

**THE RELATIONSHIP BETWEEN ANTHROPOMETRY AND RESPIRATORY MUSCLE
FUNCTION IN LAND – AND WATER – BASED ATHLETES**

BY

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Thesis presented in the partial fulfillment of the requirements for the degree of Master in
Sport Science at Stellenbosch University



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December 2007

DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

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SUMMARY

The purpose of this study was to gain more information on respiratory muscle function of team sports. This was achieved by determining the relationship between anthropometry and respiratory muscle function and the relationship between respiratory muscle function and exercise performance. The degree of respiratory muscle fatigue after a speed endurance test on land and in water was also determined.

A total of 62 subjects were tested. The group consisted of 14 netball players (age: $20.9 \pm$ SD 2.0 years; height: $172.5 \pm$ SD 6.1cm and weight: $66.6 \pm$ SD 7.8 kg); 15 rugby players (age: $21.7 \pm$ SD 2.2 years; height: $183.1 \pm$ SD 7.3cm and weight: $92.5 \pm$ SD 13.2 kg); 12 male swimmers (age: $18.9 \pm$ SD 2.5 years; height: $183.3 \pm$ SD 6.5cm and weight: $77.2 \pm$ SD 8.6 kg); 8 female swimmers (age: $17.8 \pm$ SD 1.6 years; height: $168.3 \pm$ SD 5.4cm and weight: $63.9 \pm$ SD 9.8 kg); 7 male control subjects (age: $21.4 \pm$ SD 1.5 years; height: $179.7 \pm$ SD 5.0cm and weight: $80.8 \pm$ SD 10.8 kg) and 6 female control subjects (age: $21.5 \pm$ SD 1.5 years; height: $166.9 \pm$ SD 6.5cm and weight: $60.2 \pm$ SD 6.7 kg). Testing included anthropometric measurements, lung function (FVC test), and respiratory muscle function (baseline MIP, MEP, MVV). Netball -, rugby players and the control subjects performed a speed endurance test on land and the swimmers performed a speed endurance test in the swimming pool. This test was followed by a second MIP measurement 60 and 120 seconds after the sprint endurance test.

Respiratory muscle strength showed no correlations to anthropometry for men and women. For men, height, weight, sitting height, biacromiale breath and waist girth accounted for 17% of the variance in MIP ($P = 0.34$). The variance in MEP was accounted for 15.6% by height, weight, sitting height, biacromiale breath and waist girth ($P = 0.41$). For women, weight, sitting height, arm span, biacromiale breath and chest girth accounted for 28.4% of the variance in MIP ($P = 0.17$), but MEP was accounted for only 22% by sitting height, arm length, arm span and body mass index as well as chest girth ($P = 0.32$).

Respiratory muscle endurance showed correlations to certain anthropometry variables and had a significant regression equations for MVV in men: $-312.51 + (2.83 \times \text{Arm span}) - (0.38 \times \text{Sum of 8 skinfolds})$ and arm span and sum of eight skinfolds accounted for 47.3%

of the variance in MVV. Women's MVV also had a significant regression ($P = 0.002$): $-106.7 + (1.5 \times \text{Body mass}) + (1.0 \times \text{Arm span}) - (0.2 \times \text{Sum of 8skinfolds})$ and weight, arm span and sum of eight skinfolds accounted for 45% of the variance in MVV.

Only MIP and MEP had significant correlations ($r = 0.63$, $P < 0.01$ and $r = 0.66$, $P < 0.02$ respectively) to the speed endurance test on land. Although significant, MVV and FVC showed no correlations to the speed endurance test. Both MIP and MEP had a correlation to the speed endurance test in the water ($r = -0.55$, $P < 0.02$ for both). FVC also had a correlation to the speed endurance test, although it was not significant ($r = -0.51$, $P < 0.44$). MVV had a poor correlation to the speed endurance test.

Sixty seconds after the speed endurance test the land –based group's (netball and rugby players grouped together) RM were 14.39% fatigued compared to the 9.04% of the water –based group (swimmers) and 41.02% of the control group. One hundred and twenty seconds after the sprint endurance test the land –based group's RM were 8.43 fatigued compared to the 3.54% of the water –based group and the 24.64% of the control group.

In conclusion, anthropometry plays a moderate role in RM endurance but even a smaller role in RM strength. The relationship between RM functions and the speed endurance test varied between the land – and water –based groups, but certain RM function can play a moderate role in the performance in this speed endurance test. All the groups experienced fatigue after the speed endurance test, but the degree was more in the control group followed by the land –based athletes compared to the water –based athletes. This indicates that stronger RM function can lead to less RM fatigue.

OPSOMMING

Die doel van die studie was om die respiratoriese spier funksies van span sporte te bestudeer en is gedoen deur na die verband tussen respiratoriese spier funksies en antropometrie, die verband tussen respiratoriese spier funksies en oefen prestasie en die mate van respiratoriese spier uitputting na oefening te kyk.

'n Totaal van 62 subjekte is getoets. Die groep het bestaan uit 14 netbal (ouderdom: $20.9 \pm \text{SD } 2.0$ jaar; lengte: $172.5 \pm \text{SD } 6.1\text{cm}$ en gewig: $66.6 \pm \text{SD } 7.8$ kg); 15 rugbyspelers (ouderdom: $21.7 \pm \text{SD } 2.2$ jaar; lengte: $183.1 \pm \text{SD } 7.3\text{cm}$ en gewig: $92.5 \pm \text{SD } 13.2$ kg); 12 mans swemmers (ouderdom: $18.9 \pm \text{SD } 2.5$ jaar; length: $183.3 \pm \text{SD } 6.5\text{cm}$ and gewig: $77.2 \pm \text{SD } 8.6$ kg); 8 dames swemmers (ouderdom: $17.8 \pm \text{SD } 1.6$ jaar; lengte: $168.3 \pm \text{SD } 5.4\text{cm}$ and gewig: $63.9 \pm \text{SD } 9.8$ kg); 7 mans kontrole subjekte (ouderdom: $21.4 \pm \text{SD } 1.5$ jaar; lengte: $179.7 \pm \text{SD } 5.0\text{cm}$ and gewig: $80.8 \pm \text{SD } 10.8$ kg) and 6 dames kontrole subjekte (age: $21.5 \pm \text{SD } 1.5$ years; height: $166.9 \pm \text{SD } 6.5\text{cm}$ and weight: $60.2 \pm \text{SD } 6.7$ kg). Toetsing het die volgende ingesluit: Antropometriese meetings, long funksies en respiratoriese spier funksies (basislyn maksimale inspirasie drukking (MID), maksimale ekspirasie drukking (MED), maksimale willekeuring ventilasie (MWV)). 'n Spoed uithouvermoë toets op land is deur die netbal -, rugbyspelers en die kontrole subjekte en 'n uitgevoer en 'n spoed uithouvermoë toets in die water is deur die swemmers uitgevoer. Beide hierdie toetse is gevolg deur 'n tweede en derde maksimale inspirasie drukking 60 en 120 sekondes na die toets.

Geen korrelasies is gevind tussen antropometrie en respiratoriese spier sterkte vir beide mans en dames. In die geval van mans, het lengte, gewig, bolyf lengte, bi- akromiale breedte en die omtrek van die middel 17% uitgemaak van die variansie in MIP ($P = 0.34$). Die variasie van MEP is uitgemaak deur 15.6% van lengte, gewig, bolyf lengte, bi-akromiale lengte en die omtrek van die middel ($P = 0.41$). Vir dames het gewig, bolyf length, arm reikwydte, bi -akromiale breedte en bors omtrek 'n 28.4% rol gespeel in die variansie van MIP ($P = 0.17$), maar die variasie in MEP is voorspel met 22% deur bolyf length, arm length, arm reikwydte, liggaams massa indeks en bors omtrek ($P = 0.32$).

Respiratoriese spier uithouvermoë het 'n korrelasie getoon met sekere antropometriese veranderlikes en 'n statisties beduidende vergelyking vir mans MWV: $-312.51 + (2.83 \times \text{Arm reikwydte}) - (0.38 \times \text{Som van 8 velvoue})$ waar arm reikwydte en som van ag velvoue was verantwoordelik vir 47.3% van die variansie in MWV. Die dames se MWV het ook 'n statisties beduidende vergelyking getoon: $\text{MWV} = -106.7 + (1.5 \times \text{gewig}) + (1.0 \times \text{Arm reikwydte}) - (0.2 \times \text{Som van 8 velvoue})$ waar gewig, arm reikwydte en die som van ag velvoue verantwoordelik was vir 45% van die variansie in MWV.

Slegs MID en MED het statisties beduidende korrelasies (onderskeidelik $r = 0.63$, $P < 0.01$ and $r = 0.66$, $P < 0.02$) getoon met die spoed uithouvermoë toets op land. Geen korrelasie is tussen MWV en die geforseerde vitale kapasiteit toets gevind al was die verband statistiese beduidend. Beide MID en MED het 'n korrelasie met die spoed uithouvermoë toets in die water getoon ($r = -0.55$, $P < 0.02$ vir beide). Die geforseerde vitale kapasiteit toets het ook 'n korrelasie met die spoed uithouvermoë toets, tog was dit nie statisties beduidend nie ($r = -0.51$, $P < 0.44$). MWV het geen korrelasie getoon met die spoed uithouvermoë toets op land.

Sestig sekondes na die spoed uithouvermoë toets is 'n 14.39% respiratoriese spier uitputting in die land gebaseerde groep (netbal – en rugby spelers), 9.04% respiratoriese spier uitputting in die water gebaseerde groep (swemmers) en 'n 41.02% respiratoriese spier uitputting in die kontrole groep gevind. Na 120 sekondes was die respiratoriese spiere van die land gebaseerde groep steeds 8.43% uitgeput in vergelyking met die 3.54% van die water gebaseerde groep en die 24.64% van die kontrole groep.

Dus speel antropometrie 'n matige rol in respiratoriese spier uithouvermoë en selfs 'n kleiner rol in respiratoriese spier sterkte. Die verband tussen respiratoriese spier funksies en die spoed uithouvermoë toets het gevarieer tussen die land – en die water gebaseerde groepe, maar respiratoriese spier funksies kan 'n matige rol speel in die voorspelling van die prestasie in die spoed uithouvermoë toets. Die kontrole groep het meer respiratoriese spier uitputting ervaar na die spoed uithouvermoë toets, dus beteken dit dat geoefende en ongeoeffende persone respiratoriese spier uitputting sal ervaar.

ACKNOWLEDGEMENTS

I wish to express my sincere appreciation to the following people:

Prof Elmarie Terblance, for her endless patience and assistance

My parents, Willie and Gerda, for giving me so many opportunities in life

Family and friends for their regular interests

Co- laboratory assistants: Karen, Jacolene, Ludwig, Louise for support.

The participants who took part in the study.

I wish to acknowledge the University of Stellenbosch and the National Research Foundation of South Africa for their financial assistance. Opinions expressed and conclusions arrived at, are those of the author and do not necessarily reflect those of the above institutions.

LIST OF ABBREVIATIONS

%BF	:	percentage body fat
BD	:	body density
BET	:	breathing endurance time
BM	:	body mass
BMI	:	body mass index
BPNS	:	bilateral phrenic nerve stimulation
BSA	:	body surface area
cm	:	centimeter(s)
cmH ₂ O	:	centimeters water
COPD	:	chronic obstructive pulmonary disease
CV	:	coefficient of variance
EIB	:	exercise-induced bronchoconstriction
ERT	:	endurance running time
ERV	:	expiratory reserve volume
FEF	:	forced expiratory flow (L.sec ⁻¹)
FEV	:	forced expiratory volume (L)
FEV ₁	:	forced expiratory volume in 1 second (L)
FFM	:	fat free mass
FIF	:	forced inspiration flow
FIV	:	forced inspiratory volume
FRC	:	functional residual capacity
FVC	:	forced vital capacity (L)
HG	:	maximal handgrip strength
Hz	:	hertz
IC	:	inspiratory capacity
IM	:	inspiratory muscle
IRV	:	inspiratory reserve volume
kcal/day	:	kilocalories per day
Kg	:	kilograms
km	:	kilometer(s)
kPa	:	kilopascal

L	:	liters
L.min ⁻¹	:	Liters per minute
MCS	:	magnetic cervical stimulation
MEP	:	maximal expiratory pressure (cmH ₂ O)
min	:	minute(s)
MIP	:	maximal inspiratory pressure (cmH ₂ O)
MIPFRC	:	maximal inspiratory pressure at functional residual capacity
MIPRV	:	maximal inspiratory pressure at residual volume
MSVC	:	maximum sustained ventilatory capacity
MVV	:	maximal voluntary ventilation (L.min ⁻¹)
MVV _{12/60}	:	maximal voluntary ventilation over 12 or 60 seconds
P	:	probability
PAV	:	proportional- assist ventilator
P _{di,tw}	:	transdiaphragmatic twitch pressures
PEF(R)	:	peak expiratory flow rate (L.sec ⁻¹)
P _{es,tw}	:	esophageal twitch pressures
PIF	:	peak inspiratory flow
PFK	:	phosphofruktokinase
P _{ga,tw}	:	gastric twitch pressures
r	:	correlation coefficient
RM	:	respiratory muscle
RV	:	residual volume
s	:	second(s)
SD	:	standard deviation
SE	:	standard error of mean
SV	:	stroke volume
TLC	:	total lung capacity (L)
T _{lim}	:	time to exhaustion at a specific threshold
VC	:	vital capacity
VE	:	minute ventilation (L.min ⁻¹)
VO ₂	:	volume of oxygen consumption (L.min ⁻¹)
VO _{2max}	:	maximal exercise capacity, maximal oxygen consumption or maximal aerobic consumption (ml.kg ⁻¹ .min ⁻¹)

V_t : tidal volume
yrs : years

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CHAPTER 1

INTRODUCTION

The human body consists of different systems. All these systems, together with biomechanical and psychological factors, contribute to achieve certain levels of exercise. Many researchers to date have attempted to identify the specific physiological determinants of athletic performance and thus the limits to maximal exercise. Historically, there are two views on the limitations to exercise capacity, namely either oxygen delivery or skeletal muscle metabolic capacity (i.e. oxygen utilization).

Maximal exercise capacity (VO_{2max}), also known as maximal aerobic capacity, is defined as the highest amount of oxygen a person can take up and utilize during exhaustive exercise. The importance of VO_{2max} is not only that it is a measure of aerobic metabolism, but more importantly, that it is a very good measure of the combined functional capacities of the lungs, the cardiovascular system and the muscle mitochondria.

The main physiological determinants of VO_{2max} are the cardiovascular system, skeletal muscle system and the respiratory system. The cardiovascular system is responsible for transporting the oxygenated blood to the skeletal muscles. The respiratory system is responsible for the diffusion of air from the atmosphere to the blood, and the respiratory muscles (RM) play an important role to provide sufficient oxygen to meet the metabolic needs of the tissues and muscles. The pulmonary diffusing capacity, cardiac output and the oxygen carrying capacity of blood is known as central factors, while all factors associated with adaptations in the skeletal muscles are known as peripheral factors.

Traditionally, the cardiovascular system, and more specifically maximum cardiac output, has been viewed the primary limiting factor of maximal exercise capacity. A complete discussion on the different theories of the limiting factors to maximal aerobic capacity is beyond the scope of the thesis. However, a brief overview will provide the background to illustrate the importance of further investigations into the respiratory system as a significant link in the attainment of optimal sport performance.

A. The cardiovascular system

VO_{2max} is determined by cardiac output and the arterial-venous oxygen difference (McArdle *et al.*, 2001). Cardiac output is the amount of blood pumped per unit of time and is responsible for the body's ability to meet the metabolic needs during rest and exercise of various muscles during exercise. Therefore heart rate and more importantly, stroke volume (SV), are components of cardiac output and ultimately determinants of VO_{2max} .

The traditional view of Hill and Lupton (1923) and Hill *et al.* (1924) on the limitations to maximal exercise proposed that there is an upper limit to oxygen uptake and that VO_{2max} is limited by the ability of the cardiorespiratory system to transport oxygen to the muscles. For example, during running, the oxygen requirement increases continuously as the speed increases, but oxygen intake would reach a plateau. This plateau is assumed to represent a leveling off in cardiac output and oxygen extraction by the muscles. Since oxygen uptake cannot keep pace with the increasing oxygen demand, there is an increased reliance on anaerobic glycolysis. It is therefore universally accepted that there is a physiological upper limit to the body's ability to deliver oxygen to the working muscles, which implies that the cardiovascular system is the primary limiting factor of maximal exercise performance.

It is known that the single most important discriminating factor in the VO_{2max} values of trained and untrained men and women is the variation in SV and systemic oxygen extraction between individuals. There is much less variation in maximal heart rate. Therefore, the dominant mechanism for the increase in VO_{2max} with training is an increase in blood flow and therefore oxygen delivery. Bassett and Howley (2000) suggested that 70 – 85% of the limitation in VO_{2max} is linked to maximal cardiac output.

It is true that a number of researchers have questioned this particular theory, namely that the rate of oxygen delivery is the primary limiting factor. It is argued that the absence of a plateau in the volume of oxygen consumption (VO_2) in some individuals during maximal graded exercise may point to other limiting factors. Noakes (2001) argues that oxygen transport is not the critical factor determining maximal exercise and that the original theory (i.e. the cardiovascular/anaerobic model) cannot explain fatigue and performance under all conditions. Noakes (2001) bases his argument on the fact

that the muscles of elite athletes have superior contractility. As a result, these muscles are able to achieve higher workloads during maximal exercise and therefore more oxygen can be consumed during maximal exercise. Consequently, these athletes tend to have higher VO_{2max} values. Therefore, it is not the rate of oxygen delivery, but the availability of sufficient amounts of oxygen that determines maximal exercise capacity (i.e. VO_{2max}). This latter statement is therefore in contrast with the traditional view that elite athletes are able to perform better because they have a higher maximal cardiac output and VO_{2max} .

Another theory that excludes the cardiovascular system as a limiting factor is the central governor theory (Noakes, 2000). According to this theory, healthy persons do not experience myocardial ischemia during exercise, because an oxygen sensitive organ provides feedback to the “central governor” in the brain. The “central governor” inhibits motor unit recruitment during exercise to protect the organs and tissues against an oxygen shortage or insufficient blood flow.

B. The musculoskeletal system

It is recognized that under certain circumstances other factors, than maximal cardiac output, can become the “weak link” during the transport and utilization of oxygen. A number of muscle metabolic diseases, such as McArdle’s disease, phosphofructokinase (PFK) deficiency and defects in mitochondrial electron transport can limit VO_{2max} . Both VO_{2max} and arterial-venous oxygen difference are below normal in patients who suffer from these diseases. This provides evidence that maximal exercise can also be limited through peripheral factors (Basset and Howley, 1997).

Further evidence that skeletal muscles are important determinants of VO_{2max} is related to the adaptations that place in the locomotor muscles with training. It is well known that endurance training leads to an increase in the number and size of mitochondria, an increase in mitochondrial enzymes, as well as an increase in capillary density (Bassett, 2000). This increase in capillaries not only helps to accommodate the high rates of muscle blood flow, but also to maintain or prolong the transit time of blood for optimal diffusion. Although there is only a modest increase in VO_{2max} with changes in these peripheral factors, they are nevertheless important links in the improvement in endurance performance.

C. The respiratory system

The traditional perspective is that the pulmonary system has a large reserve capacity that is more than capable to meet the demands of very heavy physical exercise. A number of arguments have been put forward to explain why exercise capacity in normal, healthy individuals is not limited by the respiratory system. Firstly, Shephard (1967) observed that even untrained subjects can voluntarily increase their minute ventilation (VE) during maximal exercise. Secondly, it is often stated that maximal exercise ventilation does not exceed maximal voluntary ventilation in healthy individuals (Freedman, 1970). However, the test for maximum voluntary ventilation only lasts 10-20s and therefore is not comparable to most exercise that lasts longer than a minute and cause exhaustion. For instance, Bye *et al.* (1984) noted diaphragmatic fatigue in active (but not trained) individuals after 5 – 10 min of maximal exercise. Lastly, arterial oxygen tensions stay constant and at near resting values during maximal exercise (Hughes *et al.*, 1968). The only exception to the latter is the exercise-induced arterial hypoxemia that is observed in some highly trained individuals at maximal exercise ($\dot{V}O_2 > 3 \text{ L/min}$).

In the last twenty years, many researchers have focused their attention on the respiratory muscles. Although plenty of research has been done on the respiratory muscle function of patients with pulmonary and musculo-skeletal diseases, as well as the effect of obesity on pulmonary function, the more recent studies have focused on the role of the respiratory muscles in healthy and trained individuals.

In order to move air in and out of the lungs at sufficient rates to meet the demands of exercise, energy is needed to recruit the respiratory muscles. In turn, the respiratory muscles need a greater percentage of the cardiac output, and must be able to extract more oxygen from the blood. It is possible that this increase in the demand for blood flow by the respiratory muscle can lead to blood flow restrictions in the locomotor muscles which may ultimately limit performance. Furthermore, this increased respiratory muscle recruitment also leads to the sensation of breathlessness. Therefore adaptations should be made in the breathing pattern during exercise to (1) meet the increased energy cost of breathing and (2) limit sensations of breathlessness.

Respiratory muscle recruitment pattern plays an important role in both these factors (Dempsey *et al.*, 2006).

Some research states that the respiratory muscle fibers are not only highly specialized for their functional tasks, but are also able to modify their properties to adapt to new requirements, which may be a result of physiological conditions such as physical exercise or from lung or respiratory diseases. This would mean that the respiratory muscles are not likely to be a limiting factor when the physiological systems are stressed (Polla *et al.*, 2004).

On the other hand, Dempsey (1986) argued that the respiratory system may not be as trainable as the cardiovascular and locomotor systems, and therefore at high levels of fitness, the gas exchange capability of the lungs, the maximum responsiveness of the chest wall and the ventilatory control system may actually become a rate limiting step in determining maximal oxygen consumption. Dempsey (1986) stated that exercise-induced arterial hypoxemia and the absence of a significant compensatory hyperventilation in the highly trained athlete imply that critical aspects of the pulmonary control system have not adapted appropriately to the increased metabolic demands.

It is fortuitous to assume that all the physiological systems and organs in the body have limitless functional capacity. The general assumption that the respiratory system does not limit maximal exercise capacity must therefore be revisited. The focus of this study was to gain a better understanding of the respiratory muscle function of selected athletic populations, in order to contribute to our understanding of the role of the pulmonary system during exercise.

CHAPTER 2

PULMONARY FUNCTION IN HUMANS

A. Introduction

The functional evaluation of the respiratory system consists of two aspects namely, lung functions (volumes and flow) and respiratory muscle function. Much information is available on lung function testing which is done routinely in clinical settings. The measurement of respiratory muscle function was traditionally limited to the diagnosis of respiratory muscle weakness due to neuromuscular disease or other respiratory limitations. Through the monitoring of respiratory muscle strength and endurance, one can monitor disease progress, as well as the responses to treatment.

Since the early nineties, the focus has expanded to respiratory muscle function of healthy, athletic populations. Athletes are specifically interested in any measures that may enhance their performance. One reason for this is the fact that commercial apparatus are now available to train the respiratory muscles and some studies have shown that respiratory muscle training (RM training) can significantly improve performance and researchers again want to conclude whether the lung is a limiting factor during exercise.

B. Lung function testing

1. Significance of lung function tests

Lung function testing is mainly used to determine the cause of breathing problems and to monitor the effectiveness of the treatment of various lung diseases. It is also routinely used as part of occupational and health screening programs. The latter also include athletic populations, where the assessment of lung function forms part of standard fitness and performance testing.

In some jobs that require high physical demands (eg. firefighters), a certain level of cardiopulmonary fitness may be a prerequisite. By determining the applicants' lung

functions, it can be determined if the person will be able to endure the demands of the job. Lung function testing is also used to monitor the losses in lung function that are work-related (eg. mine workers) (Townsend, 2000). Furthermore, lung function tests are objective measures of the severity of obstructive and restrictive lung diseases.

Normal (i.e. healthy) lung functions are indicated when airflow and lung volume variables exceed at least 80% of the predicted values. In the case of obstructive lung diseases, one or more of the airflow variables may be less than 80% of the predicted values, but lung volumes are usually normal. In general, the decrease in airflow rates is the result of an increase in airway resistance. Examples of obstructive diseases are bronchial asthma, exercise induced asthma and emphysema.

In restrictive lung diseases (inability of the lungs to inflate properly) one or more of the lung volume variables may be less than 80% of the predicted values, while the airflow variables are normal. In this case, the lungs are unable to inflate maximally, usually as a result of decreased lung tissue elasticity. Typical restrictive disorders include lung fibrosis, lung edema and asbestosis (Foss and Keteyian, 1998).

Lung function testing is not only used in the clinical setting, but also plays an important role in the health evaluation of athletes. According to Wilber *et al.* (2000), there is an increase in the incidence of exercise-induced bronchoconstriction (EIB) in competitive athletes, specifically in athletes participating in winter sports (i.e. cross-country skiing). EIB constitutes a narrowing of the airways mostly during, or shortly after the termination of exercise, causing a typical obstructive breathing pattern.

Strensrud *et al.* (2007) found that the exercise capacity of subjects suffering from EIB, measured as VO_2 peak and peak running speed, decreased significantly during exercise in cold environmental conditions compared to regular environmental conditions. Although the inspiration of cold, dry air during exercise is reported to exacerbate the symptoms of EIB, it is not known whether EIB is primarily caused by airway cooling or because of water loss due to increased ventilation. However, it is known that EIB can seriously impact on the sport performance of athletes in various types of sport. Therefore, knowledge gained by lung function tests can help to treat athletes who suffer from EIB.

Lung function testing can also be used to describe the effects of certain physical activities on the pulmonary function of athletes and the differences between athletic and non-athletic populations. The nature of some sports leads to the development of larger-than-normal static lung volumes. Through swimming and diving, for example, the inspiratory muscles are specifically strengthened, because these muscles work against the additional resistance of the mass of the water which compresses the thorax (McArdle *et al.*, 2001). Many researchers, including Cordain *et al.* (1990) found that swimmers exhibited larger vital capacities, residual lung volumes, inspiratory capacities and functional residual capacities when compared to runners and non-athletic control groups. Whether these differences are due to genetic influences or the effect of training is not entirely clear.

2. Assessment of lung function

In humans, pulmonary function (lung volumes and rates of airflow) can be easily determined using a spirometer. These parameters can either be measured statically (i.e. the spirogram), or dynamically (i.e. the flow-volume curve and flow–time curves).

The following static lung volumes and lung capacities are commonly determined through spirometry:

Tidal volume (V_t) is the amount of air that is inspired or expired in a normal breath. **Inspiratory reserve volume** (IRV) is the greatest amount of air that can be inspired at the end of a normal inspiration, while **expiratory reserve volume** (ERV) is the greatest amount of air that can be expired at the end of a normal expiration. After a maximal exhalation, the remaining air in the lungs is known as the **residual volume** (RV). However, this volume cannot be determined through simple spirometry techniques.

Inspiratory capacity (IC) is defined as the greatest amount of air that can be inspired from a resting expiratory level ($IC = IRV + V_t$). **Vital capacity** is known as the greatest amount of air that can be exhaled following a maximal inhalation ($VC = IRV + V_t + ERV$). After a normal expiration the air left in the lungs is known as the **functional residual capacity** ($FRC = ERV + RV$). **Total lung capacity** (TLC) is the greatest amount of air that can be contained by the lungs.

