis players are more proficient performers than right-handers. In this study however, handedness and proficiency were unrelated. It is true of course that since there are far more right- than left-handed tennis players, the left-handers have more opportunity of becoming accustomed to right-handed players than vice-versa. This may possibly explain why left-handers are regarded generally as more 'difficult' opponents than right-handers.

5.3.9 Comment

The results obtained from the stepwise discriminant analyses revealed that the basic and derived morphological variables tended to be more important than the physiological and biochemical variables in distinguishing between professional and amateur and between male and female groups. The derived morphological variables tended to be the most important distinguishing variables (the highest approximate F - statistics).

5.4 BIOCHEMICAL OBSERVATIONS

5.4.1 Glucose

The mean pre- and post-match blood glucose concentrations of the four groups were fairly similar. A comparison of pre- and post-match blood glucose concentrations within each group indicated larger post-match concentrations in all four groups. In the males, the post-match values were significantly higher than the pre-match values at the 7 percent level of significance.

Elevated blood glucose concentrations following marathon running were reported by Magazanik et al (1974), Maron et al (1975) and Jooste et al (1977). The increase has been ascribed mainly to the common practice of ingesting carbohydrate-supplemented solutions during the races. Similarly, many tennis players in the present study consumed 'Isotonic Game' (a replacement liquid containing glucose) at frequent intervals during their matches. This may have been partly responsible for the elevated post-match glucose levels in the tennis players. Furthermore, because there was marked dehydration (sweat-loss in excess of 2 percent of body mass) and sweat-rate was highly and significantly correlated with post-match glucose in male amateurs, it seems likely that haemoconcentration was also partly responsible for the elevated post-match glucose levels. The evidence suggests that the occurrence of hypoglycaemia in tennis players is highly unlikely.

From Table LI (p.304) it is evident that the blood glucose response to strenuous competitive tennis playing is similar to that of long-distance running.

$\dot{V}O_2$ max (ℓ/min) was highly and significantly correlated with post-match glucose in the male amateurs. For a given workload, the individual with a high $\dot{V}O_2$ max would use a smaller percentage of his $\dot{V}O_2$ max and tend to rely more heavily on fat metabolism than an individual with a low $\dot{V}O_2$ max. Since fat metabolism has a glycogen-sparing effect (Costill, 1979), the evidence suggests that a high $\dot{V}O_2$ max is associated with a more efficient utilization of blood glucose.

5.4.2 Lactate

Mean pre- and post-match blood lactate concentrations in the four groups were quite similar. Although post-match levels were higher than pre-match lactate levels in all four groups, differences were significant ($p < 0,10$) only in the male professional group. The low post-match lactate levels in the professional players may have been due partly to an efficient lactate clearance (gluconeogenesis) which occurs in response to high intensity training. The low post-match lactate levels in males and females and the high $\dot{V}O_2$ max females indicate that anaerobic metabolism may be less important and aerobic metabolism more important in tennis playing (particularly in women's tennis) than was previously believed (Åstrand and Rodahl, 1970; Mathews and Fox, 1976).

In a study conducted by Beaudin <u>et al</u> (1978), it was found that squash playing did not produce high lactate concentrations. The mean value of 2,7 millimoles per litre for squash players was very similar to the lactate level (2,6 m moles/litre) found in the male professional tennis players. As can be seen from Table LI (p.304), the mean post-exercise lactate level of the long-distance runners was very similar to the mean pre-exercise lactate level of the male professional tennis players.

5.4.3 Electrolytes

Pre- and post-match serum electrolyte differences among the four groups were small, with the exception of pre-match sodium where significantly higher mean values were found in the females than the males. The transport of sodium is regulated by certain hormones, namely, adrenocortical steroids and, in particular, the adrenocorticotropic hormone (ACTH). Under the influence of these hormones, the concentration of intracellular sodium is increased, with a concomitant decrease in the concentration of serum or extracellular sodium. Owing to sexual dimorphism in hormonal secretion, there is a larger release of these steroid hormones in the males than the females. This may partly explain the considerably lower pre-match sodium concentrations in the males.

The females' higher post-match sodium is probably the result of the presence of the luteotrope hormone (LTH) and a reduced secretion of steroid hormones in response to exercise, the reduction being proportionally greater in females than in males (Tharp and Buuck, 1974; Terblanche <u>et al.</u>, 1978). LTH acts as a stabilizer of sodium and reduces its loss in sweat. Since LTH is a female hormone, it occurs in far greater quantities in the female (personal communication S. Terblanche).

The fact that post-match sodium concentrations were significantly higher than pre-match levels in three of the four groups, confirms the observation of Terblanche <u>et al</u> (1978) that a reduced release of steroid hormones occurs in response to physical exercise. This has the effect of increasing the post-match serum sodium concentration. The elevation of the post-match sodium levels may also have been due partly to haemoconcentration which occurred as a result of dehydration.

Post-match magnesium concentrations were slightly lower than pre-match levels in the male amateurs and female professionals. This was probably due to a shift of magnesium from the extracellular into the intracellular compartments. Numerous enzymatic reactions in which magnesium is an important cation occur in the intracellular compartments (personal communication S. Terblanche). Other studies (Rose et al., 1970; Beller et al., 1975; Joose et al., 1977; Cohen and Zimmerman, 1978) have reported significant decreases in serum magnesium levels after exercise. The slightly higher post-match magnesium concentration in the male professionals compared with pre-match magnesium might have occurred because of haemoconcentration and/or certain metabolic adaptations in response to years of intensive tennis playing. According to S. Terblanche (personal communication), the metabolic adaptations may have reached a level at which a magnesium shift is unnecessary because of adequate intracellular magnesium.

As can be seen from Table LI (p.304), the pre-exercise sodium, magnesium and chloride concentrations of professional tennis players and highly trained long-distance runners were fairly similar. Post-exercise magnesium and chloride levels were smaller than pre-exercise levels in the runners, while the opposite was found in the tennis players. These differences in post-exercise electrolyte concentrations are probably due largely to the difference in duration between tennis playing and distance running.