There are two commonly used tests to measure dynamic lung functions:

2.1 Forced Vital Capacity (FVC) test

The maximum flow-volume curve is commonly used to quantify the maximum limits of the lungs and respiratory muscles. FVC is measured with a flow – volume curve which shows the relationship between rate of airflow and lung volume. FVC is the maximal volume of gas expired when the forced expiratory maneuver is continued to full expiration after a maximal inspiration.

Other important indices from the flow-volume loop are forced inspiratory flow (FIF), forced expiratory flow (FEF) and peak expiratory flow (PEF). FIF and FEF can be measured at specific lung volumes, for example at 25%, 50%, and 75% of FVC. PEF is the maximal airflow achieved during a forced expiration following a full inspiration. PEF and peak inspiratory flow (PIF) reflect the maximum shortening velocities of the inspiratory and expiratory muscles, respectively. Therefore, FVC, PEF and PIF depend greatly on the strength of the inspiratory and expiratory muscles.

Romer *et al.* (2003) determined the inter-test reliability of FVC and PEF in 46 healthy, physically active individuals on two separate occasions. They found significant differences between the test-retest measurements for FVC and PEF ($5.66 \pm \text{SD } 0.66$ vs $5.71 \pm \text{SD } 0.61$ L; $p < 0.01$ and $10.3 \pm \text{SD } 1.3$ vs $10.6 \pm \text{SD } 1.3$ L.s⁻¹; $p < 0.05$, respectively). However, the 95% ratio limits of agreement according to Bland & Altman (1986) for these measures were shown to be acceptable. In the general population, the test-retest reliability of the FVC test has been reported to be within 2-3% (Cotes *et al.*, 2006).

2.2 Flow Time Curve

The flow time curve measures forced expiratory volume (FEV). FEV₁ is the amount of gas expired during the first second of a forced expiration following a full inspiration. Other time intervals that are sometimes used are FEV_{0.5} and FEV_{0.75} (Cotes *et al.*, 2006). These parameters are particularly important in the quantification of airflow limitations in humans, both at rest and during exercise, as well as the diagnosis of exercise-induced bronchoconstriction and airway reversibility.

2.3 Maximal Voluntary Ventilation (MVV) test

MVV is the greatest amount of air a person can move in and out of the lungs with a maximal effort over 12 to 15 seconds. This volume is then multiplied by 5 (if 12 seconds) or 4 (if 15 seconds) to determine the volume that was ventilated in one minute. The MVV test is commonly used to assess respiratory muscle endurance. According to Cotes *et al.* (2006) the MVV test is effort dependent, however, test-retest reliability is within acceptable limits (4 to 6 %). In healthy individuals, MVV is usually much greater than the maximal minute ventilation during exhaustive exercise at sea level. This means that most healthy individuals will have a ventilatory reserve during maximal exercise, which allows people to exercise at relatively high intensities and for prolonged periods without undue respiratory muscle fatigue (Brooks *et al.*, 2005).

3. Lung functions in athletes and non-athletes

Table 1 and 2 illustrate the main lung function values for athletes and non – athletes that have been published in the literature. Most studies included endurance type athletes (i.e. runners, cyclists and swimmers) with only a few studies reporting on the lung functions of non – endurance activities. In all cases, the upper limits of FVC and FEV₁, were higher for athletes compared to non-athletes. Most male athletes have significantly higher values than their untrained counter parts. It is not known whether these differences are genetically determined, or whether the larger lung volumes are the result of whole-body exercise training.

Table 1: Reference lung function values in non –athletes. Values are expressed as mean \pm SD

Source	n	Age (yrs)		FVC(L)	FEV ₁ (L.sec ⁻¹)	Comment
		mean	range	mean (SD)	mean (SD)L.sec-1	
Women						
Cordain et al (1990)	11	18.9 \pm 0.3		4.12 \pm 0.17	3.62 \pm 1.8	Seated, nose clips
	11	19.6 \pm 0.8		3.98 \pm 0.19	3.41 \pm 1.3	
Men						
Mador et al (1991)	10	29.3 \pm 15.8	22 - 36	4.59 \pm 0.98	3.74 0.78	7 men, 3 women, healthy subjects

Table 2: Reference lung function values for athletes. Values are expressed as mean \pm SD

Source	n	Age (yrs)		FVC(L)	FEV ₁ (L.sec ⁻¹)	PEF(L.sec ⁻¹)	Comment
		mean	range	mean (SD)	mean (SD) L.sec-1	mean (SD)L.sec-1	
Women							
Robinson and Kjeldgaard (1982)	8	34.0 \pm 10.9			3.06 \pm 0.46	8.77 \pm 1.98	Runners
Clanton et al (1987)	16	19 \pm 1	17 - 21		3.84 \pm 0.66	7.38 \pm 0.98	Swimmers,
Schoene et al(1997)	10	23 \pm 2		3.5 \pm 0.8			Sprinters, 3 efforts, report highest
	12	24 \pm 4		3.8 \pm 0.5			800 – 1500 m runners
	8	31 \pm 5		4.8 \pm 1.3			Walkers
	5	24 \pm 1		3.5 \pm 0.6			Long jumpers
	6	24 \pm 4		4.3 \pm 0.3			High Jumpers
Cordain et al (1990)	11	19.0 \pm 0.6		4.77 \pm 0.15			Swimmers
	11	19.9 \pm 1.5		4.14 \pm 0.14			Runners. 3 efforts,report highest
Pringle et al (2005)	12	32.3 \pm 7.1	24 - 44	4.4			Runners.Seated nose clips
Men							
Loke et al (1982)	4	35.0 \pm 3.4		5.37 \pm 0.72	4.20 \pm 0.34		Runners
Robinson et al (1982)	8	44.0 \pm 7.8			3.88 \pm 0.26	12.18 \pm 0.32	Runners
Cordain et al (1987)	22		16-19	5.31 \pm 0.53			Caucasian runners
	27		20-29	5.50 \pm 0.52			Seated, nose clips
	25		30-39	5.36 \pm 0.42			
	19		40-49	5.46 \pm 0.46			
	8		50-59	4.68 \pm 0.71			
Hill et al (1991)	12	32.9 \pm 6.6		5.33 \pm SE 0.26	4.36 \pm 0.59		Triathletes, sitting
Fairburn et al. (1991)	5	22 \pm 2.7		5.5 \pm 0.9	4.4 \pm 0.3		Well trained cyclists
Schoene et al(1997)	27	24 \pm 3		5.0 \pm 0.9			Sprinters
	15	24 \pm 2		5.9 \pm 0.9			800 – 1500 m runners
	4	25 \pm 2		5.8 \pm 1.5			Walkers
	7	23 \pm 2		5.8 \pm 1.2			Long jumpers
	9	26 \pm 5		5.5 \pm 1.1			High Jumpers 3 efforts, report highest
Perret et al (1999)	12	28 \pm 7.0		5.58 \pm 0.84	4.55 \pm 0.76	9.9 \pm 2.1	4 women, 8 men cyclists
Perret et al (2000)	10	29 \pm 4			4.8 \pm 0.4	11.0 \pm 1.0	Cyclists
Romer et al (2002)	8	29.5 3.3		5.53 \pm 0.26	4.71 \pm 0.29	10.1 \pm 0.8	Competitive cyclists
Williams et al (2002)	7	20.9 \pm 1.2		5.4 \pm 1.5			2 women, 5 men, runners
Pringle et al (2005)	23	40.0 \pm 12.7	23 - 71	5.3			Runners. Same as for women

C. Respiratory muscle function

1. Anatomy and physiology of the respiratory muscles

The main function of the respiratory system is to provide oxygen to the arterial system for delivery to tissues and specifically locomotor muscles during exercise where diffusion occurs between muscle cells and the circulating blood. This increase in oxygen supply to skeletal muscles is achieved by increasing the cardiac output of the heart, whilst also taking in larger volumes of air through a process called pulmonary ventilation. The respiratory muscles are mainly responsible for the enlargement of the lungs, as well as creating a pressure gradient between the mouth and the intrapulmonary cavity for airflow into the lungs.

According to Powers and Criswell (1996), respiratory muscles are morphologically and functionally the same as locomotor muscles. The significance of various muscle fiber types is the differences between fibers in terms of oxidative capacity and maximal shortening velocity (Polla *et al.*, 2004). In humans, skeletal muscle fibers are divided into three categories namely type I, type IIa and type IIx. The highest oxidative capacity and slowest shortening velocity are found in type I fibers, while Type IIa, and Type IIx depend primarily on glycolytic metabolism and have fast shortening velocities (Dempsey *et al.*, 1996). Respiratory muscles consist of a combination of all the muscles fibers, yet, as in locomotor muscles, the fiber composition of respiratory muscles is an important determinant of their endurance and contractile properties (Koularis and Dimitroulis, 2001).

The primary task of the respiratory muscles is to displace the chest wall and move gas in and out of the lungs to maintain arterial blood gasses and pH homeostasis. By definition, any skeletal muscle that changes the dimensions of the chest wall is a respiratory muscle. This therefore may include muscles in the upper respiratory tract, as well as the waist. However, in humans, only a few respiratory muscles have been examined morphologically and functionally, especially during exercise (Dempsey *et al.*, 1996).

Respiratory muscles can be divided into inspiratory and expiratory muscles. The inspiratory muscles consist of the *Diaphragm*, *Parasternal Intercostals*, *Scalenes*, *External Intercostals* and the *Sternocleidomastoids*. The expiratory muscles include the abdominal muscles (*Rectus Abdominis*, *Internal and External Obliques* and *Transverse Abdominis*) and Internal Intercostals (Sheel, 2002).

During normal resting conditions, expiration is the result of relaxation of the *Diaphragm* and the other inspiratory muscles and the elastic recoil of the lungs and thorax. This elastic recoil decreases lung volume and creates a pressure inside the chest cavity that is higher than the atmospheric pressure. As the chest cavity decreases in volume, the intrathoracic pressure increases above that of the atmosphere. This moves the air out of the lungs into the atmosphere and is considered a passive process. Inspiration, on the other hand, is an active process and is achieved when the inspiratory muscles, primarily the diaphragm, are actively contracted. By contracting the *Diaphragm*, the muscle is pulled down and the ribs rotate upwards which increases the lung volume, while the intra-pulmonary pressure becomes sub atmospheric. This leads to air flowing into the lungs (Sheel, 2002).

During exercise, expiration is an active process. The abdominal muscles (*Rectus Abdominis*, *Internal and External Obliques* and *Transverse Abdominis*) push the diaphragm upwards and the internal intercostals pull the ribs inward and down. This increases the intrathoracic pressure quicker than could be achieved through passive elastic recoil alone and the air is therefore forced out of the lungs at a faster rate. Similarly, the process of inspiration during exercise is also an active process, whereby not only the diaphragm, but also the accessory muscles of inspiration contribute to the increase in the volume of the thorax (Plowman and Smith, 2003).

During quiet breathing most of the respiratory work, approximately 50 %, is performed by the *Diaphragm*. This explains why the majority of the muscle fibres of the diaphragm (55%) are slow-oxidative fibres (type I), while type IIa (21%) and Type IIx (24%) make up the rest of the composition. The *Internal* and *External Intercostal* muscles consist of about 60% slow fibers. In locomotor muscles, motor units are recruited according to the size principle and the same holds true for the respiratory muscles. For most ventilatory efforts, the fatigue-resistant type I fibers are recruited first. When higher levels of force production are needed, the less fatigue-resistant type IIa and IIx fibers are recruited

(Dempsey *et al.*, 1996). The fast fiber portion of the respiratory muscles are therefore primarily responsible for contraction during periods of high ventilation rates, such as during exercise.

Together with the compliance and elasticity of the lung tissue and thorax, the actions of the respiratory muscles determine the size of the lungs during breathing (i.e. the lung volumes), as well as the rate at which air can be moved in and out of the lungs. At rest, the *Diaphragm* is the primary force generator and the Intercostals are the secondary force generator. With increasing exercise intensities, and thus increasing ventilation rates, the diaphragm becomes the major flow producer through increasing its velocity of muscle fiber shortening. To expand the thorax volume, the Intercostals become the primary force producer, while the abdominal expiratory muscles become the major force producers during expiration.

At rest, breathing is primarily an inspiratory activity, while expiration is a passive process. Thus, the oxygen cost of breathing at rest is only about 2% of total body oxygen consumption. During moderate exercise, the oxygen cost of breathing increases to 3 to 5%, while during heavy intensity exercise, it may increase to 10% in the untrained person and 15% in highly fit subjects (Aaron *et al*, 1992; Sheel, 2002). The implication of this higher oxygen cost of breathing is that the respiratory muscles require a higher proportion of cardiac output with an increase in exercise intensity, thus leaving a smaller percentage of cardiac output available to the active locomotor muscles. This may therefore contribute to the onset of muscle fatigue, since the respiratory muscles and locomotor muscles compete for blood flow. Furthermore, the oxygen cost of breathing is linearly related to age, due to decreases in lung and chest wall compliance and an increase in airways resistance (Takishima *et al*, 1990). Therefore, with increasing age, the strength and endurance of the respiratory muscles thus become increasingly important factors in the oxygen cost of breathing, both during rest and exercise.

2. Significance of respiratory muscle function testing

The measurement of maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP) may be particularly useful to measure the respiratory muscle weakness that is associated with neuromuscular diseases or lung diseases such as chronic obstructive pulmonary diseases (COPD) and chronic heart diseases (Nishimura *et al.*, 1995). Patients with COPD usually have variations in their weight, which go along with variations in diaphragm muscle mass and thickness. Nishimura *et al.* (1995) compared a group of COPD patients which were divided into two groups. Group A's body weight was lower than 80% of their ideal body weight and Group B's body weight was 80% or more than their ideal body weight. These two groups' respiratory muscle strength were compared to a healthy age-matched control group (Group C). Both group A and B's percentage of MIP and MEP for predicted values were lower than the control group's (%MIP: A = $57.5 \pm \text{SD}17.4$, B = $95.6 \pm \text{SD}38.7$, C = $108.7 \pm \text{SD}18.9$ and %MEP: A = $57.9 \pm \text{SD}18.8$, B = $79.5 \pm \text{SD}24.6$, C = $82.0 \pm \text{SD}16.3$ cmH₂O). However, only group A's MIP and MEP values were statistically significantly lower than group C's ($P < 0.05$).

Abnormalities in respiratory function have also been shown in obese patients (Weiner *et al.*, 1998). It is known that pulmonary function abnormalities in obesity are reduced ERV and FRC, because obesity influences the interaction of the lungs, chest wall and the respiratory muscles. The respiratory muscles of obese individuals are inefficient and therefore maximum voluntary ventilation (MVV) also may be affected by reduced respiratory muscle strength. In the study by Weiner *et al.* (1998) the subjects underwent gastroplasty and after losing at least 20% of baseline BMI, there was an increase in FRC, TLC, RV and ERV. MIP values increased by 22.8% and MEP by 15.3%, with the highest increase in inspiratory muscle endurance namely 23.2%.

Respiratory muscle function (RM function), especially inspiratory muscle force is of great importance for swimmers. Hydrostatic compression around the chest, push the chest wall inwards when the inspiratory muscles are relaxed and therefore work against the inspiratory force and deforms the chest wall. Therefore, it can be assumed that the work done by the inspiratory muscles must increase to overcome these factors of the water (Lomax and McConnell, 2003). This example stresses the importance of respiratory muscle function for athletes.

It is known that exercise can lead to respiratory muscle fatigue (RM fatigue). Endurance exercise such as swimming, running and cycling can lead to RM fatigue (Loke *et al.* 1982; Chevrolet *et al.* 1992; Lomax and McConnell, 2003). Even athletes with above average strong respiratory muscle function might experience RM fatigue. Respiratory muscle training is one way of possibly minimizing RM fatigue. Therefore, it is important for athletes to monitor their respiratory muscle function. Even if RM training does not guarantee an increase in performance, an athlete with stronger respiratory muscle function will be able to “work” more at the same degree of fatigue.

Respiratory muscle function can also play a role in athletes participating in strength or power exercise such as weight lifting. The abdominal muscles are activated during strenuous activities that involve the trunk which lead to an increase in the pressure of the diaphragm and an increase in the muscle mass of the diaphragm. The benefit of increasing abdominal pressure during weight-bearing activities is that it lessens the axially directed compressive forces on the spine. McCool *et al.* (1997) conclude that weight- lifters had greater respiratory muscle pressures, thicker diaphragms compared to adults of similar stature who had not trained with weights.

3. Assessment of respiratory muscle function

Respiratory function is determined by the interaction of the lungs, chest wall and respiratory muscles (Weiner *et al.*, 1998). The respiratory muscles are responsible for the highly coordinated effort of breathing during exercise, which is needed for efficient gas exchange (Sheel, 2002). Accurate measurement and interpretation of indices of respiratory muscle function are essential in the diagnosis of respiratory muscle weakness, as well as in the monitoring of interventions such as inspiratory muscle training. Respiratory muscle strength (RM strength) and respiratory muscle endurance (RM endurance) are parameters of respiratory muscle function that can be determined non-invasively and with relative inexpensive equipment.

Maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP) are greatly dependent on ventilatory strength and are therefore widely accepted as indicators of RM strength. MIP and MEP are simple, non-invasive measurements, and constitutes the maximal pressures that can be generated at the mouth (Hart and Polkey, 2001).

Both pressures are measured while a person inhales and exhales with maximal effort through a tube attached to a pressure gauge. During the measurement, the nose is occluded and the lips are sealed around the tube.

Determining maximal respiratory pressures at the mouth may be influenced by different factors. Mayos *et al.* (1991) stated that the measurement procedures such as 1) the number of attempts, 2) type of mouthpiece used, 3) holding the subjects' cheeks with the hands, or 4) the pressure generated in the mouth could influence the recorded MIP. Other factors or procedural differences that can influence measurement reliability are 5) the lung volume at which maximal efforts are initiated from (e.g. RV or TLC), 6) the recovery time between efforts, 7) the number of trials performed, 8) the consistency of test directions, 9) subject posture, 10) equipment designs and 10) definition of outcome measure (peak versus mean pressure).

Two of the most important factors that varies a lot in the literature, is the number of efforts and the definition of the outcome measure. With spirometry it is known that three appropriately performed trials are sufficient for determining PEF, VC and FVC. In terms of RM function measurements, earlier studies used the best of only five or even fewer efforts. A study done by Wen *et al.* (1997) were done to determine whether performing more efforts would offer additional information. Twenty MIP efforts were performed and subjects were instructed to inhale to TLC and slowly exhale to RV, followed by a maximal inhalation.

MIP was defined as the highest pressure generated at the mouth and maintained for at least one second. MIP was calculated in two ways. The "short MIP" was defined as the average of the first three highest values with $\leq 5\%$ variability. The "long MIP" was defined as the average of the three highest values from all recorded efforts with $\leq 5\%$ variability. It was found that in both men and women, the long MIP yielded higher values than the short MIP. Therefore, the short MIP underestimated peak performance and performing the maneuver more times resulted in higher MIP values. The difference in the short and long MIP values could be because of a learning effect. When MIP was determined by the best of five efforts (Wagener *et al.*, 1984) and compared to the MIP determined by the best of 20 efforts, MIP was 5% less than the best of 20 efforts. Therefore, when performing MIP tests, 20 efforts and then using the average of the

three highest values with $\leq 5\%$ variability are a more accurate assessment of the true inspiratory muscle strength of an individual.

A mouthpiece without a leak measures the pressure created by suction in the mouth and can be as high as 120 to 160 cmH₂O. The function of a leak is to avoid the influence of pressure generated in the mouth, which could also increase the variability of the measurement. However, Mayos *et al.* (1991) concluded that the pressures measured with or without a leak did not vary that much in terms of the absolute magnitude of the measured pressures. One reason for this could be because the pressure generated at the mouth seems to be individually unpredictable and dependent on conditions such as the closure of the glottis.

In most research MIP was measured at RV and MEP at TLC (Cordain *et al.*, 1987; Fuso *et al.*, 1996; Fiz *et al.*, 1998). The reason for this is to standardize the initial length of the inspiratory muscles before initiating each effort. In order to perform and obtain the highest MIP value, the subject must have exhaled all the air in his or her lungs (RV). According to Volianitis *et al.* (2001) RV is more reproducible than FRC. In the case of MEP, a full inspiration (TLC) is needed to perform a maximum expiration.

There is no consensus on the body position of the subject while performing the MIP and MEP measurements. Some research used the standing position (Romer and McConnell, 2003) and other used a sitting position method (Mayos *et al.*, 1991). A direct comparison of different body positions have not been done yet.

In 1994, Hamnegard and colleagues compared the accuracy and reliability of a commercially available hand-held device (Precision Medical, UK) with a "laboratory standard", which consisted of a Validyne MP45-1 differential pressure transducer in 13 healthy subjects (age: 24 – 44 years) and 11 patients with respiratory disease (age: 19 – 77 years). They found excellent agreement between the mouth pressure meter and the laboratory standard, with mean differences of 0.12 ± 0.20 kPa for MIP and -0.14 ± 0.18 kPa for MEP. Hamnegard *et al.* (1994) thus showed that the portable measurement of respiratory muscle strength is both accurate and reliable

Although both MIP and MEP are considered effort-dependent maneuvers, it appears that the test-retest reliability of both measures is within acceptable limits. McConnell and

Copstake (1999) reported no significant differences between the first and second measurements in 39 elderly (mean age of 70) Caucasian volunteers (MIP men: $94.3 \pm \text{SD } 25.9 \text{ cmH}_2\text{O}$ vs $96.9 \pm \text{SD } 26.3 \text{ cmH}_2\text{O}$; MIP women: $73.0 \pm \text{SD } 28.3 \text{ cmH}_2\text{O}$ vs $76.3 \pm \text{SD } 27.2 \text{ cmH}_2\text{O}$; MEP men: $122.8 \pm \text{SD } 28.4 \text{ cmH}_2\text{O}$ vs $123.3 \pm \text{SD } 27.1 \text{ cmH}_2\text{O}$; MEP women $81.7 \pm \text{SD } 30.7 \text{ cmH}_2\text{O}$ vs $81.0 \pm \text{SD } 29.9 \text{ cmH}_2\text{O}$; $p > 0.05$). They reported that the coefficients of reproducibility for MIP and MEP were acceptable (between 10.2 and 12.8% for MEP and MIP, respectively), with 95% of the subjects generating retest pressures within 11% of the initial reading. Larson *et al* (1993) found similar results in an elderly group of patients with chronic obstructive disease. They reported a test-retest repeatability of 19% for MIP. It seems that the repeatability of respiratory muscle function measures is better in healthy, younger subjects. Aldich and Spiro (1995) reported a coefficient of variation of 8.7% in MIP measurements taken on nine occasions, while Black and Hyatt (1969) reported a coefficient of variation of 9% for both men and women and for both MIP and MEP.

From the above studies it can be concluded that respiratory muscle function can be assessed accurately and reliably, but that test-retest reliability may be larger compared to the measurements of lung volumes and airflow.

The other parameter of RM function, RM endurance, is generally defined as the ability to sustain a level of minute ventilation for a specified time period (Hart & Polkey, 2001). RM endurance may be measured by using either resistive or threshold inspiratory loads and expressed either as the time a particular load is tolerated or as the maximum load tolerated for a specific time (Fairburn *et al.*, 1991; Fiz *et al.*, 1998).

RM endurance can also be determined by maximal ventilatory ventilation (MVV) (as described on p10). According to Romer & McConnell (2003), MVV is a repeatable maneuver. They found no significant differences in MVV ($187 \pm \text{SD } 28$ vs $188 \pm \text{SD } 27 \text{ L}\cdot\text{min}^{-1}$, $p > 0.05$) between baseline and repeated measurements 46 healthy, physically active male subjects.

4. Respiratory muscle function in athletes and non-athletes

Although the equipment to measure respiratory muscle function is accurate and reliable and that the actual measurement is simple and non-invasive, it is clear from the literature that there is wide intra-individual and inter-individual variability in the measurement of MIP and MEP (Fuso *et al*, 1996). This may be attributed to a wide variation of populations studied, as well as differences in methods and techniques of measurement.

In the study done by Fiz *et al*. (1998) a wide age range of non-athletes were used to determine respiratory muscle endurance with an endurance breathing test. The coefficient of variance (CV) for time to exhaustion at a specific threshold (T_{lim}) (ranged between 21 and 33 % (men) and between 5 to 41% for women (Table 3). The variation in MIP values ranged from 2 to 41% in men and women and MEP from 15 to 38% (Table 4). The CV for athletes seemed to be smaller (Table 5). The variation in MIP ranged from 3 to 23% and for MEP from 17 to 26%.

Table 3: RM endurance reference values for non-athlete population. Values are reported as mean \pm SD

Source	n	Age(yrs)		RME		Comment
		Mean \pm SD	range	$T_{lim}(sec)$	MVV(L)	
	MEN					
Fiz et al (1998)	10	22.8 \pm 1.9	20-29	701.2 \pm 228.2		Healthy volunteers, with sedentary lifestyles
	10	35.0 \pm 3.6	30-39	565.8 \pm 185.9		
	10	45.0 \pm 3.3	40-49	470.6 \pm 104.5		
	10	55.5 \pm 3.5	50-59	344.0 \pm 71.5		
	10	67.3 \pm 3.0	60-70	316.6 \pm 79.2		
Leith and Bradley (1976)	4	31.0 \pm 5.8	26 - 36		199.25	MVV 15 sec, average of 3 highest values
	WOMEN					
Fiz et al (1998)	10	22.0 \pm 1.2	20-29	650.0 \pm 267.3		Same as for men in the study by Fiz et al. (1998)
	11	32.4 \pm 3.6	30-39	412.2 \pm 196.2		
	9	42.1 \pm 2.6	40-49	386.2 \pm 146.5		
	9	52.9 \pm 3.2	50-59	374.3 \pm 121.3		
	10	65.2 \pm 4.0	60-70	297.3 \pm 56.5		

Table 4: RM strength reference values (MIP and MEP) for non-athletes. Values are expressed as means \pm SD.

Source	n	Age		MIP	MEP	Comment
		mean	range	Mean (SD) (cmH ₂ O)		
MEN						
Ringqvist (1966)	100		18-83	130 \pm 32	237 \pm 46	
Black and Hyatt (1969)	60		20-54	124 \pm 44	233 \pm 84	Healthy subjects. Leak was used. MIP measured at RV; MEP measured at TLC Pressures maintained at least 1s, 2 efforts, report highest
Leech et al (1983)	46		<17	111 \pm 34	131 \pm 30	Healthy Caucasian subjects,. Leak was used. MIP at RV; MEP at TLC 3 efforts, report average
	77		17-20	115 \pm 38	133 \pm 41	
	54		21-25	121 \pm 32	163 \pm 37	
	90		26-30	112 \pm 42	157 \pm 41	
	108		31-35	111 \pm 34	161 \pm 42	
Smyth et al (1984)	29		13-18	107 \pm 26	114 35	Caucasian adults MIP at RV; MEP at TLC Pressures maintained for 2 -3s, 2 efforts, using highest value.
Wilson et al (1984)	48	34.7 \pm 14		106 \pm 31	148 \pm 34	British Caucasian adults and children, MIP - RV; MEP - TLC, leak was used Pressures maintained at least 1s, at least 3 efforts, 2 identical readings
	137	11.1 \pm 2.2		75 \pm 23	96 \pm 23	
Bruschi et al (1992)	266		18-70	119.84 \pm 36.51	139.83 \pm 30.16	Healthy subjects. MIP - RV; MEP - TLC. Leak was used, 5 efforts, using highest values
Fiz et al (1998)	10	22.8 \pm 1.9	20-29	135.0 \pm 3.0	208.9 \pm 47.5	Volunteers with sedentary lifestyles Leak was used Pressures maintained for longer than 1s MIP at RV; MEP at TLC
	10	35.0 \pm 3.6	30-39	124.1 \pm 35.1	188.0 \pm 50.1	
	10	45.0 \pm 3.3	40-49	99.1 \pm 14.4	171.2 \pm 58.3	
	10	55.5 \pm 3.5	50-59	93.3 \pm 6.6	147.1 \pm 38.9	
	10	67.3 \pm 3.0	60-70	74.3 \pm 22.7	133.7 \pm 42.2	
WOMEN						
Ringqvist (1966)	100		18-83	98 \pm 25	165 \pm 30	
Black and Hyatt (1969)	60		20-54	87 \pm 32	152 \pm 54	Normal subjects. Leak was used. MIP at RV; MEP at TLC Pressures maintained at least 1s, 2 technically satisfactory, using higher value
Leech et al (1983)	68		<15	85 \pm 28	95 \pm 29	Healthy Caucasian subjects,. Leak was used. MIP at RV; MEP at TLC 3 efforts were performed
	145		15-20	80 \pm 27	95 \pm 33	
	138		21-25	70 \pm 27	95 \pm 32	
	130		26-30	65 \pm 25	93 \pm 35	
	75		31-35	66 \pm 29	92 \pm 31	
Smyth et al (1984)	37		13-18	76 \pm 25	86 \pm 22	Caucasian adults MIP was measured at RV; MEP was measured at TLC Pressures maintained for 2 -3s, 2 efforts, using highest value.
Wilson et al (1984)	87	36.8 \pm 13		73 \pm 22	93 \pm 17	British Caucasian adults and children, MIP at RV; MEP at TLC, leak was used Pressures maintained at least 1s, at least 3 efforts, 2 identical readings
	98	11.6 \pm 2.5		63 \pm 21	80 \pm 23	
Bruschi et al (1992)	359		18-70	83.71 \pm 30.11	95.26 \pm 20.08	Normal subjects. MIP at RV; MEP at TLC. Leak was used, 5 efforts, highest values
Fiz et al (1998)	10	22.0 \pm 1.2	20-29	89.8 \pm 26.1	120.8 \pm 34.0	Volunteers with sedentary lifestyles, Leak was used Pressures maintained for longer than 1s MIP at RV; MEP at TLC
	11	32.4 \pm 3.6	30-39	82.2 \pm 22.6	138.0 \pm 40.5	
	9	42.1 \pm 2.6	40-49	91.0 \pm 19.6	133.9 \pm 35.5	
	9	52.9 \pm 3.2	50-59	81.9 \pm 20.8	109.1 \pm 16.8	
	10	65.2 \pm 4.0	60-70	66.1 \pm 14.8	96.3 \pm 21.8	

Table 5: RM strength and RM endurance reference values for athletes. Values are reported as mean \pm SD.

Source	n	Age		MIP	MEP	Comment
		mean	range	Mean (SD) (cmH ₂ O)		
Men						
Cordain et al (1987)	22		16-19	142 \pm 26	207 \pm 43	Caucasian runners MIP was measured at RV and MEP at TLC Pressures measured until no increases, using highest values
	27		20-29	140 \pm 30	204 \pm 34	
	25		30-39	122 \pm 22	202 \pm 46	
	19		40-49	117 \pm 25	204 \pm 38	
	8		50-59	111 \pm 25	178 \pm 46	
Fuso et al (1996)	27	23 \pm 3		113.80 \pm 3.1		professional soccer players MIP was measured at RV Leak was used Eight efforts
McConnell et al (1997)	24	23	18-29	171.5 \pm 28.3(peak) 157.8 \pm 28.8(avg)		moderately trained not more than 3 efforts, using 2 values that were within 5% of one another
Women						
Source	n	Age		RME		Comment
		mean	range	T _{lim}	MVV ₁₂ (L.min)	
Women						
Robinson and Kjeldgaard (1982)	8	34.0 \pm 10.9			122.0 \pm 114.0	Runners, standing MVV, report highest
Clanton et al (1987)	16	19 \pm 1	17 - 21		154 \pm 17	Swimmers
Pringle et al (2005)	12	32.3 \pm 7.1	24 - 44		138.5	Runners
Men						
Robinson et al (1982)	23	44.0 \pm 7.8			141.0 \pm 10.8	Runners, same as for women
Fairbarn et al (1991)	5				206 \pm 15	well trained cyclists
Hill et al (1991)	12	32.9 \pm SE 1.9			183 \pm SE 7.0	Triathletes
Perret et al (1999)	12	28 \pm 7.0			188 \pm 3.1	4 women and 8 men cyclists, MVV 15sec
Perret et al (2000)	10	29 \pm 4			194 \pm 21	Cyclists ,MVV 20sec
Williams et al (2002)	7	20.9 \pm 1.2			189.0 \pm 52.4	5 men and 2 women runners
Romer et al (2002)	8	29.5 \pm 3.3			195.4 \pm 16.3	8 competitive cyclists, MVV 15sec
Pringle et al (2005)	23	40.0 \pm 12.7	23 - 71		175.1	Runners

From the above tables it is evident that there is not only a difference between men and women, but also between athletes and non-athletes in terms of respiratory muscle function. Athletes tend to have stronger RM strength and better endurance RM compared to the non-athletes.

Not all sports are performed at the same intensity or duration and have different effects on the physiological systems and their mechanisms. This could be the reason why there is also a difference in the various RM functions between the various sports. It is also evident that little research is done on the RM functions of athletes competing in team sports and on women. One of the few studies was done by Fuso *et al.* (1996), who also hypothesized that different sports may have different

effects on the respiratory muscles. In this study the elite soccer players had significantly higher inspiratory pressures compared to sedentary subjects.

CHAPTER 3

DETERMINANTS OF PULMONARY FUNCTION

A. Introduction

Anthropometry is used to describe the physique and body composition of various populations. It is known that anthropometry plays an important role in the performance of athletes (Claessens *et al.*, 1999). Not only does it have an influence on performance but it is also used to predict percentage body fat (%BF), lung function and respiratory muscle functions.

1. Anthropometry as a determinant of athletic performance

Superior athletic performance is a function of the complex interaction of various physiological, psychological and biomechanical factors. Most system models that are used to analyze sport performance include these factors, as well as anthropometric dimensions and body composition.

A number of studies have reported on the differences in morphological characteristics among athletes in different sports, or events within sports (Claessens *et al.*, 1999). Distinct differences have also been reported between athletes at various levels of performance (international and recreational) and athletes in different playing positions in team sports. Most anthropometric measurements, such as height, are highly heritable. Athletes who compete at international level generally display distinctive body size, shape and composition characteristics compared with the normal population. Therefore, the potential to become, for instance, an elite high jumper, is under a degree of genetic control. However, this does not mean that all tall individuals will be successful high jumpers. It merely means that tall individuals have a greater chance of success in a sport such as high jump (Pitsiladis, 2005).

It is well accepted that there is a relationship between competitive sport performance and physical traits or anthropometry (Slater *et al.*, 2005). Different sports command different anthropometry. Sports requiring abilities like running and jumping demand relatively low body fat, whereas strength and power activities are enhanced by larger muscle mass (Heyward and Wagner, 2004)

It is thus tempting to assume that a specific athletic ability and physique is inborn and that this may be a prerequisite for athletic success in a particular sport. For instance, the importance of a “gymnastic-specific” body build (i.e. short stature, light body mass, narrow hips, broad shoulders, etc) for achieving top level performance in artistic gymnastics is well documented (Claessens *et al.*, 1991; Claessens *et al.*,1992). Claessens *et al.* (1999) found that 32 – 46% of the variance in gymnastics competition scores is explained by anthropometric characteristics, somatotype and chronological age. Although it is widely accepted that certain somatotypes are advantageous or even prerequisites for athletic success, the ideal physique is by no means the sole, or even most important, predictor of athletic performance.

As a result of the significant impact that anthropometric characteristics and body composition have in attaining success in sport, these measurements are routinely included in talent identification programs for various sports. It further helps coaches to understand the important aspects for success in competition, and it is used to gather normative data of athletes in various sports codes. Coaches and sport scientists use these data to construct profiles of the athletes, which may then be used to guide the selection process and provide information for designing the training program.

Sometimes anthropometric dimensions and body composition are used to establish possible predictors of athletic performance. Most of these studies regarding the relationship between anthropometry and performance were done on endurance sport athletes. Tittel and Wutscherk (1992) defined endurance as “the ability to maintain an actual, quantified, muscular performance for a period characteristic of the event concerned.” Endurance thus depends on the intensity and duration of the exerted force. Therefore, to find the anthropometric characteristics associated with endurance performance, one should investigate the parameters that correlate with muscle strength.

To this end, it has been found that body masses (i.e. total body mass, muscle mass, bone mass and fat mass) correlate strongly with the total strength of the skeletal musculature. Therefore, since the latter correlates with endurance performance, it follows that body masses are important determinants of endurance performance. This relationship has been confirmed by the study of Wyndham *et al.* (1971) who reported linear relationships between VO_{2max} and body mass (BD) ($r = 0.76 - 0.96$; $p = 0.01$). Wyndham concluded that depending on somatotype, body masses (total body mass, lean body mass and muscle mass) show the closest correlation with VO_{2max} , although body surface area and somatotype were also found to be discriminating factors.

Other important factors that influence endurance performance include the body proportions, such as standing height, leg and arm length. Amongst endurance athletes it has been shown that track event athletes are taller, because leg length is longer. A tall athlete has a greater leverage of the muscles which contribute to the amplitude of movement. Swimmers need propulsive leverage and therefore the length of the arm and leg plays an important role. In rowers and canoeists all of the above, as well as sitting height, are considered important determinants of athletic success. Endurance athletes usually also have a medium body build, with a somatotype between mesomorph and ectomorph (Heath and Carter, 1967). Strength endurance athletes are usually mesomorphic.

Anthropometric characteristics and body composition have been correlated with various physiological parameters, most notably, those that are considered predictors of athletic performance. Although most studies report on the relationship with cardiovascular and metabolic performance parameters, only a few studies have been done on the determinants of respiratory muscle function.

2. Determinants of lung function

In general, lung volumes are correlated with body size. Thus, larger lung volumes are found in taller people and in men. The four main factors that influence lung volumes and airflow are gender, age, standing height and body mass (Lazarus *et al.*, 1998; Leech *et*

al., 1983). These four variables are typically incorporated in prediction equations for various lung function parameters.

It is known that skeletal muscles are affected by aging. The force production ability of skeletal muscles decreases between 20 to 40% with increasing age. This is accompanied by a decrease in the size and muscle mass of the fibers. These changes occur because of muscle disuse related to the general reduction in physical activity. However, because the respiratory muscles are chronically active, even in the elderly, respiratory muscles might be differently affected by age than locomotor muscles. It is known that diaphragm strength is reduced with age (Polla *et al.*, 2004) and this will have profound effects on the lung volumes of the elderly. Furthermore, with increasing age, the resilience of the lungs and vital capacity is lowered because the elastic lung tissue deteriorates. Arthritic changes and decreased flexibility can also lead to movement restrictions in the chest cage. These restrictions can therefore limit pulmonary ventilation, which will be specifically evident during exercise.

Pulmonary function prediction equations are generally based on age and height regressions, as most authors found little or no association between body mass and ventilatory function (Ferris *et al.*, 1965; Knudson *et al.*, 1976). In a classic study of Hutchinson in 1846, the author described how vital capacity increased steadily with increasing body mass up to a certain point. However, vital capacity then decreased significantly in overweight individuals. However, most authors have not distinguished between fat and FFM and therefore the influence of body composition on pulmonary function may have been underestimated. When total body mass is divided into its two components, namely FFM and fat mass, Lazarus *et al.* (1998) found that percentage body fat (%BF) is negatively correlated to FVC, while FFM is positively correlated to FVC in 1235 subjects (men and women). Lazarus *et al.* (1998) thus found that the effect of body fat on ventilatory function is not only limited to morbid obese individuals, as previously thought (Ray *et al.*, 1983; Burki and Baker, 1984). It was speculated that extra fat mass, particularly in the trunk area, may cause a mechanical restriction on ventilatory function. The findings of Lazarus *et al.* (1998) suggest that prediction equations for ventilatory function could be improved by the inclusion of %BF and fat FFM in regression equations.

It has also been shown that low but statistically significant correlations ($r = 0.2 - 0.4$) exist between handgrip strength and FVC, and these associations were independent of age and sex (Kannel *et al.*, 1983). If one then considers that FFM partly accounts for muscle tissue mass, the association between FFM and FVC is at least partially explained by the former association.

Other factors that influence lung functions are height, gender, smoking and training. Trained athletes have better lung functions (Tables 1 and 2, page 10 and 11), but whether better lung functions are the consequence of athletic training, is still controversial. In commercial male divers (mean age = 29.5 ± 5.4 years) Crosbie *et al.* (1979) concluded that diving seems to be related to an increase in FVC in men under 30 years, but FVC decreased in men over 30 years. The relationship between diving experience (years) and ventilatory functions were also studied. Divers with five to 10 years diving experience had significantly larger FVC values than those divers with less than one and between one and five years experience. However, the effects of age must also be considered.

The study done by Eastwood *et al.* (2001) also demonstrated that trained marathon runners had significantly higher lung functions such as TLC, FVC and FEV_1 compared to sedentary subjects (athletes: TLC = 7.8 ± 0.6 L; FVC = 5.8 ± 0.6 L; $FEV_1 = 4.7 \pm 0.4$ L.sec⁻¹; non – athletes: TLC = 7.1 ± 0.7 L; FVC = 5.4 ± 0.6 L; $FEV_1 = 4.4 \pm 0.4$ L.sec⁻¹). These findings suggest that a long – term background of endurance training may lead to lung function adaptations.

In a study by Leech *et al.* (1983) 369 men between the ages of 15 to 35 years and 555 women between the ages of 13 to 35 years were studied to establish the determinants of respiratory functions in young healthy adults. For men and women, the major determinant for FVC and FEV_1 was height ($r = 0.45 - 0.46$ and $0.41 - 0.43$ respectively). The effect of current smoking and ex-smoking status had a negative effect on FVC and FEV_1 , but was not significant.

3. Determinants of respiratory muscle strength in the general population

The relationship between physical characteristics and respiratory muscle strength has been the focus of a few studies. The regression equations that resulted from these descriptive studies usually incorporate age, height and/or body mass as independent variables, similarly to the prediction equations for lung functions. Harik-Khan *et al.* (1998) pointed out that from all the studies, there is only agreement on the fact that gender is a significant determinant of MIP. Other factors, such as age, height, body mass, physical activity level and smoking history have been investigated, but conflicting results have been published.

3.1 Gender

In all previous studies it has been shown that there are significant differences in the respiratory muscle function of men and women (Wilson *et al.*, 1984; Bruschi *et al.*, 1992). Black and Hyatt (1969) suggested that the values for women are usually between 65 – 70% of those obtained in men. This was confirmed by Harik-Khan *et al.* (1998) when they reported that MIP values were on average 30% higher in men than in women across all age groups (20 – 90 years).

3.2 Age

Most studies have found a strong negative correlation between age and MIP for both men and women (McConnell and Copestake, 1999; Harik-Khan *et al.*, 1998; Ringquist, 1966; Vincken *et al.*, 1987). Although the study subjects of Enright *et al.* (1994) were elderly (> 65 years), they also reported a significant effect of age on respiratory muscle strength. These age-related changes in RM function are probably explained by the changes in muscle mass with age. There is a decrease in muscle mass and therefore a decrease in strength of the muscles. However, it seems that the decrease in muscle mass and strength in women may not be strongly age-related.

The exception to these results are the study of Bruschi *et al.* (1992) who reported that age in subjects over 55 years did not significantly affect MIP. Some studies (Wilson *et al.*, 1984; Berry *et al.*, 1996) have only noted significant effects of age on MIP in older men, while Black and Hyatt (1969) only found the correlation in older women. Black and Hyatt (1969) found no significant relationship between MIP and MEP, and age in subjects younger than 55 years, while MEP decreased with age in both men and women in subjects older than 55 years.

Since age-related declines in pulmonary function only manifest itself during the middle thirties, it is understandable why there is no relationship between age and MIP in young adults (Leech *et al.*, 1983). It is known that increasing age leads to changes in respiratory muscle properties. For instance, there is a reduction in the type IIx muscle fibres of the intercostals and diaphragm, which leads to a decrease in isometric and dynamic muscle force. Therefore, older subjects are predispositioned to develop inspiratory muscle fatigue, especially during exercise.

3.3 Height

It is unclear whether standing height is a significant predictor of RM strength. Some report positive correlations in women only (Ringquist *et al.*, 1966; Leech *et al.*, 1983; Wilson *et al.*, 1984; Harik-Khan *et al.*, 1988), while others report no to poor correlations between stature and RM strength (McConnell & Copestake 1999; Black & Hyatt, 1969). Enright *et al.* (1994) reported a significant effect of height on RM strength in a very large sample of healthy, elderly subjects, however, it must be noted that the coefficient of determination was only about 0.2%.

3.4 Body mass, Body mass index and Body surface area

Both Harik-Khan *et al.* (1989) and Leech *et al.* (1983) reported that body mass (BM) is a statistically significant positive predictor of MIP in healthy men and women ($r = 0.26 - 0.37$). They explained that this effect can probably be attributed to two factors. Firstly, it may be related to the relationship between BM and the isometric length of different muscle groups (Tornvall, 1963) and secondly, that changes in BM is associated with

changes in diaphragm muscle mass (Arora and Rochester, 1982). However, McConell and Copestake (1999) only noted significant positive correlations between BM, body mass index (BMI) and body surface area (BSA) in healthy elderly women (63-81 yrs), while these three variables correlated negatively with MIP in healthy elderly men (59-84 yrs). They found similar findings for MEP.

Most authors agree that body mass alone is not a good predictor of respiratory muscle function. In fact, only Enright *et al.* (1994) and Harik-Khan *et al.* (1989) have included body mass as a co-variant in their prediction equations, together with age.

3.5 Other predictors

A few studies have investigated the effect of other factors on RM strength, such as handgrip strength, smoking history and physical activity level. Enright *et al.* (1994) found a positive relationship between handgrip strength and MIP in an elderly population. McConnell and Copestake (1999) found strong positive correlations between physical activity (expressed as kcal/day) and MIP and MEP ($r = 0.87$ and 0.67 , respectively) in a small sample ($n = 10$) of healthy individuals. They suggested that this relationship may be explained by the fact that respiratory muscles respond to training in the same way as other skeletal muscles, and thus more physically active individuals should also have stronger respiratory muscles and therefore higher MIP and MEP values.

In a study to determine the relationship between respiratory muscle function and other factors, Chen and Kuo (1989) reported a positive correlation between physical activity in men and inspiratory muscle endurance ($n = 80$; $r = 0.2862$; $P < 0.01$) and that physically active men had greater inspiratory muscle endurance (expressed as inspiratory pressure-time index = $38.3 \pm SE 3.5s$) than sedentary subjects ($14.6 \pm SE 1.8s$).

Several investigators found no effect of smoking on respiratory muscle strength (Vincken, Bruschi *et al.*, 1992; Harik-Khan *et al.*, 1999), however, Enright *et al.* (1994) reported the opposite. Further studies, where the effects of age and physical activities are compensated for, are necessary to establish whether smoking has detrimental effects on RM function.

4. Determinants of respiratory muscle endurance in the general population

Factors that seem to predict respiratory muscle endurance are age and height. According to Fiz *et al.* (1998), T_{lim} (the time to exhaustion at a specific threshold) correlated with height ($r = 0.42$; $P < 0.0001$) and age ($r = -0.59$; $P < 0.0001$) in 99 healthy subjects, while body mass had no effect on respiratory muscle endurance.

In a study by Chen and Kuo (1989) inspiratory muscle endurance also tend to correlate with age. Eighty men and women volunteers were divided into four groups of different age groups. Inspiratory muscle endurance was expressed as a inspiratory pressure-time index. The youngest group of women (mean age = 23) had an endurance time of $41 \pm SE 4.02s$ compared to the oldest group (mean age = 65.9) of women ($14 \pm SE 2.17s$). This observation was also evident for the men. The youngest group of men (mean age = 24.2) had an endurance time of $33 \pm SE 4.597s$ compared to the oldest group (mean age = 66.9 ± 1.0) of men ($17 \pm SE 3.65s$). It was concluded that inspiratory muscle endurance decreased as age increased. There were no sexual differences in inspiratory muscle endurance.

It is evident that most anthropometric variables have a correlation with maximal respiratory pressures. All the studies above included healthy, but sedentary or untrained subjects. Very few studies have been done on the respiratory muscle function and its relationship with anthropometric parameters in trained individuals. From the literature it is apparent that athletes have significantly different anthropometric characteristics and body composition compared to healthy individuals. Furthermore, distinct differences exist in the morphological characteristics of athletes in specific sports. Therefore, the question arises whether there are perhaps clearer relationships between the anthropometry and respiratory muscle function of trained individuals.

5. Determinants of respiratory muscle function in the athletic population

McConnell *et al.* (1997) found no correlation between height, body mass, BMI and MIP for 24 moderately trained men (mean age = 23). Thus, those subjects with the highest MIP values were not necessarily the tallest and the heaviest and one can therefore conclude that inspiratory muscle strength is not a function of body size. The average MIP was $171.5 \pm \text{SD } 28.3 \text{ cmH}_2\text{O}$.

Fuso *et al.* (1996) investigated the respiratory muscle strength of elite soccer players. One hundred and thirty subjects, consisting of 27 elite men soccer players (age = 22 ± 3 years) and 103 healthy untrained subjects (women = 26; men = 77; age = 44 ± 19 years) participated in the study. Their MIP values were assessed through a maximal inspiratory effort against a closed valve at the end of the expiratory phase during a tidal volume breathing (MIPFRC), as well as after a maximal expiration (MIPRV).

The soccer players recorded, on average, 1.54 kPa higher MIPFRC values and 1.08 kPa higher MIPRV values than the sedentary group. The difference was only significant for MIPFRC ($p < 0.02$). In both cases (MIPFRC and MIPRV), inspiratory muscle strength was negatively correlated with age ($r = -0.473$; $r = -0.487$) and female gender ($r = -0.355$; $r = 0.324$). MIPFRC and MIPRV correlated positively with height ($r = 0.449$; $r = 0.514$) and body mass ($r = 0.359$; $r = 0.331$). Although most of these correlations are statistically significant, none are particularly high. Therefore, the true predictive value of these anthropometric parameters for respiratory muscle strength is not very strong.

From the above mentioned studies one can conclude that there are only a few published studies on healthy sedentary subjects and even less on the athlete population. A wide range of reference values were obtained from these studies. If we want to include respiratory muscle function in test batteries for athletes, we need reference values, and we need to know whether there are differences between different types of sport (endurance versus power versus strength versus land versus water).

Furthermore, it has been shown in a number of studies (Loke *et al.*, 1982; Chevolet *et al.*, 1992 and Ozkaplan *et al.*, 2005) that respiratory muscle fatigue may develop during

certain types of exercise at certain intensities even in well-trained athletes. It also has been shown (Inbar *et al.* 2000; Williams *et al.* 2002; Volianitis *et al.* 2001) that respiratory muscle function may be improved through RM training. For this reason, as well as the fact that athletes are always looking at ways to legitimately improve their sport performance, it becomes important to study respiratory muscle function in trained athletes in more detail. Another reason is, to gain an understanding of differences between various sport populations, the determinants of respiratory muscle function as well as the degree of respiratory muscle fatigue in athletes, other than endurance type athletes.

CHAPTER 4

RESPIRATORY MUSCLE FUNCTION AND ATHLETIC PERFORMANCE

A. Introduction

Normal respiratory muscle function is essential for health, as respiratory muscle failure due to fatigue, injury or disease will result in a disturbance of blood gas and pH homeostasis which could have lethal consequences. It is not yet known how important respiratory muscle performance is for athletes. This is mainly due to the fact that there is no agreement on whether respiratory muscle performance limit exercise tolerance in normal healthy individuals (Nava *et al.*, 1992), although it has been shown that strenuous endurance type exercise impair respiratory muscle performance in humans (Johnson *et al.*, 1993). The latter findings have initiated several investigations into the adaptability of respiratory muscles to exercise, as well as the effect of respiratory muscle training on the exercise performance of high level athletes.

B. Adaptations to the respiratory muscles with whole-body exercise training

It is known that endurance training and resistance training lead to different skeletal muscle adaptations. Endurance training does not increase muscle size and force, but rather enhances the activity of the oxidative enzymes, because of an increase in the number of mitochondria and mitochondrial metabolic enzymes. Resistance training, on the other hand, causes a significant increase in muscle size that is primarily the result of an increase in cross sectional area. The increase in muscle size can be either the result of hypertrophy (increase in myofibril size) or hyperplasia (increase in myofibril number (Ball and Herrington, 1998).

According to Powers and Criswell (1996) it seems that the respiratory muscles may adapt differently to endurance exercise compared to locomotor muscles. It has been reported that the training-induced increase in diaphragm oxidative enzyme activity and resting glycogen levels are between 20 and 30% after 8 – 10 weeks of treadmill

exercise training. Locomotor muscles, with the same fiber composition to that of the diaphragm, generally show a 40 – 80 % increase in oxidative enzyme activity in the same time period. Similar to limb locomotor muscles, there is also a significant decrease in type IIb and an increase in type I myosin heavy chains in trained diaphragms (Sheel, 2002). It is assumed that these adaptations cause a functional improvement in the endurance capacity of the respiratory muscles.

It is generally believed that weight-bearing exercise training does not stress the respiratory system enough to change and adapt. This is based on the observation that pulmonary ventilation and gas exchange remain adequate during heavy exercise in most healthy populations. This could be one reason why there are so few respiratory adaptations to exercise training (Plowman & Smith, 2003).

De Palo *et al.* (2004) studied the effect of respiratory muscle strength training with non-respiratory maneuvers on RM function. The experimental group (n = 4) underwent 16 weeks of training (four days per week), which consisted of a sit-up and biceps curl training program. After the 16 weeks of training, MIP increased by 29.4% ($p < 0.002$) and MEP increased by 34.4% ($p < 0.002$). Biceps circumference increased significantly from 35.4 ± 1.3 to 36.4 ± 1.7 cm ($p < 0.02$). Transdiaphragmatic pressure (P_{dimax}) was increased by 30% ($p < 0.02$) and diaphragm thickness (t_{di}) by 26% ($p < 0.01$). These improvements are similar in magnitude to the increase in strength and degree of hypertrophy induced by regular training of the lower body but could also be due to the Valsalva maneuver. These findings is in agreement with those of Polla *et al.* (2005), who stated that the respiratory muscles are not only highly specialized for their functional tasks but are also able to modify their properties to adapt to new requirements which may be a result of physical exercise or from lung or respiratory diseases.

C. Respiratory muscle function in athletes and non-athletes

Since high level aerobic training results in prolonged periods of hyperpnea, it is reasonable to suspect that the respiratory muscles of well-trained endurance athletes may develop increased strength and/or endurance capacity, similar to the adaptations that take place in the locomotor muscles. However, the literature doesn't support this assumption.