The biochemical findings of the present study indicate that strenuous competitive tennis has relatively little effect on blood glucose, blood lactate and electrolyte levels and that biochemical responses to tennis playing are very similar in professional and amateur players.

TABLE LI: Pre- and post-exercise biochemical concentrations in male tennis players and long-distance runners

		Professional Tennis Players Present Study	Distance Runners Jooste *et al* (1977)
Glucose (mg%)	1	85,4 ± 4,72☼	80,9 ± 3,01
		↑ 7 ↓	↑ 5 ↓
	2	108,1 ± 11,73	115,3 ± 11,03
Lactate (m moles/ℓ)	1	1,8 ± 0,17	2,6 ± 0,35
		↑ 10 ↓	
	2	2,6 ± 0,45	1,9 ± 0,13
Sodium (mEq/ℓ)	1	138,1 ± 0,83	142,3 ± 0,95
		↑ 6 ↓	
	2	140,7 ± 1,05	143,3 ± 1,82
Magnesium (mEq/ℓ)	1	2,0 ± 0,07	1,9 ± 0,06
			↑ 5 ↓
	2	2,1 ± 0,08	1,6 ± 0,06
Chloride (mEq/ℓ)	1	103,4 ± 2,61	103,9 ± 0,22
	2	104,8 ± 2,62	101,0 ± 1,88

1 = pre-exercise concentration, 2 = post-exercise concentration.

☼ = Standard error of the mean.

Means connected by arrows differ significantly at the percentage levels indicated.

5.5 SUMMARY

5.5.1 Questionnaire

The popularity of squash among the professional players, particularly the females, indicates that little or no habit interference is experienced by proficient players who have well established tennis techniques.

A surprisingly high percentage of professional players participated in no form of training other than their tennis practice sessions. Most players appear to be unaware of the importance of progressive resistance and flexibility training.

While participating in tennis, players appear to be most susceptible to sprains of the shoulder and ankle joints. The lower incidence of 'tennis elbow' among the professionals indicates that the occurrence of this injury may well be inversely related to the level of tennis proficiency.

While the optimum playing age of male tennis players has remained unchanged over the past 4 decades, female players appear to reach their optimum age 3 years sooner than the female champions of 40 years ago. The age at which tennis playing was first commenced was not related to the level of tennis proficiency attained in adulthood. This contradicts the common belief that a young starting age is a prerequisite for top class tennis performance.

5.5.2 Morphological observations

Height appears to be an advantage in tennis since the male professionals were on the average 'very tall' while the male amateurs were classified as 'tall'. The professional players' ability to impart greater velocity to the ball, does not appear to be the result of a longer upper limb or lever arm length.

The large mean wrist diameter of professional tennis players may be the result of bone hypertrophy in response to habitual racket manipulation. Narrow hips appear to be an advantage in tennis playing.

Intensive tennis playing increases upper and lower limb girths, particularly in the forearm and thigh regions. Compared with the males, the females had a greater tissue mass in the lower limb than in the upper limb. Forearm girth correlated highly and significantly with a surprisingly large number of morphological and physiological variables.

Mean skinfold measurements of professional and amateur tennis players were fairly similar. Sex differences in regional deposits of subcutaneous adipose tissue appear to be genetically determined.

A more masculine physique or androgyny index does not constitute an advantage to male players, but appears to be an advantage to female tennis players.

5.5.3 Body composition

The 'ideal' body mass for tennis was lower than the measured body mass in all four groups. The tennis players' average mass was from 2 to 3 kilograms heavier than the 'ideal' mass. Body mass can be used to predict accurately the 'ideal' mass for tennis in professional and amateur players.

Intensive tennis playing appears to increase lean body mass in male and female players. Body mass can be used to predict accurately LBM in tennis players.

There appears to be little difference in the results obtained from the expression of bone index either in terms of relative mass or in terms of relative cross-sectional area. The evidence suggests that intensive tennis playing causes marked bone hypertrophy in the dominant forearm.

Differences in results can be expected when muscle index is expressed in terms of relative mass and in terms of relative cross-sectional area. Intensive tennis playing results in marked muscular hypertrophy in the dominant upper limb, particularly in the forearm. Upper limb muscular hypertrophy is relatively greater in female professionals than in male tennis players.

The frequency and intensity of tennis playing appears to have little effect on absolute fat mass as well as on local fat deposits. These findings are not in agreement with the 'spot reduction' theory. The larger biceps and triceps skinfolds in the dominant upper limb of the players may be due to a reduced skin compressibility associated with muscular hypertrophy.

5.5.4 Somatotype

The mean Heath-Carter anthropometric somatotype of the male (2,2 - 4,6 - 3,0) and female (3,1 - 3,9 - 2,6) professional players differed significantly from those of the amateur players. Top class tennis performances, particularly in females, appear to have definite physique requirements. The evidence suggests that intensive tennis playing may increase the mesomorphic component but have little effect on the endomorphic component.

5.5.5 Physiological observations

Although the males had significantly higher absolute $\dot{V}O_2$ max values than the females, they had lower relative $\dot{V}O_2$ max values. Compared with the males, the females had high absolute $\dot{V}O_2$ max values and small gross and lean body masses. This may explain partly the observed finding. A high $\dot{V}O_2$ max appears to be important for the female but less important for the male player. This may be due to differences in the physiological demands of men's and women's tennis. None of the morphological or physiological variables could be used to predict $\dot{V}O_2$ max with a high degree of accuracy.

While the net mechanical efficiency of cycling was fairly similar in the professional and amateur groups, the efficiency of singles tennis playing ($\dot{V}O_2$ % $\dot{V}O_2$ max) was far better in professional players (male).

The gross absolute energy cost of singles tennis playing was very similar in the professionals and amateurs but the relative energy cost ($\dot{V}O_2$ % $\dot{V}O_2$ max) was considerably lower in the professional players. There appears to be an inverse relationship between relative energy cost and proficiency in tennis.

The absolute and relative sweat-rate of professional and amateur tennis players were fairly similar. The professionals' large BSA suggests a high cooling rate and efficient thermoregulation during exposure to heat.