Many studies show that the respiratory muscle strength of trained athletes, i.e. skiers (Coast *et al.*, 1990), swimmers and runners (Cordain *et al.*, 1990; Armour *et al.*, 1993; Eastwood *et al.*, 2001) are not enhanced through whole-body endurance training. McConnel *et al.* (1997) studied the relationship between RM strength (MIP) and aerobic fitness (multi – stage shuttle run) in 24 moderately trained men (mean age = 23). No correlation was observed between aerobic fitness and RM strength. It was suggested that either aerobic training does not influence inspiratory muscle strength, or that fitness status may not reflect respiratory utilization in a predictable way. It was further suggested that the high ventilation rates that is typically found during marathon running may not be of sufficient intensity to induce the central and peripheral adaptations that are typically seen in locomotor muscles. Perhaps only elite endurance athletes actually reach the mechanical limits of the respiratory system. The results so far can thus perhaps be explained by the fact that most studies are done on sub-elite athletes, or even untrained individuals.

On the other hand, it seems that respiratory muscle endurance may be improved after swimming (Clanton *et al.*, 1987), running (Robinson and Kjeldgaard, 1982) and cycling (O’Kroy and Coast, 1993) training. For instance, Robinson and Kjeldgaard (1982) showed that a 20 week running program increased MIP by 14.4% and MVV by 13.6% in 11 active, subjects, indicating that both RM strength and RM endurance can be improved by regular training.

Eastwood *et al.* (2001) compared the inspiratory muscle performance of endurance athletes and sedentary subjects. Six endurance – trained marathon athletes (age = 37.5 ± 5.3 years) and six sedentary subjects (age = 28.0 ± 4.5) were tested over a period of two weeks. The marathon runners had significantly greater VO_{2max} -values than the sedentary subjects (58.5 ± 7.7 mL.min.kg⁻¹ lean body weight versus 38.6 ± 7.2 mL.min.kg⁻¹ lean body weight; $p < 0.05$). The sedentary subjects had lower RM strength values than the marathon runners (141 ± 25 cmH₂O and 152 ± 41 cmH₂O respectively), but this difference was not statistically significant. However, the sedentary subjects had significantly lower RM endurance compared to marathon runners ($78 \pm 10\%$ of MIPmax vs $90 \pm 8\%$ of MIPmax; $p < 0.05$). These findings therefore suggest that whole body exercise training may indeed increase RM endurance.

It is clear from the literature that more work should be done to clarify the effects of whole-body exercise on RM function. Furthermore, all studies thus far involve endurance type activities and therefore the effect of short-term high intensity training on human respiratory performance is unknown.

D. Do athletes experience respiratory muscle fatigue?

Fatigue of the respiratory muscles has been demonstrated after short term exercise to exhaustion (Coast *et al.*, 1990; Johnson *et al.*, 1993; McConnell *et al.*, 1997; Ozkaplan *et al.*, 2005), as well as after prolonged submaximal exercise, i.e. a marathon (Loke *et al.*, 1982) and in subjects with a variety of fitness levels. Studies in which the effect of short-term exercise was investigated, included incremental running tests to exhaustion, high intensity cycling and VO_{2max} testing on a treadmill or cycle ergometer.

McConnell *et al.* (1997) demonstrated that an incremental shuttle-run to fatigue (exercise lasting between 10-15 min) lead to a significant reduction in MIP, and thus respiratory muscle fatigue in moderately trained men. Subjects with the weakest inspiratory muscles experienced the greatest fatigue after a shuttle-run to exhaustion. Ozkaplan *et al.* (2005) found that MIP was significantly reduced in moderately trained men and women after a VO_{2max} test (men = $83 \pm 16\%$; women = $78 \pm 15\%$). Although the men had significantly higher MIP values than the women, this did not protect them from developing respiratory muscle fatigue. These studies demonstrate that maximal exercise will lead to fatigue of some of the respiratory muscles, regardless of how strong your respiratory muscles are, and irrespective of gender.

Lomax and McConnel (2003) studied the degree of RM fatigue in seven competitive swimmers (age = 29.9 ± 6.4 years) after a single 200 meter swim. The swimmers demonstrated a significant reduction (29%; $p \leq 0.01$) in MIP (in the supine position) after exercise. These results suggest that swim training does not prevent inspiratory muscle fatigue. Subjects also showed a lower MIP value in a supine position in water than in an upright position on land. These findings make an interesting contribution regarding information on the degree of respiratory muscle fatigue after exercise and how it differs for land compared to water based sports.

Johnson *et al.* (1996) compared highly fit ($\text{VO}_2 = 73 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; $n = 6$) and average fit ($\text{VO}_2 = 49 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; $n = 5$) subjects to determine the role of fitness in diaphragm fatigue. They concluded that a high level of fitness (i.e. a high $\text{VO}_{2\text{max}}$) does not protect the diaphragm from fatigue during heavy exercise (95% of $\text{VO}_{2\text{max}}$). However, the fitter subjects' diaphragms were able to perform more "work" at the same degree of diaphragmatic fatigue. Thus if subjects were matched for diaphragmatic power output, the highly fit subjects would incur less fatigue than the less fit subjects.

Coast *et al.* (1990) reported slightly different results. They found that MIP was significantly reduced (10-17%) following an incremental cycle test to exhaustion in sedentary subjects, but not in elite cross-country skiers. They concluded that the respiratory muscles of the skiers were more fatigue resistant, due to the 30% difference in pre-exercise MIP between the athletes and the sedentary subjects. Therefore it seems that superior strength is associated with fatigue resistance. It may also suggest that the respiratory muscles of the skiers adapted to training in much the same way as locomotor muscles. Eastwood *et al.* (1994) suggested that respiratory muscles appear to be highly fatigue resistant, even more so than any other striated muscles. This may explain why some studies report no changes in RM strength measures in trained individuals during endurance-type activities.

Chevrolet *et al.* (1992) studied 21 marathon runners (age = 44 ± 9 years) and 12 half – marathon runners (age = 34 ± 8 years). MIP and MEP values were obtained one hour prior to the race and at 11 ± 4 minutes (t1); 59 ± 7 minutes (t2) and 139 ± 9 minutes (t3) after completing the race. MIP was significantly lower for both marathon runners ($P < 0.0001$) and half – marathon runners ($P < 0.05$) after the race. The decrease was more for the half – marathon runners and this may probably be related to the difference in exercise intensity between a half marathon and a marathon. Loke *et al.* (1982) found similar results after subjects completed a marathon, namely a 16% decrease in MIP after a marathon in four runners. They also observed greater changes in the RM strength than in RM endurance. A reason for this may possibly be that long distance runners train long hours and this training may lead to a carry over effect on the endurance of respiratory muscles, but not to the strength of respiratory muscles.

Nava *et al.* (1992) studied six well – trained runners (mean age = $29.5 \pm \text{SD } 4.2$). RM strength (MIP) was determined before, at 7.5 km, after 17 km and 30 minutes post-run. There were no significant changes in MIP during and after the 17 km run (before: $154 \pm \text{SD } 20.9 \text{ cmH}_2\text{O}$; 7.5km: $157.5 \pm \text{SD } 23.7 \text{ cmH}_2\text{O}$; after 17 km: $155.8 \pm \text{SD } 22.5 \text{ cmH}_2\text{O}$ and 30 minutes after the run: $152.3 \pm \text{SD } 17.6 \text{ cmH}_2\text{O}$, $p > 0.05$). All the runners also finished at a time very close to their maximal best performance for the same distance. These results show that there was no respiratory muscle fatigue and therefore the athletes' performances were not impaired. It is possible that the distance of the race (17 km) was too short or the intensity at which the athletes ran was not high enough to lead to RM fatigue, which is known to set in at high intensities of above 85% of $\text{VO}_{2\text{max}}$.

Ten runners (8 men; 2 women) of 38.3 years of age participated in a study to look at the occurrence of IM fatigue during an ultra-marathon (87km) race. Pre-testing consisted of MIP (RM strength) and breathing endurance time (at 75% of MIPmax). After completion of the ultra-marathon race, respiratory muscle testing was performed three days later. The runners' pre-race MIP values were compared to 105 healthy individuals who acted as controls. There was no significant difference between the pre MIP values of the runners ($109 \text{ cmH}_2\text{O}$) and the control group ($113 \text{ cmH}_2\text{O}$). There was a significant ($p < 0.002$) decrease in the breathing endurance time (26.5%) after three days. Ker and Schultz (1996) concluded that ultra endurance running does not affect RM strength measured 3 days later. However, ultra- endurance running does lead to respiratory muscle fatigue as determined by a breathing endurance test.

Hill *et al.* (1991) studied the effect of an endurance triathlon on pulmonary function. The triathlon consisted of a successive 3.8km swim; a 180km bicycle ride and a 42km run. Twelve male triathletes (age = 32.9 ± 1.9) were recruited. Complete pulmonary tests were obtained on the afternoon before the competition, 10 minutes after each event and on the morning after the competition. Ten minutes after the last segment (running), FVC and FEV_1 were significantly decreased by 7.1 and 8.4 % respectively, compared to baseline measurements ($P < 0.05$). By the following morning, only FEV_1 was still significantly below baseline values. MIP was not significantly reduced after the swim, but significant reductions occurred after the cycle (26%) and running (25%) events ($p < 0.05$). Full

recovery had occurred by the following morning. MEP did not change significantly after any of the three events. This study raises the possibility that respiratory muscle responses to endurance exercise are dependent on the type of exercise.

Perret *et al.* (2000) studied the influence of endurance exercise on respiratory muscle performance. Ten healthy men (age = 29 ± 4 yrs) participated in the study. MIP_{max} was determined and an incremental breathing test was performed to select a target pressure for the constant load test (constant load breathing test to determine breathing endurance as an indicator of respiratory muscle performance). The subjects performed an endurance-cycling test at 65; 75; 85 and 95 % of VO_{2max} . Breathing endurance was determined at 10 minutes (t₁₀) and 45 minutes (t₄₅) after the cycling test. Breathing endurance was similarly reduced during the constant – load breathing test at t₁₀ after exhaustive cycling at 65; 75; 85 and 95% of VO_{2max} compared to the pre breathing endurance test ($p < 0.01$). After 45 minutes the breathing endurance time was only significantly reduced after exhaustive cycling at 65; 75; 85% of VO_{2max} compared to the pre-breathing endurance test ($p < 0.05$). Therefore, endurance exercise does have an effect on respiratory muscle performance (in terms of breathing endurance). However, the effect was independent of exercise intensity.

The study by Romer *et al.* (2002) showed that two minutes after a 20- and 40km time trial the trained cyclists revealed significant declines in MIP from baseline values ($17 \pm SD 4\%$ and $13 \pm SD 3\%$ respectively; $p < 0.05$), and these values did not return to pre-exercise levels within 30 minutes post exercise. Furthermore, a greater reduction in post exercise inspiratory muscle function was noted after the 20 km time trial compared to the 40 km time trial. This finding suggests that the intensity or duration of exercise influence the magnitude of respiratory muscle fatigue and is thus in contrast to the findings of Perret *et al.* (2000). These findings also means that normal endurance training fails to provide an optimal training stimulus to the inspiratory muscles.

To date, it seems that the capacity to ventilate maximally declines only in long- term exhausting exercise and the decrease is more prominent for untrained individuals. Furthermore, it seems that respiratory muscle strength, not whole-body endurance capacity, is related to the degree of respiratory muscle fatigue following exhaustive

exercise. Research also shows that respiratory muscles are fatigued by different intensities and types of exercise, although it is not clear if some types of activities may predispose athletes more to RM fatigue than others. Therefore, if the objective of performance is to exercise for more than 60 minutes, respiratory endurance may be one of several factors limiting prolonged heavy exercise. Although Bender and Martin (1985) found that RM endurance was not compromised after short-exercise (3-10min) to exhaustion, more studies should be done on short-term exercise to clarify this matter.

E. Does respiratory muscle fatigue affect performance?

The role of respiratory muscle fatigue in limiting exercise performance in trained athletes is still controversial, especially with regards to short duration exercise. Most studies that investigated the relationship between RM fatigue and performance involved endurance-trained athletes (Nava *et al.*, 1992; Harms *et al.*, 2000 and Pringle *et al.*, 2005). Performance outcome measures were either maximal exercise capacity (VO_{2max}), time to exhaustion, or time to complete a fixed distance (i.e. time trial).

Pringle *et al.* (2005) were of the opinion that RM function may actually be important determinants of athletic performance. Pringle *et al.* (2005) studied the correlation between certain measures of lung function and lung capacity and performance in a 10km race. Thirty-five recreational runners (23 = men; 12 = women) between the ages of 23 to 71 years took part in the study. Both men and women had FVC, MVV and MIP values that exceeded the predicted values. MEP values, however, were below the age predicted values for men (111.5 cmH₂O vs. the predicted of 197.8 cmH₂O) and for women (88.3 cmH₂O vs. the predicted 152.2 cmH₂O). In his study, Cordain *et al.* (1987) speculated that the reduced values may be related to the high volumes that runners breathe at rest and during exercise over an extended period of time. This may cause a reduction in airway resistance, since the latter is inversely related to lung volumes. Therefore, airway resistance will be reduced when subjects breathe at high lung volumes.

In the regression equation for the prediction of 10km run time MVV explained 27 % ($r = -0.52$), FVC 15.2 % ($r = -0.39$) and inspiratory capacity 72.3 % ($r = -0.35$) of the variance in 10km run performance (Pringle et al., 2005) This finding suggests that lung capacity and respiratory muscle endurance are indeed determinants of endurance performance. In the light of these findings, athletes may be encouraged to train their respiratory muscles specifically in order to develop their lung capacity and respiratory muscle function to the fullest.

Mador and Acevedo (1991) observed that the induction of inspiratory muscle fatigue impaired the subsequent performance of healthy subjects during a cycle test at 90% VO_{2max} to fatigue. Minute ventilation was higher and the pattern of breathing was altered during the cycle exercise after inspiratory muscle fatigue. These results are supported by those of Martin *et al.* (1982) who found that reduced ventilatory muscle endurance (caused by 150 min of sustained maximal ventilation), was sufficient to decrease short-term maximal running performance. In the light of these findings, Boutellier (1998) observed that if respiratory muscle fatigue reduces performance, then increased fatigue-resistance of the respiratory muscles, through RM training, should improve performance.

Seven cyclists performed a VO_{2max} exercise test on an electromagnetically braked cycle ergometer (Harms et al., 2000). Six to eight weeks later a VO_{2max} was performed but with inspiratory muscle unloading. Inspiratory muscle unloading was performed by a feedback controlled proportional- assist ventilator (PAV) to reduce the work of the inspiratory muscles during exercise. One to six months later six of the seven cyclists repeated the VO_{2max} test but under inspiratory muscle loading conditions. Inspiratory muscle loading was done to increase the inspiratory work during exercise. Dyspneic ratings and rating of perceived exertion were determined after each VO_{2max} test.

When the inspiratory muscles were unloaded, the time to exhaustion (T_{lim}) during the VO_{2max} test was longer than during the VO_{2max} test with respiratory muscle loading (1.0 ± 0.8 min versus 1.3 ± 0.4 min; $p < 0.05$). With loading, the VO_2 was $6.3 \pm 0.2\%$ higher than baseline values ($p < 0.05$). On the other hand, VO_2 was $6.9 \pm 0.2\%$ lower than baseline values during exercise with unloading ($p < 0.05$). An association was thus found between the work of breathing and endurance performance. The

higher load on the respiratory muscles may have caused a redistribution of blood flow away from the locomotor muscles, which may compromise oxygen delivery and carbon dioxide removal. Alternatively, respiratory muscle loading may cause the earlier onset of fatigue due to respiratory muscle fatigue, since Johnson *et al.* (1993) have established that diaphragm fatigue sets in when the exercise intensity exceeds 85% of VO_{2max} . In both cases, athletic performance will be negatively influenced.

Performance is easier to measure in individual endurance sports, because performance can be objectively quantified by means of a time trial or test to exhaustion in a controlled laboratory environment. Team sports require a combination of fitness attributes such as strength, power, agility, speed and endurance and various skills and techniques. Each component must be evaluated separately, for instance, the bench press test is a measure of determining strength of the upper body and power of the lower body is determined by the vertical jump test. Agility can be tested by the agility – t test and speed by sprinting over various distances. It is therefore a challenge to measure and quantify performances in team sports. Consequently, researchers choose to measure one or more of the fitness components separately, or try to combine one or more of the fitness components into one test. For these reasons, very little information exists concerning respiratory muscle function during efforts performed outside a laboratory (especially for team sports) to assess the relationship between respiratory muscle function and athletic performance.

F. Effect of respiratory muscle training on performance

Usually sport performance is enhanced because of the adaptations that various physiological systems, most notably the locomotor muscles, make in response to exercise training, and the refinement of specific skills which are needed for a particular sport. However, if a relationship exists between athletic performance and respiratory muscle function, it may suggest that athletes should aim to optimize respiratory muscle function. It is also possible that athletes would be able to further enhance their performance through deliberate training of the respiratory muscles.

From a physiological point, the respiratory muscles must be able to be trained (Enright *et al.*, 2006). Both the inspiratory muscles and the diaphragm are

morphologically and functionally the same as skeletal muscles and should therefore adapt to training in the same way as locomotor muscles would (McCool *et al.*, 1997). However, there is little information on the structural changes in human respiratory muscle fibers in response to respiratory training.

Most RM training studies have used two modes of training, namely (i) voluntary isocapnic hyperpnoea to improve RM endurance, or (ii) inspiratory resistive loading to improve RM strength.

Various devices are used to train the respiratory muscles (POWERbreath; Powerlung and Threshold Trainer) and they operate on the same principles. No information exists to suggest that there are any differences between the devices, or that they may cause different results. The duration of the training period varied between four to 12 weeks. Most studies used inspiratory efforts to train the respiratory muscles (Inbar *et al.*, 2000; Volianitis *et al.*, 2001; Romer *et al.*, 2002; Williams *et al.*, 2002). However, concurrent inspiratory and expiratory efforts can also be used (Wells *et al.*, 2005). Training is performed daily for between four to six times a week, or even twice daily. The resistance of the efforts is determined by measuring MIP. A training program then starts at 30% of MIP and progressively increases to 80% of MIP over the training period.

As before, the subjects used in the RM training studies were either sedentary (Boutellier, 1998), healthy (Chathman *et al.*, 1999) or athletes competing in endurance sport (Fairbarn *et al.*, 1991; Inbar *et al.*, 2000; Volianitis *et al.*, 2001; Romer *et al.*, 2002; Williams *et al.*, 2002 and Wells *et al.*, 2005). Whether respiratory muscle training improves performance in the field, is still open to debate. A number of studies found no effect of RM training on physical performance (Morgan *et al.*, 1987; Fairbarn *et al.*, 1991; Williams *et al.*, 2002). In the studies of Fairbarn *et al.* (1991) and Morgan *et al.* (1987), the performance of cyclists was measured during short-term, near-maximal constant load exercise. Williams *et al.* (2002) also found that a four-week RM training program lead to improvements in RM strength and RM endurance, however, these changes did not translate to an improvement in an endurance run time test. The authors therefore agreed that RM training can improve RM function in endurance athletes such as cyclists, runners and swimmers, but that it did not enhance the athletic performance of trained or untrained individuals. They

argued that to increase VO_{2max} , it is known that the cardiac output and the systemic arteriovenous oxygen difference must increase to increase the amount of oxygen available to the working muscles. Exercises with rhythmic contractions of large muscle groups are likely to increase cardiac output and arteriovenous oxygen. But, because RM training involves small muscle groups, there is no reason to predict an adjustment in these above mentioned central circulatory responses and then increasing VO_{2max} . On the other hand, a few studies have found performance enhancing efforts after RM training. These positive findings were also not limited to sedentary or untrained individuals.

In a study by Boutellier (1998) sedentary and physically active subjects performed four weeks of respiratory muscle training. Endurance time on a constant – load bicycle test and RM endurance were determined before and after the four weeks of training. Boutellier (1998) concluded that both RM endurance and endurance capacity (VO_{2max}) were enhanced through RM training. The authors stated that the reason for the increase in endurance performance excluded cardio-circulatory improvements, because physical working capacity and heart rate did not change with respiratory muscle training. The change could also not have been because of improvements of leg muscles, because the sedentary subjects remained inactive during the respiratory muscle training and the physically active subjects did not change their training programs. Therefore, the improved cycling endurance capacity was attributed to an increase in respiratory muscle fitness.

Chatham *et al.* (1999) studied 22 healthy subjects (12 = women; 10 = men) with a mean age of 26 years in their study. Subjects were randomly allocated to a control or a training group. Respiratory muscle strength (MIP and MEP), as well as the multi – stage shuttle run were completed before and after a 10 week RM training program to assess the effect of inspiratory muscle training on the aerobic fitness and perception of sport performance. Both MIP and MEP increased by 31.3% ($p < 0.002$) respectively in the experimental group after the training program, while the respiratory muscle strength of the control group improved by almost 11%. This change was not statistically significant ($p > 0.05$). The experimental group improved their endurance performance statistically significantly by 9.8% ($p < 0.001$), while there was no change in the control group.

Both Boutellier (1998) and Chatham *et al.* (1999) thus observed an improvement in RM strength, RM endurance and endurance exercise capacity. Participants also reported that they experienced a decrease in breathlessness during running, swimming, and squash and cycling activities following the respiratory muscle training program (Chatham *et al.* 1999), however, these observations were only subjective opinions.

Volianitis *et al.* (2001) randomly assigned fourteen women competitive rowers (age $23 \pm \text{SD } 3.8$ years) to a control group ($n=7$) and an experimental group ($n=7$). Subjects performed MIP measurements and a six-minute all out performance on a rowing ergometer before and after 11 weeks of RM training. The experimental group performed 30 inspiratory efforts twice daily, against a resistance equivalent to 50% of their peak inspiratory mouth pressure. The control group performed 60 breaths once daily at a resistance of only 15% of their MIP-value. Both groups used the same inspiratory muscle trainer (POWERbreath[®], IMT Technologies Ltd., Birmingham, UK). The MIP values of the experimental group increased by $45.3 \pm 29.7\%$ ($P < 0.01$) and performance on the six minute all out rowing test by $3.5 \pm 1.2\%$ ($P < 0.05$). The control group had an increase of $6 \pm \text{SEE } 11$ cmH₂O ($5.3 \pm 9.8\%$; $P < 0.21$) in MIP values and an increase of $1.6 \pm 1.0\%$ ($P < 0.05$) on the six minute all out test. This study shows that RM training may improve short-term rowing performance. The authors suggested that RM training possibly increased the mechanical efficiency of ventilation, which is particularly important during rowing where athletes are in a semi-crouched, sitting position. The metabolic requirements of the respiratory muscles are therefore reduced and needs less blood flow to function. More blood is then directed to the locomotor muscles instead.

Romer *et al.* (2002) randomly divided sixteen male competitive road cyclists in an experimental group ($n=8$) and the control group ($n=8$). After a 6 week RM training program, MIP and $\text{VO}_{2\text{max}}$ improved significantly in the experimental group ($28 \pm 7\%$ and $22 \pm 8\%$, respectively; $p < 0.05$), while the control group showed no changes. The experimental group also completed the 20- and 40km time trials significantly faster than the control group ($3.8 \pm 1.7\%$ and $4.6 \pm 1.9\%$ respectively, $p < 0.05$). These findings confirm that normal endurance training fails to stimulate the inspiratory muscles in a way to lead to adaptations in the respiratory muscles.

Chatham *et al.* (1999) suggested that the reason why some researchers don't find increases in RM function with specific RM training is that the training load may not be of adequate loads which may lead to adaptations of the RM. It is well known that the response of locomotor muscles depend greatly on the characteristics of the training load. However, many researchers fail to control the workload in RM training studies adequately and therefore the amount of work that is done may be too little to actually result in measurable training adaptations. The frequency and duration of training in most RM training interventions have been arbitrarily set at 30 minutes twice daily, and programs typically last between two to four weeks. Astrand and Rodahl (1986) pointed out that primarily neural adaptations take place over the first four weeks of a training program, while morphological changes, i.e increases in oxidative capacity, vascularization and hypertrophy, are only evident in the weeks thereafter. Thus, general strength and conditioning training suggests that RM training interventions should last more than four weeks.

It has been shown that respiratory muscle fatigue occurs during both short-term and prolonged exercise, as well as in trained and untrained subjects. Furthermore, the degree of RM fatigue is dependent on the duration of the activity and the strength of the respiratory muscles. Thus, one can conclude that if respiratory muscle fatigue reduces athletic performance, then increased resistance to respiratory muscle fatigue should improve performance (Boutellier, 1998). This has important implications for any athlete and suggest that, to achieve optimal performance, athletes should engage in respiratory muscle training.

CHAPTER 5

PROBLEM STATEMENT

A. Introduction

Each sport consists of different defining elements. Components like speed, agility, strength and specific skills each contribute to varying degrees to overall performance in a specific sport. Furthermore, optimal sport performance is also dependent on the complex interaction of several physiological systems. Some of these systems, most notably the cardiovascular and musculo- skeletal systems, have been thoroughly studied in a wide variety of populations and under different circumstances. Since the respiratory system has traditionally not been considered a limiting factor during exercise, less has been published on the role of the respiratory system in obtaining optimal sport performance.

A few studies have shown that athletes, particularly those involved in endurance –type activities, can improve their performance through respiratory muscle training. Since athletes are always looking for legitimate ways to improve performance, it is worthwhile to investigate the role of the respiratory system, particularly the respiratory muscles, in a wide variety of athletic activities and in different athletic populations.

The main aims of this study were to determine:

1. the relationship between anthropometry and respiratory muscle function.

It is known that there is a relationship between competitive success and physical traits or body composition. Research has shown that respiratory muscle functions in the general population have some relationship to age, height, gender and body mass. The relationship between various lung function variables and anthropometry has also been studied, both in the general population and among athletes.

2. the relationship between respiratory muscle function and exercise performance

Athletes are continuously trying to find ways to improve their performance. Before improvement is possible, the factors that influence performance must be defined. Although research has shown that there is a difference between the respiratory muscle function of untrained and trained individuals, consensus has not been reached on whether the individual with better respiratory muscle function would perform better in a specific sport or activity. Very little information exists on the relationship between respiratory muscle function and performance of team sports athletes. One reason is the difficulty to determine and measure performance of a team sport, as success in team sports is dependant on a combination of fitness components such as strength, power, agility, speed and endurance. It has been shown that respiratory muscle training can improve respiratory muscle function, but it is not evident that this would lead to better performance in a specific sport. Therefore, the aim of this study was to investigate the association between respiratory muscle function and anaerobic speed endurance in selected athletic populations.

3. the degree of respiratory muscle fatigue

All sports are performed at different intensities and durations and have different recovery time between movements or efforts. Therefore, the demands on the physiological systems are varied, including the stress on the respiratory system. Research has indicated that both trained and untrained subjects experience respiratory muscle fatigue after exercise, although the degree of fatigue is less in the trained individual. Most studies have been done on endurance sport and therefore it has not been established whether short –term high intensity exercise also causes respiratory muscle fatigue. The aim of this study was to establish the degree of respiratory muscle fatigue in athletes participating in team sports and to determine whether there is a difference between water – based sports compared to land – based sports.

The overall aim of this study was to gain a better understanding of respiratory muscle function in athletic populations. The findings of this study may determine whether more attention should be given to (1) include respiratory muscle function measures in routine fitness testing and (2) whether team –based athletes benefit from specific respiratory muscle training

CHAPTER 6 METHODOLOGY

A. Study design

In this descriptive study data were collected to characterize the anthropometrical profile and respiratory function of selected water- and land based team sport athletes.