A large absolute lung power (FEV_1), relative lung size (VC/BSA) and IC probably constitute an advantage in tennis. Competitive tennis training and playing over a number of years appear to have beneficial effects on respiratory structure and function.

Tennis playing seems to increase trunk flexion-extension while reducing joint mobility in the dominant upper limb, particularly in the elbow and wrist joints. The reduced static flexibility is presumably the result of an increased muscle mass and intra-muscular changes associated with this hypertrophy.

Unilateral female players were generally more proficient than crossed lateral players. Most of the professionals were unilateral and the indications are that unilaterality is preferable to crossed laterality in tennis players.

From the stepwise discriminant analyses it was evident that morphological variables were more important than physiological and biochemical variables in distinguishing between the professionals and amateurs and between the males and females.

5.5.6 Biochemical observations

Elevated post-match blood glucose levels (compared with pre-match levels) may have been caused by the ingestion of 'Isotonic Game' and haeomoconcentration. Hypoglycaemia rarely occurs in tennis players. It appears that a high $\dot{V}O_2$ max is associated with more efficient utilization of blood glucose.

Tennis playing does not produce high lactate concentrations and the evidence suggests that aerobic metabolism is more important in tennis playing than was previously believed.

Elevated post-match serum sodium levels appear to be caused by a reduced release of steroid hormones in response to exercise and haemoconcentration. Reduced post-match serum magnesium levels (compared with pre-match levels) were probably caused by a shift of magnesium from the extracellular into the intracellular compartments. The male professionals' elevated post-match magnesium concentration may have resulted from short-term haemoconcentration and/or long-term metabolic adaptations.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

In this chapter the author draws conclusions from the findings and tenders answers to the questions posed in Chapter 1. Numerous suggestions and recommendations are made as well.

6.1 CONCLUSIONS

6.1.1 Morphological and physiological norms of tennis players

A. Male professional

The male professional tennis player is, on the average, very tall (182,8 cm), has a large mass (76,5 kg) and body surface area (2,0m^2), broad shoulders (39,7 cm) and large wrist (6,0 cm) and ankle (7,3 cm) diameters. He has muscular upper and lower limbs and an ecto-mesomorphic somatotype rating of 2,2 - 4,6 - 3,0. For a professional sportsman, he has a fairly large amount of body fat (relative = 11,8% and absolute = 9,0 kg). He also has a fairly high $\dot{V}O_2$ max (absolute = 3,8 ℓ/min and relative = 50 ml/kg/min), absolute net cycling mechanical efficiency (30,1%), gross absolute energy cost of singles playing (36,8 kJ/min) and sweat-rate (absolute = 1,3 ℓ/hr and relative = 0,67 ℓ/m^2/hr). His static and dynamic pulmonary volumes are large (VC = 5,9ℓ and FEV$_1$ = 5,1 ℓ/sec), his static flexibility is above average, particularly in the hip-joint, and he tends to be unilateral (eye-limb concordance).

B. Male amateur

In comparison with male professionals, the male amateur is, on the average, shorter (176,5 cm), lighter (69,9 kg), smaller (1,9 m^2) and has narrower shoulders (39,1 cm) and smaller wrist (5,7 cm) and ankle (6,9 cm) diameters. His upper and lower limbs are considerably less muscular. He has an ecto-mesomorphic mean somatotype rating (2,2 - 4,3 - 3,2) which *is similar to the professionals' mean rating. The* amateur has a slightly higher fat percentage (12,0%) but a lower absolute fat mass (8,4 kg). His $\dot{V}O_2$ max is smaller (absolute = 3,4 ℓ/min and relative 48,8 ml/kg/min) and he has a lower absolute net cycling mechanical efficiency (27,5%), gross absolute energy cost of singles playing (35,4 kJ/min), and sweat-rate (absolute = 1,2 ℓ/hr and relative = 0,66 ℓ/m^2/hr) than the professional. Furthermore, he has considerably smaller static and dynamic pulmonary volumes (VC = 5,3ℓ and FEV_1 = 4,6 ℓ/sec). He is generally not as flexible as the professional but tends to be also unilateral (eye-limb concordance).

C. Female professional

The female professional tennis player is, on the average, relatively tall (167,3 cm), with a large body mass (60,7 kg) and body surface area (1,7 m^2), relatively broad shoulders (36,2 cm) and narrow hips (26,5 cm). She has a large wrist diameter (5,2 cm), muscular upper and lower limbs and an endo-mesomorphic mean somatotype rating of 3,1 - 3,9 - 2,6. She has a surprisingly large amount of body fat (relative = 22,1% and absolute = 13,7 kg). With regard to her physiological characteristics, she has a very high $\dot{V}O_2$ max (absolute = 3,4 ℓ/min and relative = 56,6 ml/kg/min) and a fairly high absolute net cycling mechanical efficiency (27,8%) and sweat-rate (absolute = 0,8 ℓ/hr and relative = 0,51 ℓ/m^2/hr). She has large static and dynamic pulmonary volumes (VC = 4,2ℓ and FEV_1 = 3,7 ℓ/sec), above average static flexibility, especially in the hip-joint, and is generally unilateral (eye-limb concordance).

D. Female amateur

A comparison between the two female groups revealed that the female amateur tennis player is, on the average, similar in stature (167,9 cm) to the female professional, but she is lighter (55,4 kg) and smaller (1,6 m^2) and has narrower shoulders (35,2 cm) and broader hips (26,8 cm). She has a smaller wrist diameter (5,0 cm) and is markedly less muscular in her upper and lower limbs. She has less relative (20,5%) and absolute (11,6 kg) body fat and her meso-ectomorphic physique (2,6 - 3,2 - 3,6) differs considerably from the female professional's endo-mesomorphic physique. Although her $\dot{V}O_2$ max (absolute = 2,9 ℓ/min and relative = 51,4 ml/kg/min) is lower, it is nevertheless classified as high. The female amateur has a slightly higher absolute net cycling mechanical efficiency (29,5%) and sweat-rate (absolute = 0,9 ℓ/hr and relative = 0,53 ℓ/m^2/hr). Her static and dynamic pulmonary volumes (VC = 3,5ℓ and FEV_1 = 3,2 ℓ/sec) are considerably smaller and she is not as flexible. In contrast to the female professional, she tends to be crossed lateral (eye-limb discordance).

It was correctly hypothesised that the professionals and amateurs would differ markedly with regard to somatotype and body composition (lean volume), but it was surprising to find that absolute and relative body fat differences between the professionals and amateurs were small and statistically non-significant and that the professionals, particularly the females, had fairly large amounts of body fat. Although it was correctly predicted that $\dot{V}O_2$ max and FEV_1 differences between the professionals and amateurs would be significant, the similarities in cycling mechanical efficiency, sweat-rate and static flexibility were rather unexpected.

6.1.2 Structural and functional effects of tennis playing

A number of morphological and physiological differences between the professionals and amateurs were probably due largely to long-term participation in competitive tennis playing and training. However, as stated in the previous chapter, constitutional dissimilarities and preselection may also have been partly responsible for these observed differences.

Comparisons of the measurements of professionals with those of amateurs, and of the tissue composition of the dominant with that of the non-dominant upper limbs, revealed that intensive tennis playing increases lean body mass and results in marked bone hypertrophy in the dominant forearm and pronounced muscle hypertrophy in the dominant upper limb. The evidence suggests that a degree of pre-selection may have been partly responsible for the observed differences between the male professionals and amateurs in respect of upper limb muscularity, particularly in the forearm. Although intensive playing does reduce body fat, the findings indicate that the frequency and intensity of tennis playing has little effect on either the local fat deposits or the absolute fat mass. The bone and muscle responses to strenuous competitive tennis playing were correctly predicted, but the findings regarding fat responses were unexpected.

A study of the physiological findings revealed that, while women's tennis appears to result in an increased $\dot{V}O_2$ max, men's tennis has relatively little effect on aerobic capacity. The evidence suggests that strenuous, competitive, tennis playing over a period of years results in improved tennis playing efficiency ($\dot{V}O_2$ % $\dot{V}O_2$ max), larger static and dynamic pulmonary volumes and reduced joint mobility in the dominant upper limb. While most of the long-term physiological responses to intensive playing were correctly predicted, the reduced joint mobility was a completely unexpected finding.

There can be little doubt that strenuous, long-term tennis competition and training has a marked influence on both the morphology and physiology of the body and that most professionals are characterised by pronounced structural and functional asymmetry. Structural asymmetry is not restricted to the upper limb and is evident also in the musculature of the trunk. Pronounced asymmetric hypertrophy of the back muscles could result in changes in the alignment of the spinal column and could be a major cause of the chronic backache, headache and dizziness experienced by many professional tennis players.

8.1.3 Biochemical responses to tennis playing

In contrast to the original hypothesis, the findings indicate that strenuous, competitive tennis playing of long duration (90 minutes and longer) has little effect on blood glucose, blood lactate and electrolyte levels and that the biochemical responses to tennis playing in professional and amateur players are similar.

8.1.4 Important contributors to tennis proficiency

The findings of the present study indicate that the following morphological and physiological characteristics are important to the tennis player:

A. Stature

If all other factors are held constant, the taller tennis player is less likely to make a mistake when serving and smashing and can also safely impart greater force to the ball during the execution of these strokes than the shorter player.

B. Wrist and hip diameters

A large, strong wrist enables the player to manipulate the racket more effectively, while narrow hips (particularly in the female), reduce the degree of lateral hip rotation and thus increase the mechanical efficiency of running. Running entails a large proportion of the total energy cost of tennis playing.

C. Muscularity

Relatively muscular upper limbs enable the player to impart more force to the ball, while muscular lower limbs ensure the necessary 'leg' power which is a prerequisite for rapid movement about the court. The indications are that a masculine physique with a high mesomorphic rating contributes to the level of proficiency in the female tennis player.

D. Body fat

Adipose tissue is non-contractile tissue and an excess thereof constitutes a burden to the tennis player since it increases the workload and is also a hindrance to the player's movement about the court. It is, therefore, an advantage to have as little body fat as possible.

E. $\dot{V}O_2$ max

A high $\dot{V}O_2$ max is an advantage to the tennis player. A player with a high $\dot{V}O_2$ max has greater cardio-respiratory efficiency and can utilize a larger proportion of his/her $\dot{V}O_2$ max without increasing blood lactate levels than can a player who has a low $\dot{V}O_2$ max. Because of the greater emphasis on aerobic metabolism in women's tennis, a high $\dot{V}O_2$ max is particularly important to the female player.

F. Static and dynamic pulmonary volumes

A player who is characterised by a large inspiratory capacity, relative lung size (VC/BSA) and absolute lung power (FEV_1) is very likely to have a more efficient pulmonary ventilation and work output than a player with smaller volumes. These static and dynamic volumes (IC, VC/BSA and FEV_1) therefore, are of particular significance to the tennis player.

G. Eye-limb concordance/discordance

It appears that unilaterality (in which an individual is either right-eyed and right-handed, or left-eyed and left-handed) is important in tennis playing, especially in women's tennis.

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G. Eye-limb concordance/discordance

It appears that unilaterality (in which an individual is either right-eyed and right-handed, or left-eyed and left-handed) is important in tennis playing, especially in women's tennis.

6.1.5 Determination of IBM and tissue indices

The author's method, by which IBM is determined from body mass and 4 skinfolds (biceps, triceps, subscapular and supra-iliac), provides a reliable and simple means of assessing the most 'suitable' body mass for tennis playing and of detecting unwise gains or losses in the body mass of competitive tennis players. The use of linear regression equations or graphs, which have a high degree of predictive accuracy, makes the application of this method even simpler since body mass is the only measurement that is required.