B. Subjects

The aim was to recruit well-trained athletes in selected sport codes and test them during the competition phase of their season.

1. Recruitment of athletes

The Maties rugby, netball, water polo and swim clubs were approached for subject recruitment. If the subject met the inclusion criteria, an appointment was made for the first visit to the testing laboratory. Fifteen rugby- ; 14 netball- ; 20 swimmers and 13 control subjects volunteered to take part in the study.

2. Athletes were included in the study if

- 2.1 they met the criteria of competitive experience in their specific sport for at least three years and engaged in their specific sport at least three times a week;
- 2.2 they were free of respiratory tract infection at least four weeks prior to testing;
- 2.3 they had no prior experience of performing lung and respiratory muscle function tests.

3. Recruitment of control subjects

Men and women, between the ages of 19 and 24, were personally contacted to volunteer as control subjects for this study.

4. Subjects were eligible for the control group, if

- 4.1 they were inactive, or only participated in recreational activities on less than four days a week;
- 4.2 they were free of respiratory tract infection at least four weeks prior to testing;
- 4.3 they had no prior experience of performing lung and respiratory muscle function tests.

5. In all cases, subjects were excluded if

- 5.1 they showed any abnormality in resting pulmonary function during baseline testing;
- 5.2 they could not complete all test measurements within the study period.

C. Ethics

All testing procedures and the risks involved with participation in the study, as stated in the consent form (see Appendix A), were explained to each subject individually and the opportunity was given for questions. The subjects agreed to all testing requirements and procedures by given his/her written consent. The study protocol did not include any invasive procedures and all the physical tests are standardized laboratory fitness tests.

D. Experimental overview and procedures

Tests were conducted over two days. During the first visit, the study protocol was explained and subjects completed the informed consent forms. Thereafter, the lung function tests (FVC, MVV), the respiratory muscle strength test (MIP, MEP) and the sport performance test were completed. During the second visit, the anthropometrical profile of the subject was determined. All testing, including the sport performance tests (repeated sprint-ability test and swim speed-endurance test) were performed indoors.

1. Lung function tests

1.1 Flow – volume curve

Forced vital capacity (FVC), forced expiratory volume in one second (FEV_1) and peak expiratory flow rate (PEF) were measured by means of a flow-volume curve. The aims of the test were to measure functional lung capacity and assess normal pulmonary function. A turbine flow meter and the Spirometry reader 2000 (Cosmed Quark b² Spirometry version 8.0b, Rome, Italy) were used to measure spirometric variables. The spirometry standards of the European Respiratory Society (ERS93) were used to assess the validity and repeatability of each subject's flow-volume curves. The spirometer was calibrated prior to each testing session using a 3 L - syringe.

Maneuvers were performed by subjects while seated and wearing a nose clip. The subject had to seal his/her mouth around a carton mouthpiece connected to the flow meter. The test started by registering two normal breaths. The subject was then instructed to inhale to total lung capacity, and then to exhale up to residual volume. Subjects were motivated to exhale as quickly and forcefully as possible and to keep exhaling until residual volume was reached. Trial maneuvers were performed until the curves were technically satisfactory. Hereafter, each subject performed a minimum of three and a maximum of eight maneuvers. The recordings were considered valid and reliable when the FVC and FEV_1 of at least two flow-volume curves did not differ by more than five percent. A rest period of 30 to 60 seconds was given between maneuvers. The curve with the greatest sum of FVC and FEV_1 was selected as the final measurement. PEF was also obtained from the flow-volume curve data and is expressed in liters per second. FVC was measured in liters and FEV_1 in liters per second. Subjects who did not achieve at least 80% of their predicted lung function were excluded from the study sample.

2. Respiratory muscle function tests

2.1 Respiratory muscle strength

Maximum inspiratory mouth pressure (MIP) and maximum expiratory mouth pressure (MEP) were measured with a device which consisted of a two-way valve. The valve

marked expiratory pressure allows the subject to inspire fully through the valve, which then closes during expiration to allow the meter to measure the maximum expired pressure averaged over one second. The valve marked inspiratory pressure works in the exact opposite manner. The one opening was connected to a plastic cylinder, 120mm in length and 38mm in diameter, with a small leak (1.5 mm in diameter) at the distal end of the cylinder. This small opening prevents the registration of a false high reading generated by closure of the glottis and compression of air in the mouth using the facial muscles. The other opening was open to the atmosphere through which expiration took place. A rubber mouthpiece was connected to the valve. The device was connected to a digital pressure meter (Micro RPM meter), and connected to specialized PC (Puma) Software.

Ringqvist (1966) found that the highest maximal expiratory pressures were obtained at lung volumes greater than 70% of TLC, while the highest maximal inspiratory pressures were obtained at volumes less than 40 – 50% of TLC. The highest MIP and MEP should therefore be recorded when the measurement of MEP is initiated from TLC and MIP from RV.

Using the inspiratory valve, all the subjects were in a standing position and wore a nose clip during the measurements. The maneuver started with a maximal exhalation to residual volume (RV). The subject was then instructed to inhale as forcefully and as rapidly as possible through the device over at least a two second period. Pressure (in cmH₂O) was measured at a sampling frequency of 16Hz over 2 seconds, and displayed on the computer monitor, which was also visible to the subject. Trial maneuvers were performed until technically satisfactory before the actual recording of data started. Twelve technically satisfactory maneuvers were performed by each subject and the average of the three highest measurements, within five percent variance, was considered as the final MIP. Maneuvers were separated by rest periods of 30 seconds.

For the MEP procedure, the expiratory valve was used and the maneuver started with a maximal inhalation to total lung capacity (TLC). The subject was then asked to exhale forcefully and as rapidly as possible through the device over a period of at least two seconds. Again 12 maneuvers were performed and the final MEP was considered as the average of the three highest measurements, within five percent variance. The same rest periods were used as with the MIP procedure.

2.2 Respiratory muscle endurance

Maximum voluntary ventilation (MVV) in 12 seconds was measured to assess respiratory muscle endurance. While in a standing position, the subject was instructed to inhale and exhale through the mouthpiece as maximally and as rapidly as possible for 12 seconds. Trial maneuvers were performed until technically satisfactory before the recording of data started. This procedure was performed at least three times, to obtain two reproducible efforts within 5 %. The highest value of these two efforts was taken as the final measure. A rest period of 30 to 60 seconds was given between maneuvers. Ventilated air was measured in liters per minute (L/min).

E. Anthropometry

All measurements were done by an ISAK accredited anthropometrist (Level 1) and according to the International Standards for Anthropometric Assessment (Marfell – Jones *et al.*, 2006).

1. Stature

The subject stood with his/her back and heels against the wall. An anthropometer (Siber-Hegner, Germany) was placed in front of the subject while the head was in the Frankfort plane. After the subject took a deep breath, the measurement was taken to the nearest 0.1cm.

2. Sitting height

A measuring tape was mounted to the wall. A chair with a height of 44 cm was placed against the wall with the midpoint of the chair in-line with the mounted measuring tape. The subject was instructed to sit upright with buttocks against the wall, while the feet were placed on the floor and the lower legs were at right angles with the thighs. The subject was instructed to take a deep breath while keeping the head in the Frankfort plane. A piece of cardboard was placed on the vertex and the measurement was recorded to the nearest 0.1 cm. The sitting height was then calculated by subtracting the chair height from the measured value to the nearest 0.1 cm.

3. Arm span

Arm span was measured using a modified method of Hahn (1990). A steel measuring tape was mounted to the wall more or less at shoulder height of a person with normal height. A piece of steel was mounted at the zero mark of the measuring tape, perpendicular to the floor. The subject was instructed to stand with his feet shoulder width apart, facing the wall with his third fingertip just touching the piece of steel at the zero mark. The subject was instructed to stretch out, with his torso pressed against the wall and his head turned sideways, to obtain the greatest possible span. The span was read to the nearest 0.1cm.

4. Arm length

Arm length was taken with a segmometer (Rosscraft, Canada) from the acromial landmark to the tip of the third finger of the right arm. The subject was instructed to stand upright with his arm straight and relaxed at the side, with palm placed on the thigh. Measurements were taken to the nearest 0.1cm.

5. Body mass

Body mass was measured with an electronic scale (UWE BW – 150 freeweight, 1997 model, Brisbane, Australia) to the nearest 0.1 kg. The subject wore light clothes and stood on the centre of the scale without support and with the weight evenly distributed on both feet.

6. Girths

Six girths were taken with a flexible, non-extensible steel tape (Rosscraft, Canada) at the specific standardized sites. Measurements were taken to the nearest 0.1cm. The six girths were: upper arm (relaxed at the mid-acromiale-radiale point, perpendicular to the long axis of the arm); upper arm (tensed at maximum girth); chest (at meso-sternal landmark which is the midpoint of the corpus sterni at the level of the centre of the articulation of the fourth rib with the sternum); waist (at the level of the trunk where the

girth is minimal); gluteal (at the level where there is the greatest protuberance of the gluteals) and calf (maximum girth).

7. Breadths

The breadths measured included the humerus, femur, biacromial and biliocrystal widths. The humerus breadth was taken at the linear distance between the most lateral aspect of the lateral humeral epicondyles and the most medial aspect of the medial humeral epicondyles. Femur breadths were taken at the linear distance between the most lateral aspect of the lateral femoral epicondyles and the most medial aspect of the medial femoral epicondyles with a small sliding caliper (Rosscraft, Tommy 3, Canada). The biacromial breadth was taken at the linear distance between the most lateral aspect of the acromion processes and the biliocrystal breadth was taken at the linear distance between the most lateral point of the iliac with a large sliding caliper (Rosscraft, Campbell Caliper 20, Canada). All these measurements were taken to the nearest 0.1 cm.

8. Body fat percentage

Percentage body fat was determined through bioelectrical impedance analysis (Body Composition Meter 1000, South Africa, 1991), as well as with the skinfold method.

9. Skinfolds

Eight skinfolds were taken at specific landmark sites as described by Marfell-Jones *et al.* (2006) with a Harpenden skinfold caliper (Britian). Each measurement was taken once and recorded two seconds after the full pressure of the caliper was applied.

The **triceps skinfold** was measured parallel to the long axis of the arm at the tricep skinfold site. This site is obtained at the mid-point between the acromiale and radiale landmarks at the posterior surface of the arm. The **biceps skinfold** measurement was taken parallel to the long axis of the arm, on the anterior surface of the arm in the mid-line at the level of the mid-acromiale-radiale landmark. The **subscapular skinfold** measurement was taken with the fold running obliquely downwards at the subscapular skinfold site, which is the undermost tip of the inferior angle of the scapula. The **iliac**

crest skinfold measurement was taken horizontally at the centre of the skinfold raised immediately above the marked iliocristale where a line was drawn from the mid-axilla, on the longitudinal axis of the body, to meet the ilium. The point at the intersection of two lines, namely 1) the line from the most inferior or undermost part of the tip of the anterior superior iliac spine to the anterior axillary border, and 2) the horizontal line at the level of the marked iliocristale, were used to measure the **supraspinale skinfold** obliquely and medially downward. The **abdominal skinfold** site is the point five centimeters horizontally to the right hand side of the omphalion and the measurement were taken vertically at the site. The mid-point of the linear distance between the inguinal point and the patellare were used as the **front thigh skinfold** site and the front thigh skinfold were taken parallel to the long axis of the thigh. The point on the most medial aspect of the calf at the level of the maximal girth was used as the **medial calf skinfold** site and the measurement were taken vertically at this site.

Body fat percentage was calculated using the regression equation of Withers et al. (1987) for body density (BD) ($R^2 = 0.75$, $SEE = 0.0058$):

For men:

$$BD = 1.10326 - (\text{age} \times 0.00031) - (0.00036 \times \sum 6 \text{ skinfolds (triceps, subscapular, supraspinale, abdominal, thigh and medial calf)}) \dots\dots\dots 7.1$$

For women:

$$BD = 1.07878 - (0.00035) \times \sum 6 \text{ skinfolds (triceps, subscapular, supraspinale, abdominal, thigh and medial calf)} + (0.00032 \times \text{age}) \dots\dots\dots 7.2$$

The regression equation of Siri (1961) was used to calculate percentage body fat:

$$\%BF = 459/BD - 450 \dots\dots\dots 7.3$$

10. Bioelectrical impedance analysis

Whole-body impedance measurements were performed with a multifrequency bioelectrical impedance analyzer. The subject was asked to remove his shoes and socks and to lie supine for 10 minutes with the arms and legs spread slightly. Measurements were taken from the right side of the body via a tetrapolar (KENDALL,

MEDI TRACE™ 200) electrode arrangement. The hand, wrist, ankle and foot were cleaned with alcohol swabs. The leads were connected to the:

- 1) first electrode on the dorsal surface of the hand, 1 cm proximal to the middle knuckle (red lead);
- 2) second electrode on the wrist next to the wrist joint (black lead);
- 3) third electrode on the dorsal surface of the foot, on the ankle at the level of the protruding bones on the sides of the ankle (black lead);
- 4) fourth electrode on the dorsal surface of the foot at the base of the toes, 1cm proximal to the joint of the second toe (read lead).

A sinusoidal current of 200 μ A was applied and serial resistance and reactance were recorded at 50 kHz. These measurements were then used to calculate percentage body fat and lean body mass.

11. Body Mass Index

Body Mass Index (BMI) was used to assess weight relative to height and is calculated by dividing body weight in kilograms by height in meters squared (kg/m^2).

F. Performance tests

1. Repeated sprint-ability test

The purpose of this test was to measure the subject's speed-endurance, muscle endurance of the legs, ability to resist intermittent high intensity fatigue and agility. This test was performed by the control group, as well as the rugby and netball players.

Five beacons were placed 5 m apart on a straight line over a distance of 25 meters. Subjects had a warm up period of five minutes, where exercises of their own choice were done. Subjects started at point 0, and upon an auditory signal (by the head time keeper), sprinted to cone 1, touched the base of the cone with the hand, returned to point 0, reached down to touch the base, and then sprinted to point 2. The subject continued in this manner sprinting to the remaining beacons (3, 4 and 5) making sure to return to point 0 between each outward shuttle. A whistle was blown after 30 seconds, which indicated the end of that stage of the shuttle-run. At this time the subject was

allowed to take a 35-second recovery period (rest period timed by another time keeper), and the subject's completed distance (to the nearest two and a half meters) covered during the 30 seconds exercise period was recorded. The distance measured was recorded from the position of the front foot of the subject as the whistle was blown. During the recovery period, the subject had to make his/her way back to the start point (0) and upon completion of the 35 seconds, began the next set of shuttles. Six 30-second periods were completed by each subject. For each run, the distance the subject covered, was recorded. To assist with pacing, the subjects were advised to complete each run at about 90% of their maximum pace. Subjects only had one trial for performing this test.

2. Speed endurance swim test

The purpose of this test was to determine speed endurance and muscle endurance of the arms and legs. All the swimmers performed this test in an indoor 25-m pool.

Subjects had the option of swimming a few lengths as a warm up before performing the test. Each swim utilized a push start. The subjects were instructed to swim 6 x 50m sprints on 60s each. Thus, if the swimmer completed a sprint in, for example 30 seconds, he/she had a 30 second rest period before the next sprint. The first observed movement was used as the starting time, while the finishing time was recorded as the swimmer touched the wall. All times were recorded to a tenth of a second with a stopwatch (Medalist, South Africa). Subjects only had one trial for performing this test.

For both the performance tests, athletes wore a Polar Heart Rate monitor to quantify the intensity (percentage of age predicted heart rate) at which they completed the tests. This was done to make sure all the subjects gave an all out effort.

The repeatability of both these performance tests was determined by testing a group of swimmers and netball players twice over a period of 24 hours. Both the repeated sprint and the speed endurance test in the water had a significant test –retest correlation of 0.9 ($P < 0.01$).

G. Assessment of respiratory muscle fatigue

Apart from performing baseline MIP measurements, subjects also performed the MIP test after 60- and 120 seconds after completion of the performance test. The swimmers performed these measurements outside the pool. This was done to determine the decrease in strength of the inspiratory muscles after exercise and thus the degree of respiratory muscle fatigue following exhaustive exercise. The degree of fatigue was expressed as a percentage.

The following equation was used:

$$\left[\frac{MIP_{(baseline)} - MIP_{(after\ 60\ seconds)}}{MIP_{(baseline)}} \right] \times 100 \dots\dots\dots 6.1$$

H. Statistical analysis

To compare the subjects, the subjects were divided into a land- and water –based group. The netball, rugby players formed the land –based group and the swimmers formed the water –based group. Descriptive statistics were calculated as mean ± SD, unless indicated otherwise. A single – factor Anova was used to test for differences between the various groups. Where the significance levels were less than 0.05, unpaired Student’s t –tests were used to determine which group varied significantly from the other. Pearson product moment correlations were used to determine relationships 1) between anthropometry variables, 2) between respiratory muscle function and lung function, 3) between respiratory muscle – and lung function and the performance test. The test-retest repeatability of the performance tests was determined with the Pearson correlation coefficient. SPSS 15.0 were used to draw box-and-whisker plots. Stepwise multiple regression analyses were performed to determine the predictors for MIP, MEP and MVV. Significance levels were set at P < 0.05.

CHAPTER 7

RESULTS

A. Introduction

One of the aims of the study was to establish whether certain anthropometry variables are related to respiratory muscle function in a healthy, active and young population. To this end a stepwise multiple regression analysis was performed between anthropometry and respiratory muscle factors with anthropometry as independent variables and respiratory muscle strength and –endurance as dependant variables.

Another aim was to determine the relationship between respiratory muscle function and high intensity exercise. For this purpose, the respiratory muscle function of the various athletic groups was compared to the performance in an anaerobic speed endurance test.

The final aim was to determine the degree of RM fatigue after high intensity exercise and to compare the outcomes between water- compared to land-based sports.

B. Subject characteristics

Subjects, who were recruited, were athletes who competed at national, provincial of first team university club level.

The subject characteristics of the various groups who participated in the study are reported in Table 6. The swimmers (both men and women) were statistically significantly younger than the netball players ($P < 0.001$) and the rugby players ($P < 0.01$) respectively. The male swimmers were statistically significantly lighter and had a lower BMI than the rugby players ($P < 0.001$).

When comparing the land-, water-based athletes and the control group (Table 7) it is evident that the water-based athletes were significantly younger than the land-based athletes ($P < 0.001$) and the control subject ($P < 0.001$). The BMI of the water-based

athletes were also statistically significantly lower than the land-based athletes ($P < 0.01$). However, height and body mass were similar between the three groups.

Table 6: Subject characteristics of the individual groups (n = 62)

Variable	Netball (n=14)	Rugby (n=15)	Swimmers (women: 8; men: 12)	Control (women:6; men:7)	P value
Age (yrs)					
Women	20.9 ± 2.0 (19 - 27)		17.8 ± 1.6# *	21.5 ± 1.8 (19 - 24)	P = 0.001
Men		21.7 ± 2.2\$	18.9 ± 2.5 (15 - 22)	21.4 ± 1.5\$ (19 - 23)	P = 0.01
Height (cm)					
Women	172.5 ± 6.1 (162.9 - 183.4)		168.3 ± 5.4 (160 - 176.5)	166.9 ± 6.5 (159 - 175.6)	P = 0.12
Men		183.1 ± 7.3 (172 - 197)	183.3 ± 6.5 (168.3 - 191)	179.7 ± 5.0 (171.8 - 188.2)	P = 0.47
Body mass (kg)					
Women	66.6 ± 7.8 (53 - 87.3)		63.9 ± 9.8 (50.10 - 77.8)	60.2 ± 6.7 (53.3 - 71.3)	P = 0.29
Men		92.5 ± 13.2 (77.4 - 120)	77.2 ± 8.6□	80.8 ± 10.8 (66.5 - 95.9)	P = 0.004
BMI					
Women	22.4 ± 2.3 (18.9 - 26.9)		22.5 ± 2.5 (19.0 - 25.7)	21.7 ± 3.2 (17.9 - 26.5)	P = 0.82
Men		27.5 ± 2.8\$ (23.9 - 34.5)	22.9 ± 1.8 (20.1 - 25.4)	24.1 ± 1.6 (22.4 - 26.3)	P = 0.0003

Statistically significantly different from the female control subjects

* Statistically significantly different from the netball players

■ Statistically significantly different from the male control subjects ($p < 0.05$)

□ Statistically significantly different from the rugby players ($p < 0.001$; $P < 0.05$)

\$ Statistically significantly different from the male swimmers ($p < 0.01$)

Table 7: Subject characteristics of the land- and water-based athletes and the control subjects (men and women combined)

Variable	Land-based Athletes (n = 29)	Water-based Athletes (n = 20)	Control (n = 13)	P-value
Age (yrs)	21.3 ± 2.1# (19 – 27)	18.5 ± 2.2Δ (15 – 22)	21.5 ± 1.6 (19 – 24)	P = 0.001
Height (cm)	177.9 ± 8.5 (162.9 – 197)	177.3 ± 9.5 (160 – 191.5)	173.8 ± 8.6 (159 – 188.2)	P = 0.37
Body mass (kg)	80.0 ± 16.9 (53 – 120)	71.88 ± 11.2 (50.1 - 92.8)	71.3 ± 13.8 (53.3 - 95.9)	P = 0.09
BMI	25.0 ± 3.6# (18.9 - 34.5)	22.8 ± 2.1 (19 – 25.7)	23.5 ± 3.4 (17.9 – 30.6)	P = 0.05

Statistically significantly different form the water-based athletes (p < 0.01)

Δ Statistically significantly different form the control group

* Statistically significantly different form the control group

C. Anthropometric characteristics

Table 8 shows that the rugby players' percentage body fat was statistically significant higher than the male subjects in the control group (P < 0.001), while the netball players also had a higher percentage body fat compared to the female swimmers (P < 0.004). Although there were no statistically significant differences between the groups in terms of sitting height, arm length and arm span, swimmers tended to have wider arm spans and longer arm lengths than the other groups. Overall, rugby players tended to have statically significantly greater limb girths compared to the swimmers (p < 0.05). There were, however, no significant difference between the women groups with regards to girths and most of the breadth measurements. The only exception was the biiliocristale breadth, which was statistically significantly less in the netball players, compared to the swimmers and the control group (Table 9).

Table 8: The percentage body fat and limb lengths of the individual groups (n = 62)

Variable	Netball (n=14)	Rugby (n=15)	Swimmers (women: 8; men: 12)	Control (women: 6; men:7)	P-value
% Fat					
Women	20.6 ± 4.6		16.2 ± 2.5*	18.6 ± 2.4	P = 0.02
Men		12.0 ± 3.1□	7.2 ± 1.5	9.7 ± 3.8	P = 0.0005
Sum of 8 Skinfolds(cm)					
Women	118.8 ± 36.7		82.7 ± 21.5	103.4 ± 20.1	P = 0.03
Men		91.4 ± 26.2 \$	51.9 ± 14.6	71.0 ± 34.0	P = 0.001
Lengths (cm)					
Sitting Height					
Women	93.4 ± 12.0		91.2 ± 4.2	88.7 ± 2.7	P = 0.57
Men		96.9 ± 6.2	97.7 ± 4.5	94.8 ± 3.0	P = 0.50
Arm Length					
Women	75.3 ± 3.0		76.7 ± 7.6	72.67 2.41	P = 0.3
Men		81.3 ± 3.5	82.6 ± 2.1	79.5 ± 2.6	P = 0.10
Arm Span					
Women	175.6 ± 7.3		173.1 ± 7.9	168.8 ± 4.9	P = 0.16
Men		188.8 ± 7.2	190.5 ± 5.7	184.8 ± 5.1	P = 0.17

* Statistically significantly different from the netball players (p < 0.004)

\$ Statistically significantly different from the men swimmers (p < 0.001)

□ Statistically significantly different from the male control subjects (p < 0.001)

% Fat = percentage body fat estimated from the \sum of 6 skinfolds

Table 9: The limb girths of the individual groups (n = 62)

Variable	Netball (n=14)	Rugby (n=15)	Swimmers (women: 8; men: 12)	Control (women: 6; men:7)	P - value
Girths (cm)					
Arm relaxed					
Women	27.75 ± 2.1		28.09 ± 2.9	26.95 ± 3.3	P = 0.71
Men		34.63 ± 3.5 \$	30.85 ± 2.1 ■	33.11 ± 2.2	P = 0.01
Arm flexed					
Women	28.64 ± 3.0		29.50 ± 3.0	27.83 ± 3.1	P = 0.59
Men		37.37 ± 3.0 \$□	33.54 ± 2.6	35.27 ± 1.5	P = 0.003
Chest					
Women	86.92 ± 3.7		87.89 ± 4.8	84.57 ± 7.7	P = 0.47
Men		102.08 ± 7.2	98.37 ± 4.8	99.49 ± 6.1	P = 0.30
Waist					
Women	70.81 ± 4.0		72.35 ± 4.5	70.75 ± 8.2	P = 0.78
Men		88.88 ± 8.5 \$	80.08 ± 5.6	82.63 ± 10.2	P = 0.02
Gluteal					
Women	99.51 ± 5.1		96.50 ± 6.6	95.48 ± 2.8	P = 0.22
Men		104.77 ± 6.7 \$	96.78 ± 4.7	100.14 ± 5.6	P = 0.005
Calf					
Women	37.38 ± 2.6		36.28 ± 2.8	35.37 ± 2.3	P = 0.27
Men		40.01 ± 2.1 \$	37.65 ± 2.2	37.83 ± 2.9	P = 0.03

\$ Statistically significantly different from the men swimmers (p < 0.001)

■ Statistically significantly different from the male control subjects (p < 0.05)

Table 10: The limb breadths of the individual groups (n = 62)

Variable	Netball (n=14)	Rugby (n=15)	Swimmers (women: 8; men: 12)	Control (women: 6; men:7)	P - value
Breadths (cm)					
Humerus					
Women	6.71 ± 0.3		6.86 ± 0.4	9.18 ± 0.4	P = 0.08
Men		7.42 ± 0.6	7.78 ± 0.4	10.07 ± 0.9	P = 0.19
Femur					
Women	9.46 ± 0.4		9.24 ± 0.4	9.18 ± 0.4	P = 0.28
Men		10.11 ± 0.8	10.14 ± 0.5	10.07 ± 0.9	P = 0.98
Biacromial					
Women	38.23 ± 2.0		39.46 ± 2.5	37.50 ± 4.3	P = 0.40
Men		42.61 ± 2.7	43.46 ± 3.3	44.57 ± 1.8	P = 0.30
Billiocrystal					
Women	27.71 ± 2.0 Δ		30.31 ± 3.1*	32.62 ± 4.8	P = 0.01
Men		30.75 ± 2.8 □	32.01 ± 2.2	33.57 ± 2.0	P = 0.05

* Statistically significantly different from the netball players (p < 0.001)

Δ Statistically significantly different from the control group (p < 0.05)

In Table 11 and 12 the anthropometry values of the land- , water-based athletes and control group subjects were compared. Land- based athletes had statistically significantly higher percentage body fat values and skinfold thickness compared to the water- based athletes ($P < 0.001$). Water –based athletes, on the other hand, had lower skinfold thickness than the control group ($P < 0.05$).

Land –based athletes’ gluteal girths and calf girths was statistically significantly larger compared to the water – based athletes and the control group (Table 12). The land – based athletes had statistically significantly lower biliocristale values compared to the water –based athletes and the control group ($P = 0.001$ and $P = 0.01$ respectively).

Table 11: The percentage body fat and limb lengths of the land- and water-based athletes and the control subjects (men and women combined)

Variable	Land-based athletes (n = 29)	Water-based Athletes (n = 20)	Control (n = 13)	P - value
% Fat	16.4 ± 6.0#	11.03 ± 4.9	13.8 ± 5.6	P = 0.01
Sum of 8 Skinfolde(cm)	105.5 ± 34.9#	64.2 ± 23.1Δ	86.0 ± 32.06	P = 0.0001
Lengths (cm)				
Sitting Height	95.0 ± 9.4	95.1 ± 5.3	92.0 ± 4.2	P = 0.4
Arm Length	78.4 ± 4.4	80.2 ± 5.7	76.35 ± 4.29	P = 0.3
Arm Span	182.4 ± 9.8	183.5 10.9	177.4 ± 9.6	P = 0.21

Statistically significantly different from the water-based athletes ($p < 0.001$)

Δ Statistically significantly different from the control group ($p < 0.05$)

Table 12: The limb girths and breadths of the land- and water-based athletes and the control Subjects (men and women combined)

Variable	Land-based athletes (n = 29)	Water-based Athletes (n = 20)	Control (n = 13)	P - value
Girths (cm)				
Arm relaxed	31.3 ± 4.5	29.7 ± 2.7	30.3 ± 4.1	P = 0.4
Arm flexed	33.2 ± 5.3	31.9 ± 3.4	31.8 ± 4.5	P = 0.6
Chest	94.8 ± 9.6	94.2 ± 6.9	92.6 ± 10.2	P = 0.8
Waist	80.2 ± 11.3	77.0 ± 6.4	77.1 ± 10.9	P = 0.5
Gluteal	102.2 ± 6.5 # *	96.7 ± 5.3	98.0 ± 5.0	P = 0.004
Calf	38.7 ± 2.7# *	37.1 ± 2.5	36.7 ± 2.9	P = 0.03
Breadths (cm)				
Humerus	7.1 ± 0.6	7.4 ± 0.6	7.0 ± 0.7	P = 0.1
Femur	9.8 ± 0.7	9.8 ± 0.6	9.7 ± 0.8	P = 0.8
Biacromial	40.5 ± 3.2	41.9 ± 3.5	41.3 ± 4.8	P = 0.4
Biiliocrystal	29.3 ± 2.8 # *	31.3 ± 2.7Δ	33.1 ± 3.4	P = 0.001

Statistically significantly different from the water-based athletes (gluteal p < 0.002; calf p < 0.03)

Δ Statistically significantly different from the control group (p < 0.05)

* Statistically significantly different from the control group (gluteal p < 0.03; calf p < 0.04)

D. Lung function

1. Lung volumes and airflow

Swimmers tend to have higher FVC values compared to the other groups. Male swimmers had statistically significantly higher FVC values compared to the control group ($P < 0.01$) (Fig. 1b). The FVC values of the control group were statistically significantly lower than the land- ($P < 0.001$) and the water- based athletes ($P < 0.00001$) and the land –based athletes' FVC values were also lower than the water – based athletes' FVC values ($P < 0.00001$)(Fig. 1c).

Female and male swimmers had statistically significantly higher FEV₁ values compared to the control group ($P < 0.01$) (Fig. 2 a, b). The FEV₁ values of the control group were statistically significantly less than the water –based athletes ($P < 0.002$) (Fig. 2c) and the land –based athletes ($P < 0.04$). The land –based athletes' FEV₁ values were also statistically significantly less than the water –based athletes FEV₁ values ($P < 0.00001$) (Fig. 2c)

There were no statistically significant differences in terms of PEF values between the water- , land – based athletes and the control group (Table 13 and 14).

Table 13: Peak expiratory flow of the individual groups (n = 62)

Variable	Netball (n=14)	Rugby (n=15)	Swimmers (8=women; 12=men)	Control (6=women;7=men)	P - value
PEF(L.sec ⁻¹) Women	7.62 ± 0.9		7.79 ± 1.2	6.71 ± 0.3	P = 0.09
Men		9.95 ± 1.7	9.18 ± 1.3	9.22 ± 2.7	P = 0.50

Table 14: Peak expiratory flow for land- and water based athletes and the control subjects (men and women combined).

Variable	Land Based Athletes (n=29)	Water Based Athletes (n=20)	Control (n=13)	P - value
PEF(L.sec ⁻¹)	8.83 ± 1.8	8.63 ± 1.4	8.06 ± 2.33	P = 0.45

PEF = Peak expiratory flow

Overall, swimmers had higher FVC values than rugby players and netball players. In all cases, the FVC for the control group was statistically significantly less than in the other relevant groups. Land –based athletes had a wider range for FVC and were evenly distributed. Women and men had higher FEV₁ values, however more than 50% of the group had values above the mean.

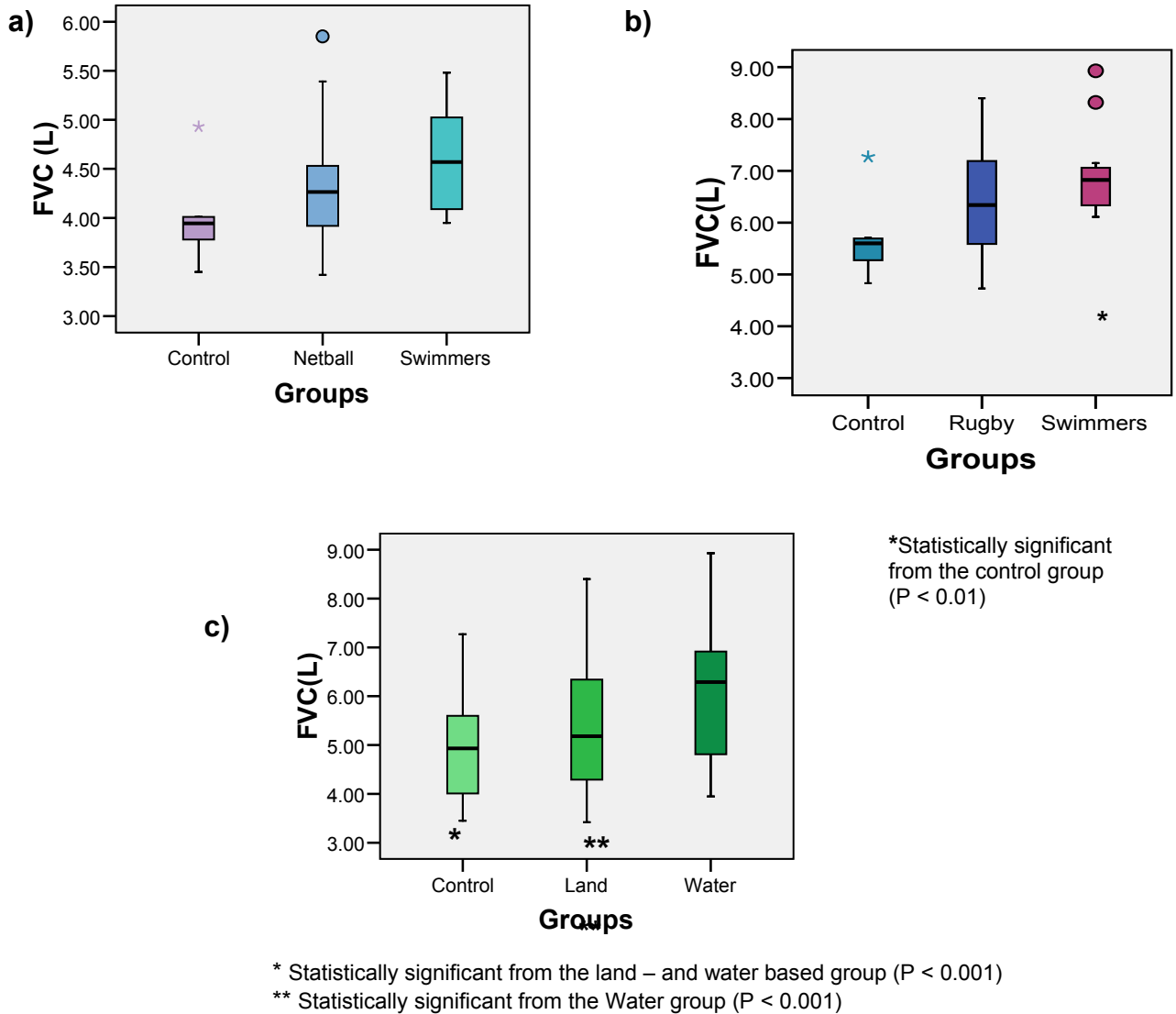
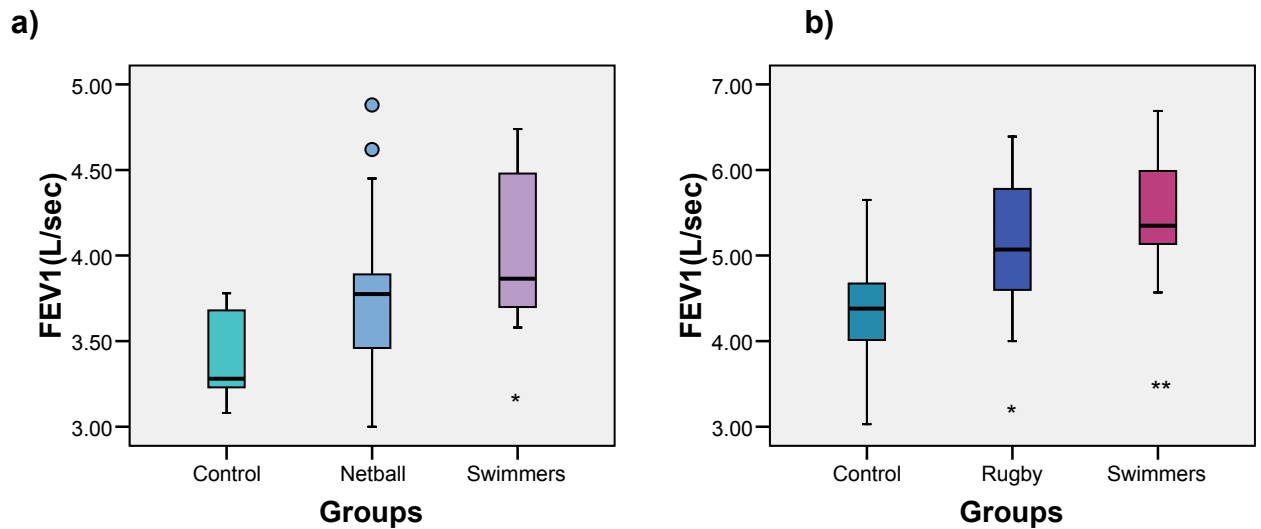
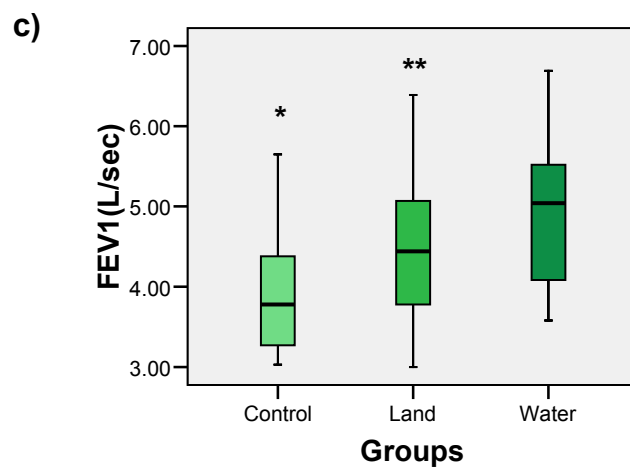


Figure 1: A comparison of the FVC values of the individual groups. a) women athletes and women subjects of the control group b) men athletes and the men of the control group c) land- vs water –based athletes and the control group(men and women).



* Statistically significant from the control group (p < 0.05)

* Statistically significant from the control group (P < 0.05)
 ** Statistically significant from the Control group (P < 0.01)



* Statistically significant from the land – and water based group (P < 0.04)
 ** Statistically significant from the water group (P < 0.001)

Figure 2: A comparison of the FEV₁ values of the individual groups: a) women athletes and women subjects of the control group b) men athletes and the men of the control group c) land- vs water –based athletes and the control group(men and women)

2. Respiratory muscle strength and –endurance

Table 15 shows the respiratory muscle functions of the various groups. Both the netball players and the female swimmers had higher MEP average values compared to the female control subjects. But only the netball players' values were statistically significant higher ($P < 0.03$) than the females in the control group. The female swimmers' values bordered on statistical significance level ($P < 0.05$) when compared to the control group.

In Figure 3, 4 and 5 it is evident that female controls have lower values in all the RM measures than athlete groups, though it is not statistically significant. The difference is less for men (between the controls and athletes). Although not significant, female swimmers had higher maximum MIP values but the range for netball players were larger for netball players, and more than 50% of the group had MIP values above the average. Water – and land –based athletes had more or less the same average MIP values and were evenly distributed around the mean.

Netball players and the female swimmers had higher MEP values compared to the women in the control group. However, the ranges for MEP values were wider for netball players compared to the swimmers. The MEP values for men were the same, but in contrast with the range for MIP, the ranges for MEP values were wider for male swimmers. Not only were the MVV values higher for the men, but the range was also wider. The water –based athletes had statistically significantly higher MVV values compared to the control group ($P < 0.05$)

Sixty and 120 seconds after the performance tests (Table 15), the netball players and the female swimmers had statistically significant higher MIP values compared to the female control subjects ($P < 0.01$ and $P < 0.002$ respectively).

In Table 16 the respiratory muscle function of the land – and water –based athletes and the control group is compared. Sixty seconds after the performance test the water –based athletes' MIP values were statistically significant higher than the land –based ($P < 0.05$) and control group's subjects ($P < 0.001$). One hundred and twenty seconds after the performance test the control group's MIP values were statistically

significant lower than the land- (P < 0.001) and the water –based athletes (P < 0.0005).

Table 15: Respiratory muscle function of the individual groups (n = 62)

Variable	Netball (n=14)	Rugby (n=15)	Swimmers (8=women; 12=men)	Control (6=women;7=m en)	P - value
MIP(avg) cmH₂O					
Women	97.1 ± 26.5		107.8 ± 23.6	76.8 ± 18.3	P = 0.09
Men		145.0 ± 26.5	138.3 ± 26.6	133.3 ± 34.1	P = 0.71
MEP(avg) cmH₂O					
Women	116.2 ± 19.7 Δ		112.5 ± 12.1 $\#$	90.0 ± 22.2	P = 0.02
Men		157.8 ± 29.1	163.00 ± 39.6	160.3 ± 55.9	P = 0.94
MIP60s cmH₂O					
Women	78.5 ± 27.6 Δ		97.6 ± 28.1 $\#$	42.2 ± 23.6	P = 0.003
Men		121.3 ± 32.9	136.0 ± 25.7	91.4 ± 40.8	P = 0.02
MIP120s cmH₂O					
Women	93.9 ± 32.5 Δ		108.4 ± 25.8 $\#$	60.5 ± 19.1	P = 0.02
Men		134.7 ± 27.2	140.1 ± 25.8	108.4 ± 34.1	P = 0.06

MIP(avg) = average maximum inspiratory pressure of 12 maneuvers

MEP(avg) = average maximum expiratory pressure of 12 maneuvers

MIP60s = maximum inspiratory pressure measured 60s after the performance test

MIP120s = maximum inspiratory pressure measured 120s after the performance test

$\#$ Statistically significant from the female control subjects (p < 0.05)

Δ Statistically significant from the female control subjects (p < 0.03)

Table 16: Respiratory muscle function values for land- , water - based athletes and control subjects (men and women combined)

Variable	Land Based Athletes (n=29)	Water Based Athletes (n=20)	Control (n=13)	P - value
MIP(avg) cmH₂O	121.9 ± 35.6	126.1 ± 28.4	107.2 ± 39.7	P = 0.29
MEP(avg) cmH₂O	137.7 ± 32.4	142.8 ± 39.0	127.9 ± 55.7	P = 0.59
MIP60s cmH₂O	100.7 ± 37.0# *	120.7 ± 31.5Δ	68.9 ± 41.2	P = 0.001
MIP120s cmH₂O	115.0 ± 36.0 *	127.4 ± 29.0Δ	86.3 ± 36.8	P = 0.001

MIP(avg) = average maximum inspiratory pressure of 12 maneuvers

MEP(avg) = average maximum expiratory pressure of 12 maneuvers

MIP60s = maximum inspiratory pressure measured 60s after the performance test

MIP120s = maximum inspiratory pressure measured 120s after the performance test

Statistically significant different from the water-based athletes (p < 0.05)

Δ Statistically significant different from the control group (MIP60s p < 0.001; MIP120s p < 0.0005)

* Statistically significant different from the control group (MIP60s p < 0.03; MIP120s p < 0.01)

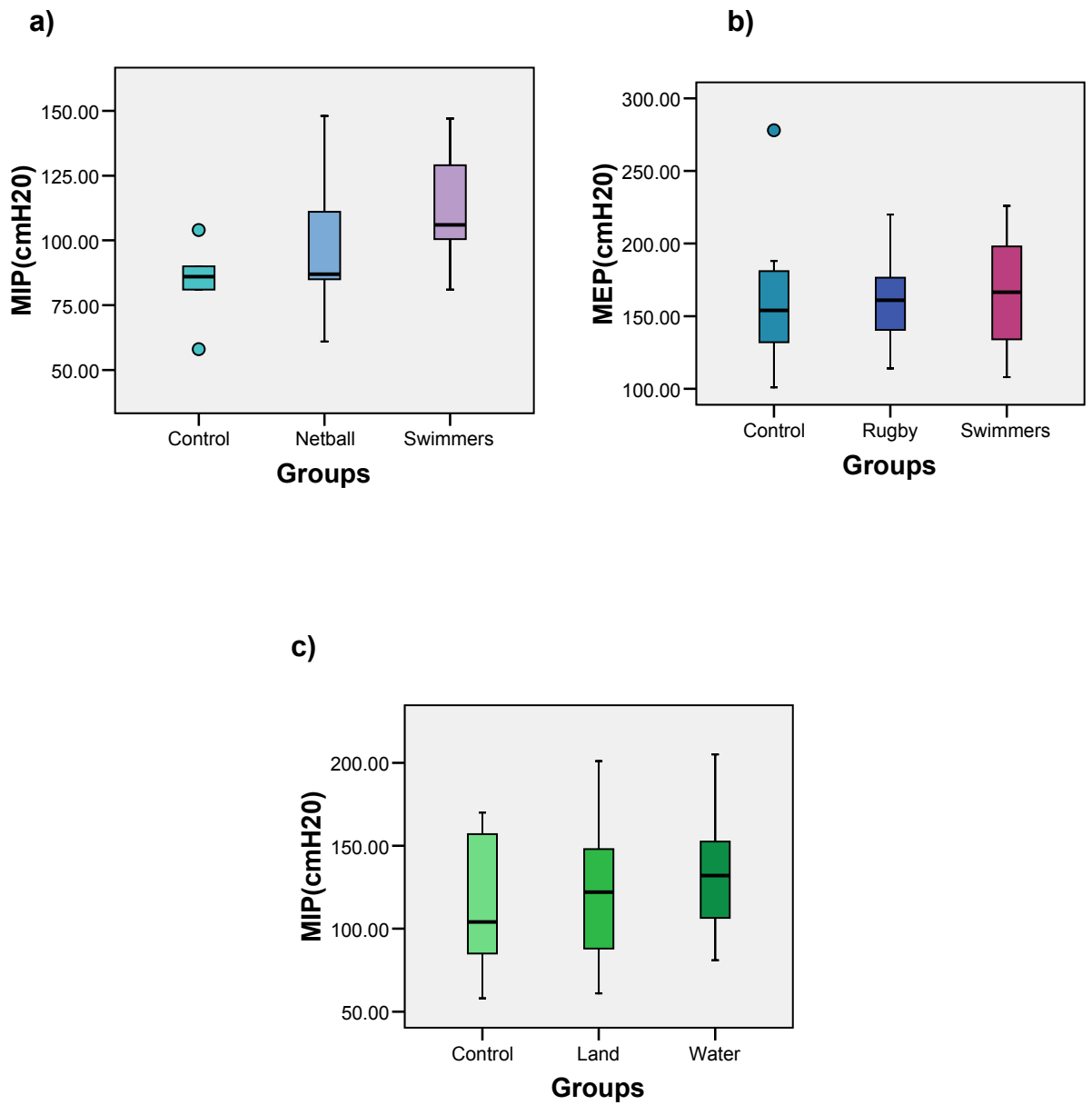


Figure 3: A comparison of the maximum MIP values of the individual groups: a) women athletes and women subjects of the control group b) men athletes and the men of the control group c) land- vs water –based athletes and the control group.

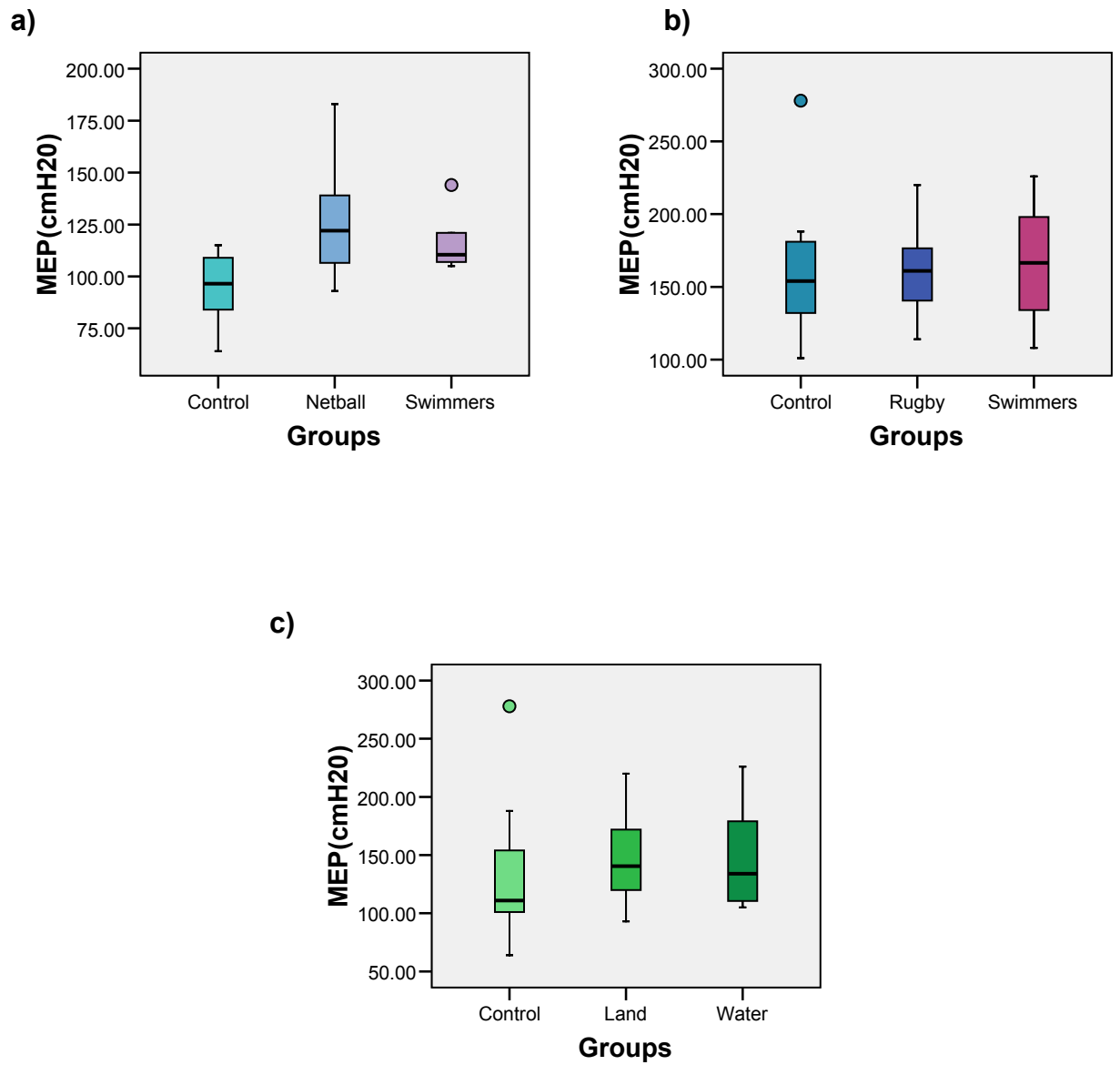


Figure 4: A comparison of the maximum MEP values of the individual groups: a) women athletes and women subjects of the control group b) men athletes and the men of the control group c) land- vs water –based athletes and the control group.

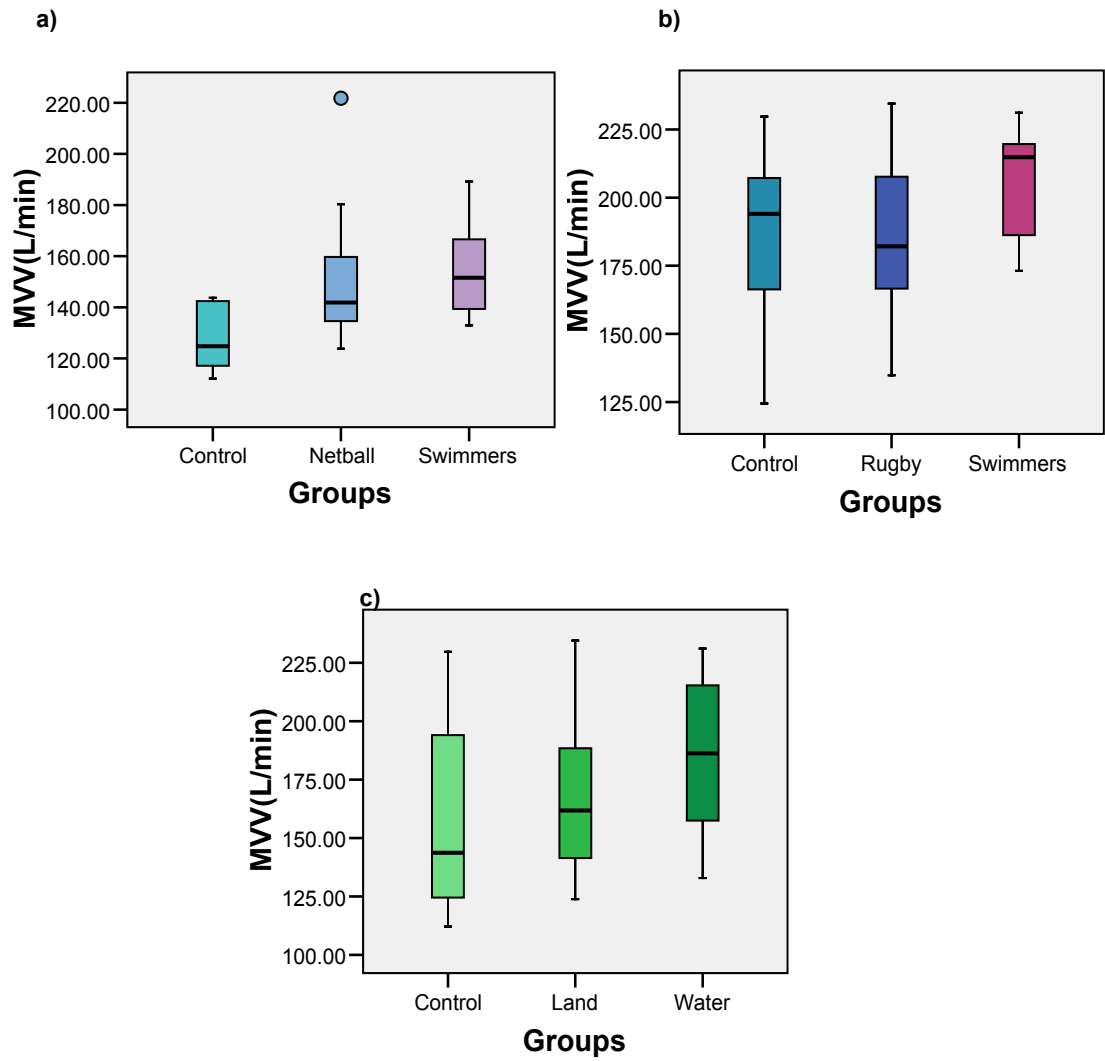


Figure 5: A comparison of the MVV values of the individual groups: a) women athletes and women subjects of the control group b) men athletes and the men of the control group c) land- vs water –based athletes and the control group

3. The relationship between anthropometry and respiratory muscle functions

Lung functions such as FVC and FEV₁ in women showed moderate to strong correlations to height (FVC: r = 0.6; FEV₁: r = 0.55, P < 0.01) body mass (FVC: r = 0.63, P < 0.01) arm length (FVC: r = 0.59, P < 0.01) and arm span (FVC: r = 0.69; FEV₁: r = 0.58; P < 0.01). Lung function in men did not show a strong correlation to body mass, but only to height (FVC: r = 0.69, FEV₁: r = 0.69; P < 0.01), arm length (FVC: r = 0.67, FEV₁: r = 0.68; P < 0.01) and arm span (FVC: r = 0.68, FEV₁: r = 0.68; P < 0.01)

Stepwise multiple regressions were done between anthropometry variables and MIP, MEP and MVV for men and women. For men, height, weight, sitting height, biacromiale breadth and waist girth accounted for 17% of the variance in MIP (P = 0.34). The variance in MEP was accounted for 15.6% by height, weight, sitting height, biacromiale breadth and waist girth (P = 0.41). MVV had a significant regression (P = 0.00005) and arm span and sum of eight skinfolds accounted for 47.3% of the variance in MVV.