Wartenweiler et al (1974) have devised a method for the assessment of bone, muscle and skin-fat indices in the upper and lower extremities. This method involves the prediction of tissue mass from anthropometric measurements of length, girth, diameter and skinfolds. The value obtained is expressed as a percentage of body mass. An alternative method of calculating the tissue index was devised and used in the present study. In this method, the predicted cross-sectional tissue area is expressed as a percentage of body surface area. The bone and skin-fat indices obtained from the two methods are highly and significantly inter-correlated. Since the method proposed by the author necessitates fewer calculations, it appears to be the more practical one to use.

6.1.6 Regression formulae

The following morphological and physiological variables may be predicted with a fairly high degree of accuracy: 'ideal' body mass (mass)[✡], lean body mass (mass), upper limb muscle index expressed as a percentage of BSA (mass, stature, years played), upper limb lean volume (mass, stature, age), absolute body fat (mass, stature, years played), $\dot{V}O_2$ max expressed in millilitres of oxygen per kilogram of lean body mass per minute (age, hours per week), sweat-rate in litres per hour (mass), vital capacity (stature, age, years played), shoulder flexion-extension (hours per week, age, years played) and wrist flexion-extension (BSA, years played).

[✡] The independent variable(s) is/are shown in parentheses.

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✡ The independent variable(s) is/are shown in parentheses.

6.1.7 Male-female differences

A larger percentage of female than male professional tennis players are tennis coaches while the opposite is true among the amateur players. A higher percentage of male than female professionals have attended college or university, while the position is reversed in the amateur players.

Male professionals prefer to be idle in leisure-time, while social swimming is the female professionals' favourite leisure time activity. Circuit training is considerably more popular among the female than the male players.

While the incidence of chronic backache is greater among the male than the female professional players, the incidence of muscle ruptures, sprains and 'tennis elbow' is higher among the female professionals.

Female professionals are, on average, three years younger and commence playing one year sooner than the male professionals. It appears that the female tennis players require, on the average, less practice and less time than the males in order to become expert performers.

Predictably, the majority of the mean absolute morphological and physiological measurements are significantly larger in the male than in the female tennis players. Mass, stature, limb lengths, BSA, LBM, IBM, girths and diameters are considerably larger in the males, while skinfolds, percentage body fat and total fat mass are markedly larger in the female players. Relative bone diameters, bone masses and upper limb muscle masses are also greater in the males. The females on the other hand, have relatively longer, thicker and more muscular lower limbs than the male players. Muscular hypertrophy in the dominant upper limb and lower limb is relatively greater in the female tennis players. The evidence suggests that, while there is considerable sexual dimorphism in absolute anthropometric measurements, this does not apply to relative measurements. A comparison of the degree of absolute sexual dimorphism among tennis players (present study) and the population at large (Mathews and Fox, 1976) revealed that dimorphism of stature and mass is, on the average, considerably greater in tennis players than in the general population. However, sexual dimorphism of body fat (kg) and lean body mass is similar in the two samples. The ecto-mesomorphic somatotype of the male professionals (2,2 - 4,6 - 3,0) differed significantly from the endo-mesomorphic somatotype of the female professionals (3,1 - 3,9 - 2,6).

While the male players have a significantly higher absolute $\dot{V}O_2$ max and sweat-rate, and significantly larger static and dynamic pulmonary volumes, the females have a higher mean relative $\dot{V}O_2$ max (ml/kg/min and ml/kg LBM/min) and greater relative lung power (FEV_1I). With the exception of trunk flexion-extension, the females, particularly the professionals, have greater joint mobility than the male tennis players. The males tend to be left-eyed, while the majority of the females are right-eyed. The findings indicate that ocular dominance and eye-limb concordance/discordance are more important to the female than to the male tennis players.

6.1.8 Relationship between tennis proficiency, handedness, ocular dominance and eye-limb concordance/discordance

Proficiency in tennis is not related to handedness alone, but the evidence suggests that the right-eyed and/or the unilateral female players are generally more proficient than the left-eyed and/or crossed lateral female players. The unilateral tennis players claim to be more proficient on the forehand side, while the crossed lateral players claim to be more proficient on the backhand side.

6.1.9 General questionnaire information

Although most of the professional tennis players studied, attained international and/or national representation, some had attained only provincial or state representation.

Regular participation by highly proficient tennis players in other racket sports, particularly squash, does not appear to cause negative transfer or habit interference.

A relatively high percentage of professional tennis players do not participate in any form of off-court training programme.

Shoulder and ankle joint sprains are the most frequently occurring injuries in tennis players. The incidence of 'tennis elbow' is smaller among proficient tennis players than it is among the less proficient.

In order to become an expert tennis player, the male requires, on the average, 5,3 full-time years of tennis playing. This constitutes a total energy expenditure of about 27,3 million kilojoules. The female player requires on the average 5,0 full-time years of tennis participation to become an expert performer.

6.2 RECOMMENDATIONS

Recommendations and suggestions, based on the findings of this study, are made in the hope that they will be of assistance to the player, coach, trainer and selector. Although the recommendations are applicable to players of all standards, they are directed particularly at competitive and professional players.

6.2.1 Medical examination

All persons who play tennis regularly should undergo a thorough medical examination. In the case of competitive and professional players, an annual medical examination and exercise stress test are essential. Ideally, these should be conducted by a medical doctor, specialised in sports medicine, and an exercise physiologist.

Thorough screening of the cardio-respiratory system is possible only by means of exercise stress testing. Most medical doctors and specialists do not have the necessary equipment or training to conduct and interpret the results of such tests. According to Williams and Sperryn (1976) and Costill (1979), electrocardiographic recordings in conditioned sport participants cannot be interpreted on the same criteria as those utilized on patients in a clinical situation.

A former Wimbledon champion and leading professional player has been forced to retire from tennis because of a cardiac abnormality which apparently remained undetected for a number of years. It is likely that specialised screening procedures would have revealed this abnormality long before the symptoms became apparent. One of the professional players who was suspected of having a cardiac abnormality when this study was conducted in 1977, collapsed recently during a match with what is reported to have been a heart attack. Although it is obviously the player's responsibility to ensure that he/she is medically fit to compete, the tennis organiser or administrator should demand proof of this before a player is allowed to participate competitively.