For women, weight, sitting height, arm span, biacromiale breadth and chest girth accounted for 28.4% of the variance in MIP (P = 0.17), but MEP was accounted for only 22% by sitting height, arm length, arm span and body mass index as well as chest girth (P = 0.32). Women's MVV also had a significant regression (P = 0.002) and weight, arm span and sum of eight skinfolds accounted for 45% of the variance in MVV.

The resulting regression equations to predict MIP, MEP and MVV for men and women were:

MEN

$$1. \text{ MIP} = 205.31 - (1.11 \times \text{Height}) + (0.96 \times \text{Body mass}) + (1.66 \times \text{Sitting Height}) + (0.86 \times \text{Biacromiale breadth}) - (1.61 \times \text{Waist girth}) \dots \dots \dots 8.1$$

Where MIP is the maximum inspiratory pressure in cmH₂O and height, sitting height, biacromiale breadth and waist girth are in centimeters and body mass in kilograms.

$$2. \text{ MEP} = 295.55 - (2.20 \times \text{Height}) + (0.86 \times \text{Body mass}) + (2.55 \times \text{Sitting Height}) + (2.81 \times \text{Biacromiale breadth}) - (2.03 \times \text{Waist girth}) \dots \dots \dots 8.2$$

Where MEP is the maximum expiratory pressure in cmH₂O and height, sitting height, biacromiale breadth and waist girth are in centimeters and body mass in kilograms

$$3. \text{ MVV} = -312.51 + (2.83 \times \text{Arm span}) - (0.38 \times \text{Sum of 8 skinfolds}) \dots \dots \dots 8.3$$

Where MVV is the maximum voluntary ventilation in L.min⁻¹ and arm span is in centimeters and sum of 8 skinfolds in millimeters.

WOMEN

$$1. \text{ MIP} = -308.63 - (1.40 \times \text{Body mass}) + (1.17 \times \text{Sitting Height}) + (1.24 \times \text{Arm Span}) + (1.5 \times \text{Biacromiale breadth}) + (1.40 \times \text{Chest girth}) \dots \dots \dots 8.4$$

Where chest girth, sitting height, biacromiale breadth and arm span are in centimeters and body mass in kilograms

$$2. \text{ MEP} = -140.60 + (0.80 \times \text{Sitting Height}) - (0.40 \times \text{Arm Length}) + (1.21 \times \text{Arm Span}) - (2.7 \times \text{BMI}) + (0.82 \times \text{Chest girth}) \dots \dots \dots 8.5$$

Where sitting height, arm length, arm span and chest girth is in centimeters and BMI is the body mass index (BMI = weight / height² (m))

$$3. \text{ MVV} = -106.7 + (1.5 \times \text{Body mass}) + (1.0 \times \text{Arm span}) - (0.2 \times \text{Sum of 8 skinfolds}) \dots \dots \dots 8.6$$

Where body mass is in kilograms and arm span is in centimeters and sum of 8 skinfolds are in millimeters.

4. The relationship between lung function and respiratory muscle function

In women there were strong correlations between RM endurance, FVC and FEV₁ significant. These correlations were slightly less in men. In both groups, high FVC

were associated with high FEV₁ values. Overall, however, there were not a strong relationships between RM function and lung functions.

Table 17: Correlations between respiratory muscle function and lung function (men and women)

	MIP(avg)	MEP(avg)	MIP(max)	MEP(max)	FVC	FEV1	PEF	MMV
Men (n =34)								
MIP(avg)	1							
MEP(avg)	0.53	1						
MIP(max)	0.98*	0.55	1					
MEP(max)	0.54	1.00**	0.56	1				
FVC	0.18	0.05	0.19	0.06	1			
FEV1	0.13	-0.03	0.16	-0.03	0.84*	1		
PEF	0.02	0.06	0.07	0.06	0.24	0.47	1	
MMV	0.09	0.02	0.13	0.01	0.54	0.73*	0.50	1
Women(n=28)								
MIP(avg)	1							
MEP(avg)	0.70*	1						
MIP(max)	0.97*	0.67	1					
MEP(max)	0.66	0.72*	0.76*	1				
FVC	0.22	0.12	0.25	0.35	1			
FEV1	0.41	0.17	0.44	0.40	0.88*	1		
PEF	0.10	0.06	0.05	0.05	0.43	0.55	1	
MMV	0.45	0.27	0.42	0.28	0.71*	0.83*	0.56	1

* Strong correlations with statistically significance ($p < 0.01$)

** Strong correlations with statistically significance ($p < 0.10$)

E. Performance test

Netball players covered a statistically significantly greater distance in the repeated sprint compared to the women in the control group ($P < 0.0002$). However, there was no difference in the performance of the rugby players, compared to the control group. In all cases, subjects exercised at an intensity that was more than 90% of their age predicted maximal heart rates and the subjects ran for at least three minutes.

1. Repeated sprint

Table 18: Results of the repeated sprint test in individual groups

Variable	Netball (n=14)	Rugby (n=15)	Control (women=6; men=7)	P value
Distance (m)				
Women	647.1 ± 37.8 Δ		509.2 ± 6	P = 0.001
Men		686 ± 35.7	672.9 ± 5	P = 0.2
Average HR (bpm)				
Women	169.5 ± 24.2		155.0 ± 16.5	P = 0.2
Men		168.5 ± 9.73	162.9 ± 8.00	P = 0.2
% pred HR				
Women	95.9 ± 8.8 Δ		91.0 ± 0.04	P = 0.001
Men		97.1 ± 10.0	93.0 ± 0.02	P = 0.4

Δ Netball players are statistically significant from the female control subjects
Age-predicted heart rate was calculated as 220 – age.

2. Swim test

Women tended to swim at an intensity that was slightly less than the men (88.5 ± 0.04 and 94.31 ± 10.70% respectively). On average each swimmer sprinted for 3.21 minutes.

Table 19: Results of the speed endurance test for the swimmers

Variable	Swimming (8=women; 12=men)
Time(sec)	
Women	36.8 ± 3.7
Men	32.3 ± 4.0
Average HR(bpm)	
Women	150.9 ± 34.9
Men	158.0 ± 22.5
% pred HR	
Women	88.5 ± 0.04
Men	94.31 ± 10.70

3. The relationship between respiratory muscle function and the performance test

The average distance covered in the repeated sprint for the rugby- and netball players were compared to their average MIP, MEP, FVC and MVV values. Swimmers' average time for their 6 x 50 meters sprints were also compared to the mentioned respiratory muscle functions.

Moderate correlations were observed between the repeated sprint and inspiratory muscle strength ($r = 0.63$, $P < 0.01$) (Fig. 6a) and expiratory muscle strength ($r = 0.66$, $P < 0.02$) (Fig. 6b). Respiratory muscle endurance ($r = 0.37$, $P < 0.02$) (Fig. 6c) and FVC ($r = 0.36$, $P < 0.10$) (Fig. 6d) showed poor correlations to the repeated sprint. The sprint endurance test in the pool showed moderate correlations to inspiratory muscle strength ($r = -0.55$, $P < 0.01$) (Fig. 7a) and expiratory muscle strength ($r = -0.55$, $P < 0.02$) (Fig. 7b) as well as respiratory muscle endurance ($r = -0.51$, $P < 0.02$) (Fig. 7c) and a weak correlation to FVC ($r = -0.35$, $P < 0.10$) (Fig. 7d).

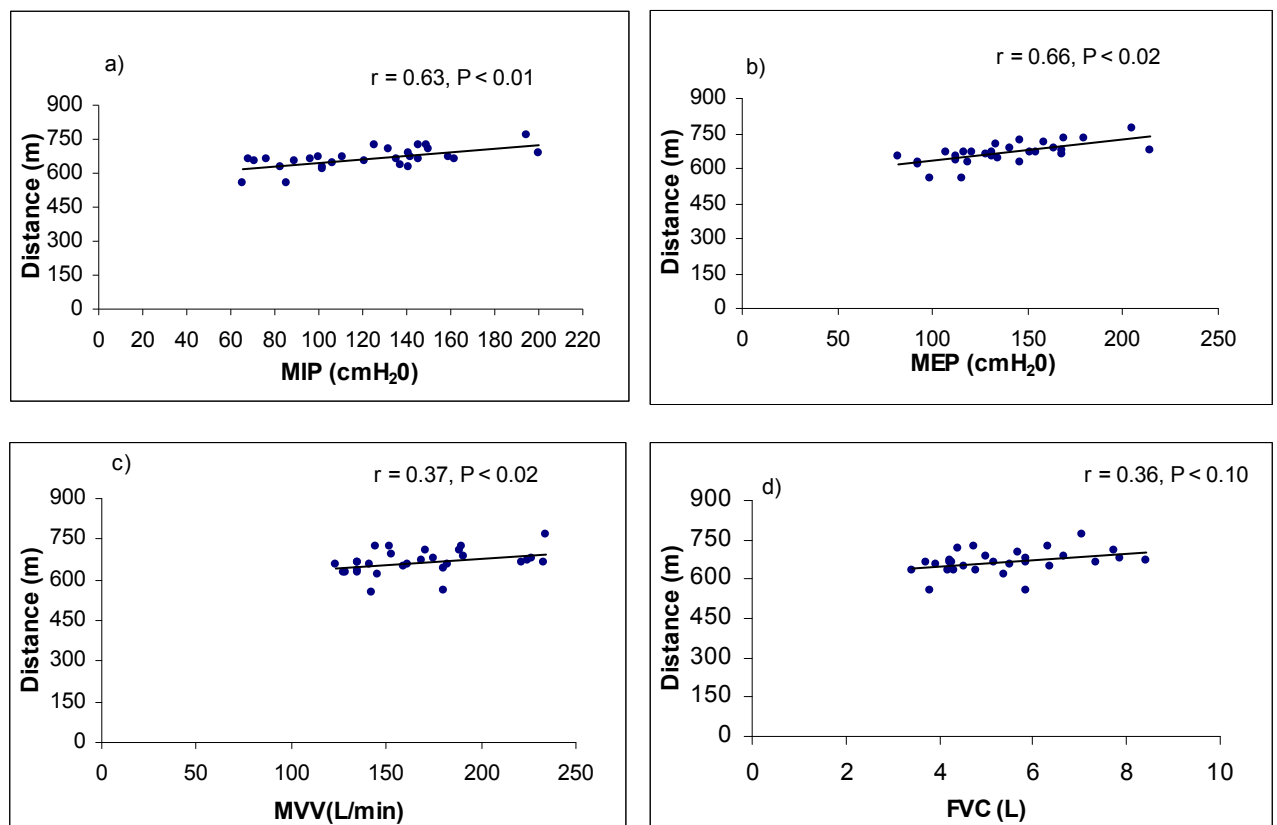


Figure 6: Relationships between various outcome variables and a speed endurance performance test on land: a) MIP b) MEP c) MVV d) FVC (r : Pearson correlation coefficient, solid line: regression line)

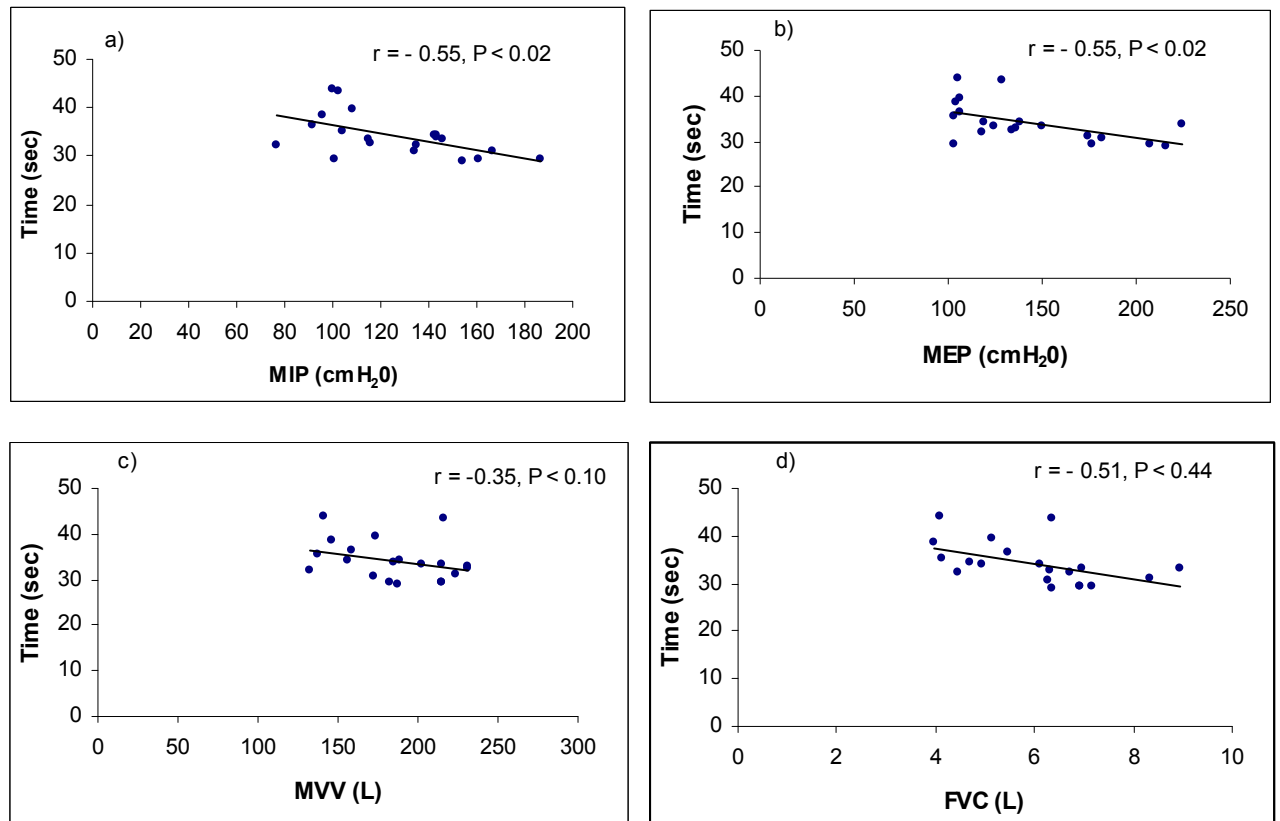


Figure 7: Relationships between various outcome variables and a speed endurance performance test in the water: a) MIP b) MEP c) MVV d) FVC (r: Pearson correlation coefficient, solid line: regression line.)

F. Respiratory muscle fatigue

In Table 20 the degree of respiratory muscle fatigue is indicated for each group. Both the rugby players' and the control subjects' respiratory fatigue (determined by the maximum MIP values) were higher 60 seconds after the performance test compared to the male swimmers. However, the degree of fatigue was more for the men in the control group ($P < 0.02$) compared to the male swimmers. The RM fatigue of the female subjects in the control group also was statistically significantly higher compared to the female swimmers ($P < 0.01$).

In Table 21 the degree of respiratory muscle fatigue is compared between the land -, water -based athletes and the control group (using the average MIP values). The degree of RM fatigue 60 seconds after the performance test was statistically significantly more in land -based athletes compared to water -based athletes ($P < 0.01$). Nevertheless, both the degree of RM fatigue in water - and land based

athletes were statistically significantly less compared to the control subjects ($P < 0.0002$ and $P < 0.01$ respectively). This degree of fatigue for the land – and water – based athletes compared to the control group stayed true for 120 seconds after the performance test ($P < 0.001$ and $P < 0.03$ respectively).

Table 20: Respiratory muscle fatigue of the individual groups (n = 62)

Variable	Netball (n=14)	Rugby (n=15)	Swimming (8=women; 12=men)	Control (6=women;7=men)	P - value
RMF60s(max)cmH₂O					
Women	-40.7 ± 36.0		-13.0 ± 17.4	-50.4 ± 21.4	P = 0.06
Men		-17.8 ± 19.2\$	-6.4 ± 6.8■	-32.9 ± 21.8	P = 0.01
RMF120s(max) cmH₂O					
Women	-8.7 ± 25.3		-3.4 ± 11.4	-28.5 ± 16.5	P = 0.09
Men		-8.2 ± 17.4	-3.6 ± 6.5■	-21.4 ± 12.2	P = 0.03
RMF60s(avg) cmH₂O					
Women	-19.3 ± 19.8Δ		-9.5 ± 17.4#	-44.8 ± 22.9	P = 0.01
Men		-15.8 ± 19.2\$	-1.2 ± 8.4■	-31.05 ± 22.5	P = 0.003
RMF120s(avg) cmH₂O					
Women	-2.9 ± 24.7		0.5 ± 10.2	-19.51 ± 22.0	P = 0.21
Men		-5.9 ± 17.3	1.7 ± 8.0■	-19.0 ± 13.9	P = 0.01

Statistically significant from the female control subjects ($p < 0.01$)

Δ Statistically significant from the female control subjects ($p < 0.04$)

\$ Statistically significant from the men swimmers (RMF60s max = $p < 0.05$; RMF60s avg. = $p < 0.02$)

■ Statistically significant from the male control subjects (RMF60s max = $p < 0.02$; RMF120s max, avg. = $p < 0.01$)

Table 21: Respiratory muscle fatigue of land -, water –based athletes and the control subjects

Variable	Land Based Athletes (n=29)	Water Based Athletes (n=20)	Control (n=13)	P - value
RMF60s(avg) cmH ₂ O	-17.5 ± 19.6# *	-4.5 ± 12.7Δ	-37.4 ± 22.9	P = 0.01
RMF120s(avg) cmH ₂ O	-4.5 ± 21.4	1.2 ± 8.5Δ	-19.3 ± 17.2**	P = 0.002

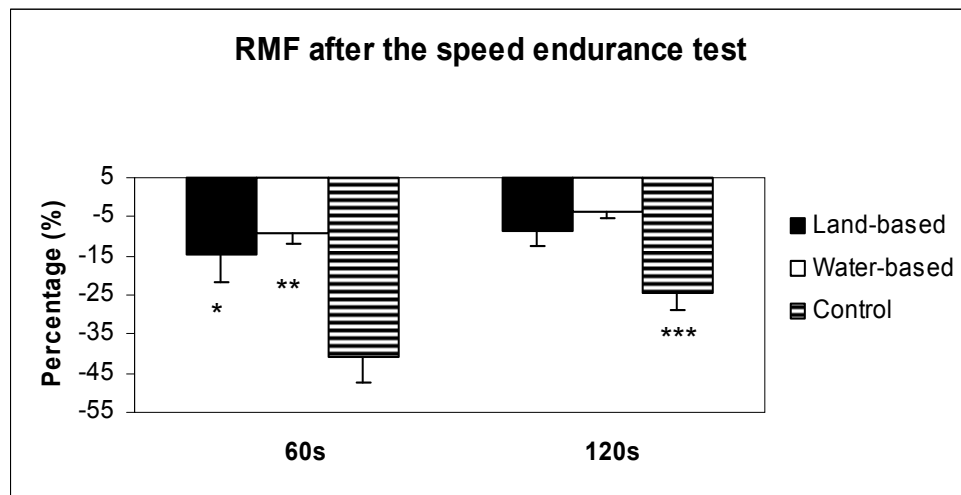
Statistically significant different from the water-based athletes (p < 0.01)

Δ Statistically significant different from the control group (RMF60s avg. = p < 0.0002, RMF120s avg. = p < 0.001)

* Statistically significant different from the control group (RMF60s avg. = p < 0.01; RMF120s avg. = p < 0.03)

** Statistically significantly different from the land –based athletes (p < 0.03)

The degree of RM fatigue (determined by the maximum MIP value, Fig. 8) was more for both the land –based athletes and the control group compared to the water –based athletes. This observation stayed true for after 120 seconds (24.64 ± SD14.21% vs 3.54 ± SD8.3%, P < 0.0001). Sixty seconds after the performance test the land –based athletes’ RM fatigue were statistically significantly higher (P < 0.01) compared to the water –based athletes. Although there was still a difference after 120 seconds, this difference was not statistically significant.



* Statistically significantly different from water-based athletes (p < 0.01)

** Statistically significantly different from control group (p < 0.001)

*** Statistically significantly different from the water – and land based group (p < 0.01)

Figure 8: Comparing the degree of fatigue after the speed endurance test between the land -, water –based and the control subjects.

CHAPTER 8

DISCUSSION

A. Introduction

Evidence has been provided for the role of the respiratory system as a limiting factor during exercise and that improved RM function can lead to an increase in performance. Few research have been done to determine predictors of RM function. Therefore, it is important for the respiratory system to be studied, especially the respiratory system of athletes, to determine factors which influence lung – and RM function.

B. The relationship between anthropometry and respiratory muscle function

Many studies in the literature report on the anthropometric characteristics of athletes in different sport and it is clear that there are distinct differences in the morphology of athletes and the general population. Some of these anthropometric characteristics have been correlated with various physiological functions, and in this respect the associations between anthropometry and lung functions are well known. Anthropometry has also been correlation with various performance outcomes, specifically endurance performance. For instance, Tittel and Wutsherck (1992) stated that an anthropometry variable such as body mass correlates with endurance performance.

The relationships between physical characteristics, sport performance and respiratory muscle function in healthy, active athletes are, however, less well described.

1. Determinants of lung function

In this study, both height and body mass correlated with FVC in men and women ($r = 0.63 - 0.69$; $P < 0.01$ and $r = 0.40 - 0.62$; $P < 0.01$). Similar correlations were found for FEV₁. These findings are in agreement with those of Leech *et al.* (1983), although their subjects were healthy non-athletes.

Land –based athletes were taller and heavier than water –based athletes, but land –based athletes did not have better lung functions compared to water –based athletes. The reason for this could be assigned to the effect of water training on lung functions. One of the effects of swim training is the increase in total lung capacity (TLC). This increase in TLC could be the reason for the higher FEV₁ values observed in the water –based athletes (Clanton *et al.*, 1987).

No correlation was found between lung functions such as FVC, FEV₁ and PEF and percentage body fat. This finding is in contrast to the study by Lazarus *et al.* (1998), who found a negative correlation between percentage body fat and FVC. The reason for this could be the fact that the subjects tested in this study, was healthy and active athletes compared to the healthy untrained subjects used by Lazarus *et al.* (1998). Another reason could be the difference in age range. The subjects used in Lazarus *et al.* (1998) study were much older. It is known that percentage body fat increase with age and because the subjects in this study were much younger, it could be possible why no correlation was found. The fact that the range for % BF in this study was large, could also explain why no correlation was found between lung function and % BF.

The findings of this study also indicate that other anthropometric variables than height, body mass and body fat may be important determinants of lung function. Some of those measures include arm length and sitting height. The importance of these variables as possible predictors of lung function in an athletic population should be investigated.

2. Determinants of respiratory muscle function

It is understandable why most studies involved elderly subjects. Traditionally, the measurement of RM function was only clinically relevant. It is known that MIP decreases with respiratory diseases such as COPD (Nishimura *et al.*, 1995), degenerative neuromuscular diseases (Folio *et al.*, 1994), congestive heart failure (Ambrosino *et al.*, 1994) and during long-term corticosteroid treatment (Perez *et al.*, 1996). Therefore, this study was performed to determine the RM function of a young athletic population.

MIP is an indicator of inspiratory muscle strength and MEP is an indicator of expiratory muscle strength. Overall, men had a 68% higher average MIP and MEP value and a

70% higher maximum MIP and MEP value compared to women. These findings are in agreement with Harik-Khan *et al.* (1998), who reported, 30% higher MIP values in men compared to women in an untrained group. Therefore gender is an important determinant of RM strength. Not only is gender an important determinant for sedentary subjects, but also in athletes as Fuso *et al.* (1996) stated that female gender has a negative correlation to RM strength in elite soccer players. Furthermore, biacromiale breadth, waist girth and chest girth were also incorporated in our predictive equations for RM Strength, although they were not significant. Table 6 and 9 showed that rugby players had a significantly higher body mass and waist girth compared to male swimmers, which explains why both these variables were part of the regression equations for MIP and MEP in men.

In agreement with previous studies (Black and Hyatt, 1969; McConnel *et al.*, 1997 and McConnell and Copestake, 1999) there was no association between RM strength and height and body mass on its own. However, with multiple regressions, height was included into the equations for MIP and MEP in men and not for women, but these equations was not significant. Harik-Khan *et al.* (1998) also included height in their equation for MIP in women. By comparing the regression equation for MIP by Harik-Khan *et al.* (1998) to the regression equation from this study, it seems that for MIP for men obtained by this study would be 6.8% higher and the MIP for women would be 17.7% higher.

There was no significant difference in MIP (3.33%) and MEP (3.5%) values between land – and water –based athletes, even though land –based athletes were taller and heavier. This result demonstrates that different kinds of training (land versus water) does not have an effect on inspiratory – and expiratory muscle strength.

McConnell and Copestake (1999) suggested that RM strength is strongly influenced by physical activity. However, the control subjects in this study RM function values did not differ from the athletes. Therefore, it is possible that physical activity is not such a strong determinant of RM strength. Even so, it could be because the athletes were not that well trained or the control group was not that untrained. Another reason could be that team sports such as netball and rugby do not lead to the same training adaptations such as in the case with endurance training. The subjects in McConnell and Copestake (1999) study were also much older than this study's population. It is known that elderly people

benefit from physical activity and therefore it is possible that McConnell and Copestake (1999) concluded a relationship between RM strength can be determined by physical activity. On the contrary, it is possible that because this population was young and active the effect of physical activity could not be seen.