6.2.2 Scientific approach

The formulation of a scientific tennis training and conditioning programme necessitates the conducting of numerous tests and measurements in order to assess a player's relative strengths and weaknesses. With this information, the exercise physiologist or academically qualified coach or trainer can prescribe a programme suited to the particular structural and functional needs of a player. Periodic re-testing is required to evaluate the effectiveness of the prescribed programme.

It should be pointed out that this approach is the only way in which a player's physical performance can be optimised. Unfortunately, there are at present relatively few persons who have both the academic qualifications and the necessary equipment to enable them to offer a highly professional physical fitness assessing and counselling service. Consequently, many players who may wish to make use of such service are unable to do so.

6.2.3 Caloric intake

Professional tennis players, particularly females, should pay special attention to their caloric intake. The meals and snacks served at most tournaments have a high carbohydrate content, so players should ensure that their diets include also sufficient amounts of protein, fat and minerals. Regression or prediction formulae or graphs for the assessment of the 'ideal' tennis-playing body mass should be used to obviate unwise gains or losses in body mass.

6.2.4 Liquid intake

To minimise the risk of dehydration and heat fatigue, the competitive tennis player should ingest small amounts of liquid at every change-over throughout a match (800 to 1300 ml/hr).

No alcohol should be consumed during the 24 hours prior to competition since this could result in a loss of heat acclimatization adaptations (Strydom, 1984). Obviously, these precautions are particularly necessary when the environmental temperature and/or humidity are high.

6.2.5 Specialised tennis training

A conditioning programme aimed at achieving specialised physical *fitness for tennis should incorporate strength, flexibility and aerobic* training. Structural and functional asymmetry resulting from this unilateral sport can be reduced by appropriate strength and flexibility training. Particular attention should be paid to the development and maintenance of adequate muscular strength and mobility in the dominant shoulder and the ankles. This will not only reduce the risk of intrinsic injury but may improve performance as well. Long-distance running and interval training are recommended for the improvement and maintenance of aerobic capacity.

6.2.6 Selection of talented players

The coach or trainer who intends selecting from a group of young players, those who have the necessary physical attributes for top class tennis performance, should use the following structural and functional criteria as guidelines: a tall ecto-mesomorphic physique in the boys; a relatively tall ecto- or endo-mesomorphic physique with a high androgyny index in the girls; and relatively strong wrists, ankles and lower limbs, a small amount of body fat, a high $\dot{V}O_2$ max, large static and dynamic pulmonary volumes and unilaterality in both boys and girls. Although these physical characteristics are not fully developed in the young player until after adolescence, the player's age and physical development as well as the physical characteristics of the parents may be used to gauge developmental potential. It should be pointed out that many of these important morphological and physiological characteristics can be developed and improved significantly in a young player who participates in a scientifically prescribed physical training and conditioning programme.

A popular article is being prepared for coaches and trainers who may be unfamiliar with the methodology and terminology used in the present study. It is hoped that this article will assist them to gain a greater understanding of the nature of tennis excellence and, in so doing, enable them to direct their efforts to players most likely to derive the greatest benefits from expert coaching and training.

APPENDICES

Appendix A: Tennis competitors brochure introducing the advisory clinic and study objectives

Dear Competitor,

A sophisticated FITNESS ASSESSING AND COUNSELLING CLINIC will be at your disposal during the Championships. A team of scientists will be at hand to provide you with highly accurate and practical information and advice concerning your specific:

1. Susceptibility or proneness to injury in a particular body region (tennis elbow, muscle strains and pulls etc.)
2. State of health
3. Inborn fitness potential or capacity
4. Liquid requirements during competition
5. Prevention of muscle cramps

This information which is rarely available from medical institutions, will be of value to you as a player and could in fact mean the difference between winning and losing a match.

The data to be obtained from a series of structural (physical) and functional (physiological) measurements, will be used to determine various factors concerning the physiology of tennis players. The results of this investigation - sponsored by the South African Sports Federation in conjunction with the Department of Sport and Recreation - will contribute significantly to our knowledge of the physical requirements of tennis.

Please note that by agreeing to participate in this project you will not be hampered in any way during this obviously important tournament. Every effort will be made to ensure a situation beneficial to your game. You are welcome to consult us at any time if you have any queries or problems.

Hope you have an enjoyable tournament,

Yours sincerely,

Bruce Copley

Bruce Copley (Exercise Physiologist, Rhodes University)

Appendix B: Test and measurement result and comment sheet

Name ....
Date........................
Age ....

Somatotype rating: ....

Comment:

Body fat

Percentage of body mass: ....

Total fat (kg): ....

Comment:

$\dot{V}O_2$ max (ml/kg/min): ....

Comment:

Lung volumes and capacities (ml)

T.V.	I.R.V.	E.R.V. ....
I.C.	V.C.	F.E.V./sec ....
		F.E.V./V.C. .... %

Comment:

Flexibility (degrees)

S.F.E.	S.R.	E.F.E. ....
R.U.S.P.	W.U.R.F.	H.E.F. ....
H.A.A.	T.E.F.	T.L.F. ....

Comment:

Energy expenditure (kJ/min): ....

Comment:

Sweat-rate (ℓ/hour): ....

Liquid intake (ml/10 min): ....

Comment:

Biochemical parameters

	REST	POST EXERCISE
LAC (mm/1)		
GLU (mg%)		
Cl (mEq/1)		
Na (mEq/1)		
Ca (mEq/1)		
K (mEq/1)		
Mg (mEq/1)		

Comment:

Eye dominance: ....

Comment:

General Comment

Appendix C: Test and measurement explanation brochure

Somatotype (Heath-Carter Anthropometric)

The somatotype expresses physique or body build in relation to its shape and proportion. Three components; endomorphy (degree of fatness), mesomorphy (muscularity) and ectomorphy (leanness or thinness) are used for this purpose. Each component is allocated a number in an open end scale which indicates the degree to which that characteristic is present in an individual. Thus an individual who has a somatotype rating of 2-7-3½ has a rating of 2 for endomorphy, 7 for mesomorphy and 3½ for ectomorphy. Note that the first number always refers to the rating for endomorphy, the second to mesomorphy and the third to ectomorphy. Somatotype ratings of various sport participants are shown in Table I.