The fact that there was no significant difference in terms of RM strength between the various groups, it is possible that the same predictions equations can be used in sports like swimming, rugby and netball to predict RM strength.

3. Determinants of respiratory muscle endurance

On average men had a 76% higher average MVV value compared to women. The male runners in the study by Pringle *et al.* (2005) also had a 78% higher average MVV value compared to women.

For both men and women, height was a significant determinant of RM endurance, while body mass in women was also a significant variable in the regression equation. This is in agreement with the findings of Fiz *et al.* (1998), although that study was based on older, healthy non-athletes (age: 20 - 70). A possible reason why body mass and height were positively correlated to RM endurance in this study could be because athletes are known to have more specific morphological characteristics i.e. they could be taller and heavier than age-matched controls. Those specific anthropometric characteristics are very sport-specific. The findings of this study also suggest that other variables, such as arm span and sum of skinfolds, may also be important predictors of RM endurance. Both these variables were included in the regression equation.

Although a number of investigators have reported reference values for RM function, these values span over relatively wide age ranges and may only be applicable to the general population, including healthy and diseased individuals. It is therefore unlikely that these reference values may be applicable to athletic populations. If the measurement of respiratory muscle function is to be included in routine medical screening of athletes and for the monitoring of interventions, such as respiratory muscle training, one has to ensure that the measurements are accurate and reproducible.

There are a diverse number of factors that can contribute to the wide array of reference values that are reported in the literature which include the wide range of populations in terms of age distribution, ethnicity, health status and different methodologies and equipment used to measure RM function.

C. Respiratory muscle function and athletic performance

Most team sports, like netball and rugby, require fitness attributes like speed and speed endurance to perform short burst movements. The repeated sprint test is a measure of determining the speed endurance ability of a player and the movements of a netball and rugby player are simulated best by the repeated sprint test. As mentioned earlier (Chapter 4), very little information exists regarding RM function of athletes performed outside a laboratory to assess the relationship between RM function and performance. To answer whether RM function is important for the performance of athletes, the performance of the subjects in the repeated sprint test was compared to their RM functions such as MIP, MEP, MVV and FVC.

Both the land – and water –based athletes' RM function correlated with the speed endurance test, even though MIP and MEP of the water –based athletes showed a weaker correlation to the speed endurance test in the water, which can be explained by the wider variation around the regression line (Figure 7 a, b). The variation could be assigned to the fact that the water –based group's subject could have been on a different competition level as the average age of the water –based group was significantly lower than the land –based athletes.

MIP ($P < 0.02$) and MEP ($P < 0.02$) are the best predictors of performance in the speed endurance test, followed by MVV ($P < 0.10$) and FVC ($P < 0.44$). Therefore, both RM strength and RM endurance can be predictors of performance in the speed endurance test and possibly predictors of performance on the field, court and in the pool.

It has been confirmed by studies that RM functions are important determinants of athletic performance (Harms *et al.*, 2000 and Pringle *et al.*, 2005). The study by Mador and Acevedo (1991) demonstrated that if exercise is performed with fatigued RM, there would be a decline in performance. Although these studies were performed on endurance athletes such as cyclists and runners and different performance test were

used, it is possible that the netball and rugby players will not only perform better in the speed endurance test but also on the court and field. This is an important finding, because no other studies on team sports like netball and rugby have investigated the relationship between RM function and their performance.

As mentioned above, it is possible that RM endurance is more important to endurance type of sports or sport performed in the water, as Pringle *et al.* (2005) showed a correlation between MVV and performance in a 10km race. However, this importance of RM endurance to swimmers was not clearly demonstrated by the relationship between the speed endurance test in the water and MVV. It is possible that the speed endurance test in the water also does not reflect the respiratory muscle utilization in a predictable way.

The ideal would have been to compare performance in a game situation to RM function and lung function. However, it is difficult to quantify a player's performance in team sports and would be time consuming. As for practical necessity, the repeated sprint was performed. Both rugby and netball is played at short bursts of high intensities which require energy from the alactic and lactic anaerobic systems. The repeated sprint stresses this energy system and therefore can be used as a replacement for a game.

The relationship between RM function and performance can also be illustrated by the effect of RM training on performance. Although, the majority of RM training studies were done on endurance sports, it is evident that improved RM function would lead to improved performance (Chatham *et al.* 1999; Markov *et al.*, 2001; Volianitis, *et al.*, 2001 Romer and McConnel, 2002).

The reason why there could be a relationship between RM function and performance of athletes can be assigned to the fact that certain adaptations occur in the RM as a result of training. It is believed that different types of training (endurance training vs resistance training vs short and high intensity training such as rugby and netball) would lead to different adaptations of the RM. The majority of research has confirmed that endurance training leads to functional improvement in the endurance capacity of the RM (Cordain *et al.*, 1990; Armour, *et al.*, 1993; Eastwood *et al.*, 2001; Sheel, 2002), however, research has shown that regular endurance training does not strengthen the inspiratory muscles. This was also confirmed by McConnel *et al.* (1997) who found no relationship

between a multi – stage shuttle run and RM strength in moderately trained subjects. Robinson and Kjeldgaard (1982) also reported no changes in the RM strength of subjects after 20 weeks of running. Cordain *et al.* (1987) also reported that runners have lower expiratory muscle strength and is likely to happen. According to Leith and Bradley (1967), there is a balance exists between opposing chest wall and lung elastic recoil forces, and as runners in the study by Cordain *et al.*(1987) exhibited a significantly larger RV than predicted, it explains why no adaptations were observed in expiratory muscle strength.

There was no statistically difference in RM strength and RM endurance between the water –based athletes (swimming which is more of an endurance type activity) and the team sports such as rugby and netball, which means that both endurance and activities of high intensities, but with a shorter duration, can lead to adaptations of the strength and endurance of RM. This finding is in contrast with the above mentioned studies. It must be stated that the water –based athletes had better lung function compared to the land –based athletes. This finding was confirmed by Clanton *et al.* (1987) who stated that swimmers are known to have larger TLC and VC. Cordain *et al.* (1990) stated that the fact that swimmers start their swim training at a significantly younger age than other sports like netball and rugby, could be the reason why swimmers have better lung function than land –based athletes. Another reason for the larger lung function found in swimmers, is that swimmers breathe against the resistance of water and the lungs are forced to expand to total lung capacity. The horizontal position of swimming is the optimal position for the diffusion of respiratory gases and also contributes to swimmers having higher volumes (Cordain *et al.*, 1990). As mentioned above, water –based athletes in this study did not have higher RM function compared to land –based athletes. According to Cordain *et al.* (1990) this finding means that the higher lung function does not lead to better RM function in water –based athletes and a possible cause is that pressures are applied over a larger lung surface area in swimmers.

A better understanding of the effect of weight-bearing exercise on RM function is achieved by the fact that there was no statistical difference in terms of RM function between the land - and water –based athletes. Previous studies only involved endurance type activities and it was believed that whole-body exercise does not stress the respiratory system enough to change and adapt. However, it has been suggested in this study that short-term high intensity training such as rugby and netball may lead to

adaptations of the RM. Therefore it is possible that different kinds of training can lead to adaptations of the RM. This finding is confirmed by the studies of De Palo *et al.* (2004) who concluded an increase in RM strength after a resistance training program and Fuso *et al.* (1996) who also confirmed that different forms of competitive sport may not have different effects on RM strength. Thus, land –based athletes such as netball and rugby do usually get the same level of physical endurance as long –distance runners or swimmers.

D. Degree of respiratory muscle fatigue

There are two potential ways respiratory muscle fatigue may limit human performance, namely through an inadequate ventilatory response to exercise (i.e. alveolar hypoventilation) or by an increased “sensation” of dyspnea. Alveolar hypoventilation may occur because of the respiratory muscles not being able to generate the needed pressure gradient for air flow and gas diffusion, or when an altered breathing pattern, sometimes associated with respiratory muscle fatigue, occurs. An increased sensation of dyspnea could occur as a result of an elevated pressure demand relative to the available pressure-generating capacity, circulating metabolites or metabolites produced within the diaphragm stimulating sensitive receptors, an altered breathing pattern (i.e., increased lung volume causing hyperinflation and increasing the elastic load), or altered respiratory muscle recruitment or motor unit recruitment within a given respiratory muscle. Thus, respiratory (diaphragm) fatigue could occur and influence performance with or without an effect on alveolar ventilation. The diaphragm is similar to Type I locomotor muscles, namely highly oxidative with dense capillary networks and thus highly resistant to fatigue. It has been reported that during exercise at intensities less than 80% VO_{2max} , the diaphragm does not fatigue. However, at higher intensities of sustained exercise, the diaphragm fatigues even though the force output of the diaphragm during exercise is less than the fatigue-threshold during voluntary hyperpnoea at rest (Sheel, 2002).

To determine the fatigue of respiratory muscles, the ability of the respiratory muscles to generate maximal force must be determined. The short or long term respiratory endurance ability can also be measured.

Insights into respiratory muscle fatigability are mostly gathered by using a maximal cycle ergometer test to volitional fatigue (Coast *et al.*, 1990); endurance activities

(cycling, running) or by specifically fatiguing the respiratory muscles through progressive loading of the respiratory muscles until exhaustion is reached. Some investigators have used an incremental breathing test can also fatigue the respiratory muscles. The subject's MIP value is determined. This followed by breathing against a resistive load at a pressure corresponding to a certain pressure of the predetermined MIP value. Usually, expiration is unloaded and breathing frequency is set and paced. The load is increased after a certain time interval by a percentage of MIP. The test stops when the subject is not able to overcome the load (Gonzales and Sheuermann 2006).

It has been confirmed that the diaphragm, which is one of the most important respiratory muscles, can be fatigued by exercise. During exercise there is a redistribution of blood to the working limb muscles (Harms *et al.*, 2000) and there is an elevation in the acid concentrations in the respiratory muscles (Johnson *et al.*, 1996). It is known that this diaphragm fatigue only occurs at relatively high intensities (from 80% of VO_{2max}) (Sheel, 2002).

One of the reasons why controversy exists on the topic of respiratory muscle fatigue in healthy individuals is because of the various methods available to measure RM fatigue. Thus far, researchers have attempted to clarify this issue by (1) measuring respiratory muscle function before and after exercise and calculate the degree of fatigue, and (2) determine the effects of respiratory muscle training versus regular endurance and resistance training on sport performance.

In this study there was a significant decrease in inspiratory muscle strength after the speed endurance test. Fatigue was determined by using the maximum MIP value obtained at baseline as well as the average MIP value. It is obvious that the degree of fatigue would be higher when using the maximum MIP value compared to the average MIP value, as some subjects were not able to produce three efforts of the same intensity at the maximum value achieved. RM fatigue was measured after 60 seconds as well as after 120 seconds. This was done, because the long term effect of exercise have not been studied yet, but rather the short term, because team sports, like rugby and netball, are performed with lots of stop and go movements. Therefore, it is important to know whether the fatigued RM would be able to recover as fast as possible and be ready to perform optimally after a short rest period.

Both the land – and water –based athletes experienced RM fatigue, but 60 seconds after the speed endurance test, the land -based athletes (degree of fatigue measured with the average MIP value) had a significantly higher degree of fatigue compared to the water –based athletes and the control group. One hundred and twenty seconds after the repeated sprint, the RM were less fatigued for the land –based athletes. The water –based group showed an even higher RM strength value compared to baseline values. Determining RM fatigue using the maximum MIP value from baseline lead to a higher degree of fatigue in both the land –based athletes and the control group compared to the water –based athletes.

The main finding that can be concluded from this study is that RM fatigue is experienced in water –based sports as well as in land –based sports and the control group. This means that both trained and untrained individuals are subjected to RM fatigue. RM fatigue is thus not determined by the lack of certain training, but rather a function of the intensity at which the activity is performed. This finding is supported by Lomax and McConnel (2003) that swim training alone does not prevent the inspiratory muscles from fatigue, even though inspiratory muscle strength and lung function are improved by swimming (Clanton *et al.*, 1987).

Not all sports are performed at the same intensity or duration. The time for recovery between points or movements during a match also differs. However, the potential for respiratory muscle fatigue exists in most sport, either because of prolonged periods of exercise (i.e. endurance sport), or repeated bouts of very high intensity exercise (i.e. most team sport). The fatigability of the respiratory muscles is therefore dependent on the demands that are placed on these muscles in terms of the forces produced, the velocity of muscle shortening and muscle length changes, compared to the capacities of the respiratory muscles to respond to these higher demands (i.e. fiber type, oxidative capacity and recruitment order) (Johnson *et al*, 1996).

RM fatigue is usually experienced at very high intensities, but it should be taken in account that these studies were done on endurance athletes (Loke *et al.*, 1982). It is evident that all the groups performed the speed endurance test at very high intensities because all the subjects performed the test between 88% and 97.1% of HR_{max}, which is equivalent of 85% of VO_{2max} and higher (Pollock and Wilmore, 1990) Therefore, it can

be concluded that land – and water -based athletes also experience RM fatigue at high intensities and that both speed endurance tests were a reliable test to fatigue the respiratory muscles. However, the degree of fatigue was less in water –based athletes compared to land –based athletes. The degree of fatigue, however, is determined by the strength of RM due to certain adaptations gained from by both long and short-term high intensity training.

The degree of fatigue was less in the water –based athletes compared to the land –based athletes. Although not significant, both male and female swimmers had better RM strength compared to rugby and netball players and the control group had the weakest RM strength compared to the other groups and this lead to a higher degree of fatigue in the control -, rugby - and netball group compared to the swimmers. This finding is supported by an earlier study of McConnel *et al.* (1997) who demonstrated that RM fatigue was higher in individuals with a lower baseline RM strength compared to the individuals with a higher baseline RM strength after an incremental, multi – stage shuttle run. A possible reason why RM fatigue was lower in the water –based athletes, is that greater strength leads to a smaller demand for force generating during exercise and according to Saltin and Karlsson (1971), although the mechanism for the decrease in RM function is unclear, it is likely that the development of RM fatigue in endurance activities such as running and swimming, may signify a more general muscular fatigue experienced with endurance exercise.

It has been confirmed that whole- body training does lead to adaptations of the RM of land and water –based athletes, but the adaptations gained from endurance training (such as in swimmers) leads to a lower degree of fatigue after exercise. During swimming the demands placed on the RM are high and can lead to adaptations which conclude why swimmers, although not significant, had better RM function and experienced less RM fatigue after the speed endurance test. This was confirmed by Coast *et al.* (1990) who stated that trained endurance subjects did not experience RM fatigue following maximal exercise compared to untrained subjects. Johnson *et al.* (1996) also concluded that highly and moderately trained subjects experienced the same degree of diaphragmatic fatigue, but more diaphragmatic “work” was performed in the fitter subjects. The majority of research is done on endurance sports, but this study concludes that team sports athletes also experience RM fatigue. These findings are in contrast with the study by Clanton *et al.* (1987) who found an increase in swimmers’ RM

strength after a 12 week swim training program and concluded that swimmers would have better RM strength compared to other sports.

Overall, endurance training lead to an increase in number and size of mitochondria, capillaries and an increase in oxidative enzymes which is associated with fat metabolism. These adaptations lead to a carry over effect to the RM and result in RM strength increases. This is confirmed by Robinson and Kjeldgaard (1982) who found increases in RM strength after a 20 week running period.

In conclusion, whole-body training can lead to adaptations of RM and RM function and ultimately be a determinant of performance in both land - and water –based sports. Endurance sports (swimming, running, cycling) as well as land based sports (netball and rugby) do experience RM fatigue during exercise at high intensities, however training adaptations due to endurance training and higher RM function can lead to a lower degree of RM fatigue experience during exercise.

E. Lung function and RM function of athletes and non –athletes

Athletes from this study had higher lung functions compared to non-athletes (Cordain *et al.*, 1990; Mador and Acevedo, 1991 and Schoene *et al.*, 1997) and endurance athletes from other studies by Schoene *et al.* (1997); Cordain *et al.* (1987); Cordain *et al.* (1990); Fairburn *et al.* (1991) and Williams *et al.* (2002). The RM function of athletes in this study were higher than non-athletes in a study done by Fiz *et al.* (1998) as well as the study on soccer players by Fuso *et al.* (1996). These contrasting results were also found for RM endurance. Women from this study had lower MVV values and men had higher MVV values compared to male athletes from the study by Williams *et al.* (2002) and female athletes from Clanton *et al.* (1987).

It seems that athletes from team sports like netball and rugby and swimmers have higher lung function and RM function compared to endurance sports like cycling and running. The difference in reference values can be attributed to the fact that the study populations differed, because all these comparisons where made to endurance athletes. The varied results can be attributed to a number of factors, among others, the differences in populations studied, variations in methods, techniques and equipment used to measure respiratory muscle function, as well as the motivation and co-operation

of the participants. For this reason, Fuso *et al.* (1996) argue that each laboratory should generate its own reference values for respiratory muscle function. However, in the case of testing RM strength, most studies, including this study, have stated that measurements were made at RV and TLC for MIP and MEP. Therefore, it is likely that the differences for RM strength among laboratories can be accounted by the different starting pulmonary volumes chosen in the determination of MIP and MEP.

Both lifestyle (sedentary versus active) and level of motivation may significantly affect an individual's performance on respiratory- and lung function tests (Chen and Suku, 1989). In this study, only athletes that met strict inclusion criteria were included and therefore we are satisfied that our results reflect the status of respiratory muscle function in an active population. Care was also taken to encourage each subject in the same manner and to the same extent during the execution of the respiratory tests. However, the possibility that some subjects may still have been less motivated than others cannot be excluded.

F. Limitations

Body composition was estimated by skinfold- thickness measurements. These values are likely to be associated with greater measurement error than those of more direct measures of body compositions. However, this method was used because more accurate equipment such as DEXA and hydrostatic weighing was not available. Skinfold –thickness measurements are also much more affordable.

Age was not accounted for in this study, because the age range was smaller and the average age was much less than compared to other studies that used elderly subjects and concluded a negative correlation between RM – and lung function and age. These studies indicated that the effect of age on RM – and lung function can only be observed after the age of 55 years (Black and Hyatt, 1969 and Bruschi *et al.*, 1992). The failure to demonstrate a significant effect of age on lung functions could be because of the limited age range and the small sample size. A wider age range would have meant to include much more subjects in the study of various age groups. As mentioned above, a number of studies already have been done on the effect of age on RM function.

Another limitation to the study could be in the motivation of the subjects to perform a maximal respiratory effort following the speed endurance test, however, subjects should have recovered sufficiently after two minutes and to perform a reliable measurement.

G. CONCLUSIONS

In conclusion, the influence of anthropometry is less obvious for RM strength and RM endurance in the case of athletes. RM strength and RM endurance appear to be determined by a complex, multi-factorial inter relationship and cannot be accounted for by one or two specific characteristics, which is evident in this study's prediction equations. However, it is evident that anthropometric variables such as height and body mass seem to play an important part as determinants for athletes and non-athletes in terms of their lung functions, but a less important role in RM strength and RM endurance. It is evident from the literature that there is a negative relationship between age and RM strength and RM endurance and because a relatively young sample group was used in this study, age was not incorporated in the equations.

This study has shown that whole-body training can lead to adaptations in respiratory muscles and can improve RM function. Therefore, the possibility exists that RM function can be an important determinant of performance in both land- and water-based sports. Exercise of high enough intensity ($> 85\% \text{VO}_{2\text{max}}$) cause RM fatigue in both endurance trained athletes (swimmers, runners, cyclists), and team sport athletes (i.e. netball and rugby). However, the training adaptations associated with endurance training, as well as the improved RM function of these athletes causes a lower degree of RM fatigue after exercise.

H. Future Studies

The effect of RM training on team sport athletic performance must be researched. If RM training leads to improved performance, it will be evident that RM functions play an important part, together with other abilities such as speed, strength and power. in sports. The majority of research on the effect of RM training was done on endurance sports. The RM training in these studies only led to improvements in RM function or both improvements in RM function and in performance variables.

As the effect of age was not studied in this study, future research can be done to conclude the effect of age on a wider age range of athletes participating in team sports.

In this study the fatigue was determined by the difference in RM strength. Future studies can be done on team sports using the difference in RM endurance, because the endurance training has a carry over affect on the degree of fatigue measured as RM endurance. It is not known if the training of team sports would lead to a carry over effect on the degree of fatigue measured as RM endurance.

It is known that RM fatigue is experienced at high intensities of endurance sports and in this study, in team sports athletes. Future research can determine whether RM fatigue would be experienced at lower intensities of exercise, as a team sport athlete will not perform at such high intensities for the whole duration of the game.

Magnetic cervical stimulation (MCS) and electrical phrenic nerve stimulation are also alternative methods to determine RM fatigue. Together with these methods, the method used in this study can be used to compare whether the same results will be obtained in team sports.

In this study, the fatigue of RM in swimmers was measured in an upright position. Lomax and McConnell (2003) observed a decrease in RM function of swimmers after swimming 200m. However, RM fatigue was measured in a supine position in the water. This method is functionally more relevant to swimmers than RM function in the upright position, as the supine position replicates the body position and chest compression elicited by immersion during swimming and the shift in blood volume from the lower extremities into the chest. Therefore, future studies can determine the difference in RM fatigue for swimmers in an upright compared to a supine position in the water.

Research has shown an improvement in performance of endurance sports after RM training. Future studies can be done to observe the effect of RM training on team sports.

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APPENDIX A

Ingeligte Toestemming

Titel van navorsingsprojek:

“Anthropometry and Respiratory Muscle Function of Land-based and Water-based Competitive Athletes”

Verwysingsnommer: _____

VERKLARING DEUR PROEFPERSOON:

Ek, die ondergetekende , _____
[ID: _____], van (adres) _____

bevestig dat:

1. Ek uitgenooi is om deel te neem aan bogenoemde navorsingsprojek wat deur die Departement Sportwetenskap aan die Universiteit van Stellenbosch onderneem word.
2. Daar aan my verduidelik is dat:
 - 2.1 die doel van die projek is om te toets
 - a) of daar 'n verband tussen liggaamsamestelling veranderlikes en Respiratoriese Spiersterkte is
 - b) of Respiratoriese Spiersterkte en Respiratoriese Spieruitputting sport prestasie beïnvloed?
 - 2.2 daar van my verwag word om verskillende eksperimentele toetse te onderneem in 2 afsonderlike besoeke aan die oefeningslaboratorium .
 - 2.2.1 tydens die eerste besoek : en my longfunksies (longvolume) gaan getoets word met 'n spirometer, en die sterkte en uithouvermoë van my asemhalingspiere voor en na die spoedtoets sal getoets word.
 - 2.2.2 tydens die tweede besoek: sal my velvoue, ledemaatomtrekke, deursnitte en ledemaatlengtes sal gemeet word om my vetpersentasie en liggaamvorm en - grootte te bereken. My vetpersentasie sal ook bepaal word met 'n Bodystat meter
 - 2.3 geen indringende prosedures (bv. bloedtrek, inspuitings) of middels toegedien sal word nie.

- 2.4 ek verstaan dat ek enige tyd die toetse mag staak wanneer ek enige van hierdie simptome ondervind.
- 2.5 die navorsers/ toetsafnemers en/of die Universiteit van Stellenbosch nie verantwoordelik gehou kan word vir enige besering wat ek moontlik kan opdoen gedurende enige van die toetse ingesluit in die projek nie.
3. Ek meegedeel is dat die inligting wat ingewin word as vertroulik behandel sal word, maar dat die bevindinge wel in vaktydskrifte gepubliseer kan word.
4. Die inligting wat hierbo weergegee is, deur _____ aan my in Engels/Afrikaans verduidelik is. Ek is ook die geleentheid gegee om vrae te vra en al my vrae is bevredigend beantwoord.
5. Daar is aan my verduidelik dat my deelname vrywillig is en dat ek enige tyd aan die projek mag onttrek.
6. Ek is meegedeel dat daar geen koste aan my deelname verbonde is nie.

Ek neem die verantwoordelikheid om 'n uiterste poging aan te wend om al die toetse te voltooi.

Ek besef dat die uitkoms van elke toets afhang van hoe goed ek gemotiveerd is om my beste te gee.

Ek neem die verantwoordelikheid om hoogs gemotiveerd deel te neem aan hierdie projek en elke toets tot die beste van my vermoë af te lê.

Ek stem hiermee vrywillig in om aan bogemelde projek deel te neem.

Geteken te _____ op _____ 20_____

Toetspersoon

Getuie

VERKLARING DEUR NAVORSER

Ek, _____, verklaar dat ek:

1. die inligting vervat in hierdie dokument aan _____ verduidelik het;
2. Haar/hom versoek het om vrae aan my te stel indien daar enigiets onduidelik was;
3. Dat hierdie gesprek in Afrikaans/Engels plaasgevind het.

Geteken te _____ op _____ 20_____

Navorsers

Getuie

Informed Consent

Title of research project:

“Body Composition and Respiratory Muscle Function of Land-based and Water-based Competitive Athletes”

Reference number: _____

CONSENT OF SUBJECT:

I, _____ [ID: _____]
from (address) _____
_____.

confirm that:

1. I was invited to participate in the above-mentioned project conducted by the Department of Sport Science of the University of Stellenbosch.
2. It was explained to me that:
 - 2.1 the aim of this project is to determine
 - a) what the relationship is between body composition and respiratory muscle strength.
 - c) the effect of respiratory muscle strength and respiratory muscle fatigue on sport performance.
 - 2.2 I will participate in various experimental tests which will be divided into 2 respective visits to the exercise laboratory.
 - 2.2.1 during the first visit : my lung functions (lung volumes) will be measured with a spirometer, the strength and endurance of my respiratory muscles will be tested before and after the speed tests.
 - 2.2.2 during the second visit: my skinfolds, limb circumferences, diameters and limb lengths will be measured to determine my fat percentage and body shape/size and my percentage body fat will also be determined with a Bodystat meter.
 - 2.3 No invasive procedures (e.g. injections, draw of blood) or administration of any substances will be administered.
 - 2.4 I understand that I can stop the exercise tests at any time when I experience one of these symptoms.

- 2.5 The researcher/test observers and/or the University of Stellenbosch cannot be held responsible for any injuries that might occur during any of the tests included in the project.
3. I was informed that the information which will be obtained through this project will be handled confidentially, but that the results will be published in research journals.
4. The above information was explained to me in English by _____ . I was given the opportunity to ask questions and all the questions were satisfactorily answered.
5. It was explained to me that my participation in this project is voluntary and that I may withdraw from the study at any time. I also understand that the researcher or medical doctor may withdraw me from the study if deemed necessary for medical purposes.
6. I was informed that there are no costs involved for my participation in this project.

I voluntarily agree to participate in the abovementioned project.

I take the responsibility to endeavour to complete all tests.

I realise that the outcome of each test depends on how well motivated I am to do my best.

I take the responsibility to be and stay **highly motivated** throughout the duration of the project and to complete each test to the best of my ability.

Signed at _____ on _____ 20 _____.

Subject

Witness

STATEMENT BY RESEARCHER

I, _____, declare that I:

1. Explained the information in this document to _____;
2. requested him to ask questions if anything was unclear;
3. that this conversation took place in English/Afrikaans.

Signed at _____ on _____ 20 _____

Researcher

Witness