TABLE I

SPORT	SOMATOTYPE RATING
Golfers	4-4-2½
Boxers	3-5-3
Rowers	2½-5-2½
Non-athletes	5-3-3
American footballers	4½-5½-2
Distance runners	1½-4½-4
Basketball players	3-5-2½
Swimmers (male)	2-5-3
Swimmers (female)	3-4-3
Tennis players (male)	2-4½-3
Tennis players (female)	3-4-2½
Ice skaters (female)	3½-4½-2½
Dancers (male)	1-4½-2½

Absolute body fat

The human body consists basically of bone, muscle and fat tissue. Since muscle and fat are directly influenced by physical activity, an individual's state of training can be assessed by considering muscle and fat percentages. Body fat is usually expressed as a percentage of body mass or weight. If for example, you have a mass of 100 kg and 20% body fat, then 20 kg of your weight consists of fat tissue. Percentage body fat values are shown in Table II.

TABLE II

SPORT	BODY FAT (%)
Wrestlers (amateur)	9,8
Rugby players	11,2
Soccer players	9,8
Tennis players (male)	11,8
Tennis players (female)	22,6
Body builders	8,4
Discus throwers	16,4
Non-athletes (male)	16,8
Non-athletes (female)	25,7

Maximal aerobic power ($\dot{V}O_2$ max)

This refers to the maximum amount of oxygen that can be absorbed by the tissues of the body during strenuous physical activity. It is expressed absolutely in litres of oxygen per minute (ℓ/min) or relatively in ml of oxygen per kilogram of body mass per minute (ml/kg/min). This universally accepted measurement is probably the best single measurement of an individual's physical fitness (potential). An individual's $\dot{V}O_2$ max is largely inherited and only small improvements (10 - 20%) can be induced by training. More significant improvements can only be accomplished by long-term endurance training which is commenced at a young age. "If you want to be a good athlete, you must choose your parents carefully". A classification of $\dot{V}O_2$ max values (ml/kg/min) for specific age groups is shown in Table III. (Åstrand, I. (1960) Acta physiological Scandinavica).

TABLE III

MEN

$\dot{V}O_2$ max rating Scale (ml/kg/min)

Age (years)	Low	Fair	Average	Good	High
20-29	38	39-43	44-51	52-56	57 +
30-39	34	35-39	40-47	48-51	52 +
40-49	30	31-35	36-43	44-47	48 +
50-59	25	26-31	32-39	40-43	44 +
60-69	21	22-26	27-35	36-39	40 +

WOMEN

Age (years)	Low	Fair	Average	Good	High
20-29	28	29-34	35-43	44-48	49 +
30-39	27	28-33	34-41	42-47	48 +
40-49	25	26-31	32-40	41-45	46 +
50-65	21	22-28	29-36	37-41	42 +

Lung volumes and capacities

Although these are largely determined by body size, they can be improved by long term training. Tidal volume is the volume of air inspired or expired during breathing. Inspiratory reserve volume is the maximal volume of air that can be inspired after a normal inspiration. Expiratory reserve volume is the maximal volume that can be expired after a normal expiration. Inspiratory capacity is the maximum volume that can be inspired after a normal expiration. Vital capacity is the maximal volume that can be expelled from the lungs after a maximal inspiration. Forced expiratory volume is the maximal volume that can be expelled from the lungs in 1 second after a maximal inspiration. This is a measure of lung power. The F.E.V$_1$/V.C. ratio is derived by expressing the forced expiratory volume as a percentage of the vital capacity. Average male and female values are shown in Table IV.

TABLE IV

Lung volumes and capacities	Male (ml)	Female (ml)
Tidal volume (T.V.)	500	400
Inspiratory reserve volume (I.R.V.)	3000	2100
Expiratory reserve volume (E.R.V.)	1200	800
Inspiratory capacity (I.C.)	3500	2400
Vital capacity (V.C.)	4800	3200
Forced expiratory volume (F.E.V./sec)	3840	2560
F.E.V./V.C. ratio	80%	80%

Flexibility

This is a measure of the range of motion or movement in a joint or series of joints and it is usually expressed in degrees. The flexible individual is less susceptible to injury in sport and to the aches and pains that accompany ageing. Flexibility can be significantly increased by the correct exercises and it appears that static stretching exercises (maintaining a stretched position) are more beneficial than ballistic or bouncing type exercises. Average flexibility values for males are shown in Table V. (Leighton, J.R. (1955), Archives of Physical Medicine and Rehabilitation).

TABLE V

MOVEMENT DESCRIPTION	AVERAGE VALUES (°)
Shoulder flexion-extension (S.F.E.)	257
Shoulder rotation (S.R.)	170
Elbow flexion-extension (E.F.E.)	141
Radial-Ulnar supination-pronation (R.U.S.P.)	160
Wrist Ulnar-Radial flexion (W.U.R.F.)	75
Hip extension-flexion (H.E.F.)	54
Hip adduction-abduction (H.A.A.)	61
Trunk extension-flexion (T.E.F.)	79
Trunk lateral-flexion (T.L.F.)	97

Energy Expenditure

Physical activity can only take place when energy is released. This energy is derived from the oxidation of numerous foodstuffs. It is obvious that the less energy one uses to perform a given task for example, serving, the more efficient or economical one becomes. The amount of energy used differs from one sport to another and from person to person. Some typical average energy expenditure values are shown in Table VI. (Henry, F.M. (1968), Physiology of Work).

TABLE VI

Activity	Energy Cost (kJ/min)
Standing at ease	7,1
Canoeing (4 mph)	29,3
Cycling (13,1 mph)	46,4
Volleyball	14,6
Golf	20,9
Baseball	17,6
Tennis	29,7
Long-distance running	62,3
Sprinting (20 mph)	778,2

Sweat-rate

Physical exercise increases the body temperature and one of the mechanisms the body uses to reduce the temperature is sweating. The mere process of sweating however, does not result in cooling as it is only when sweat evaporates from the surface of the skin that cooling takes place (evaporation of 1 gram of sweat results in a heat loss of 2,4 kJ (0,58 kcal)). While the sweat mechanism is an advantage on the one hand, it is a disadvantage on the other since excessive sweating not only results in dehydration but also in electrolyte imbalances (sodium, magnesium) which may lead to serious consequences such as cramps, nausea and tiredness. The body can only function at optimum levels when the volume and composition of body fluids are delicately balanced. Unfortunately this balance cannot be maintained during exercise which induces sweat-rates in excess of 1 litre/hour. Since gastric emptying or absorption can only take place at a maximum rate of about 1 litre/hour, it is evident that if the sweat-loss is greater than the maximum rate of absorption, then dehydration will result.

Environmental conditions, especially humidity, body mass, exercise intensity and duration and the degree of physical fitness and acclimatisation are factors which determine sweat-rate. Remember that 1 litre of sweat weighs approximately 1 kg. A tennis player who has a sweat-rate in excess of 1 ℓ/hour should take the following precautions:

> Be well hydrated before competition.
> Ingest approximately 160 ml of a chilled (8-12°C) isotonic solution (2 grams of sodium chloride, 25 grams glucose and 17 milligrams of potassium per litre of water) every 10 minutes during competition. Be sure to start drinking as soon as the match commences since intestinal absorption continues at a constant rate and it is not possible to "catch up" once a water deficit has been incurred.

Biochemical parameters

The blood is responsible for the transport of gases, foodstuffs and waste products to and from the various body tissues. By studying certain substances present in the blood before and after exercise, valuable information can be gained concerning the strenuousness of the exercise (lactic acid concentration) and the utilisation of certain energy substrates (glucose, fatty acids) and ions (sodium, potassium, magnesium). Normal levels of substances found in the blood are shown in Table VII.

TABLE VII

PARAMETER	NORMAL VALUES (RESTING)	
Lactate (Lac)	1,1 - 1,3	mm/l
Glucose (Glu)	80 - 120	mg%
Chloride (Cl)	95 - 105	mEq/l
Sodium (Na)	135 - 155	mEq/l
Calcium (Ca)	4,5 - 5,5	mEq/l
Potassium (K)	3,6 - 5,5	mEq/l
Magnesium (Mg)	1,5 - 2,5	mEq/l

Eye dominance

Most people show definite eye dominance, in other words they are either right-eyed or left-eyed. A distinction is made between crossed lateral (left-eyed / right-handed or right-eyed / left-handed) and unilateral (right-eyed / right-handed or left-eyed / left-handed). Although the evidence is not yet conclusive it appears that the crossed lateral tennis player is usually better on the backhand side while the unilateral player is better on the forehand side.

Appendix D: *Heavy-duty card for data recording*

QUESTIONNAIRE (17)

Name...................... No. ...

Birth date ....

Nat and Race.....................

Sex......... Handedness..........

Tennis rep.......................

Occupations

Past..........................

Present.......................

Leisure-time

Past..........................

Present.......................

Tennis participation Years.......

Hours/week..... Weeks/yr.......

Physical Training

Past..........................

Present.......................

Serious illnesses or injuries

....

....

MORPHOLOGICAL PARAMETERS (34)

Mass (kg) ....

LENGTHS (cm)

Stand........... Acrom...........

Trochan......... Dact............

DIAMETERS (cm)

Biacrom......... Bi-il...........

Bi-trochan..... Chest (A-P)......

Bi-epicon (hum) R...... L......

Bicon (fem) R...... L......

Wrist R......... L.........

Ankle R......... L.........

GIRTHS (cm)

Arm (uncon) R....... L.......

Arm (cont) R....... L.......

Forearm R....... L.......

Calf (stand) R....... L.......

Chest (Meso after normal exp)....

SKINFOLDS (mm)

Biceps R....... L.......

Triceps R....... L.......

Subscapular R.................

Calf (med) R....... L.......

Somatotype rating...............

LENGTH INDICES

Upper limb % T.B.L. ....

Leg length % T.B.L. ....

Thigh length % T.B.L. ....

Forearm length % T.B.L. ....

Arm length % T.B.L. ....
Forearm/arm length ratio..........

WIDTH INDICES

Biacrom % T.B.L. ....
Bi-iliac % T.B.L. ....
Bi-iliac % Biacrom ....
Biepicon (hum) % upper limb.......
Bicon (fem) % leg length.......
Biepicon hum/fem ratio............

GIRTH INDICES

Chest & T.B.L. ....
Forearm % upper limb ....
Thigh % leg length ....
Calf % leg length ....
Percentage body fat ....
Muscle index ....
Bone index ....
Skin-fat index ....
Upper trunk dysplasia ....
Upper limb dysplasia ....
Lower trunk dysplasia ....
Lower limb dysplasia ....
Androgyny ....

PHYSIOLOGICAL PARAMETERS

$\dot{V}O_2$ max (ml/kg/min) ....

H.R. .... W.L. (kgm/m).......

P_B .... R.H. ....

Blood

	Glu	LA	Na	Cl	Mg
Pre					
Post					

Sweat-rate (ml) ....
I.B.M. .... F.B.M. ....
L.I. .... U.V. ....

Energy expend (kcal/min) ......
$\dot{V}_E$ .... P_B .... Temp .....
PH_2O..... ECO_2...... EO_2 ......

Blood pressure
Pre.......... Post ....

Heart rate
Pre.......... During ....

Static and Dynamic Vol
V.C. .... R.V. ....
T.L.C. .... T.V. ....
I.R.V. .... E.R.V. ....
I.C. ....

Eye dom Crossed / Unilateral

Inter-pup distance (mm) ....

Flexibility (°)
Shoulder flex-exten R..... L.....
Shoulder rotation R..... L.....
Elbow flex-exten R..... L.....
Rad-Uln sup-pron R..... L.....
Wrist Uln-Rad flex R..... L.....
Hip exten-flex ....
Hip abd-add ....
Trunk exten-flex ....
Trunk lateral flex ....

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