Developing $\dot{V}O_{2max}$ prediction functions from the physical, motor performance and anthropometric components of a cohort of adolescents: The PAHL-Study

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It all starts here ™

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FOREWORD

This thesis was only possible through the Grace, Favour and Wisdom of my Saviour Lord Jesus Christ. I dedicate this entirely to my Creator and the King of Kings, "*with whom there is no variation or shadow of turning" - James 1:17*

"In Christ Alone" – Owl City

In Christ alone, my hope is found
He is my light, my strength, my song
This cornerstone, this solid ground
Firm through the fiercest drought and storm
What heights of love, what depths of peace
When fears are stilled, when strivings cease
My Comforter, my All-in-All
Here in the love of Christ I stand

There in the ground His body lay
Light of the World by darkness slain
Then bursting forth in glorious day
Up from the grave He rose again!
And as He stands in victory
Sin's curse has lost its grip on me
For I am His and He is mine
Bought with the precious Blood of Christ

No guilt in life, no fear in death
This is the power of Christ in me
From life's first cry to final breath
Jesus commands my destiny
No power of hell, no scheme of man
Can ever pluck me from His hand
Till He returns or calls me home
Here in the power of Christ I'll stand

I truly am Greatly Blessed, Highly Favoured and Deeply Loved, just an ordinary girl Loved by an Extraordinary God.

Thank You Jesus

DECLARATION

The co-authors of the three articles, which form part of this thesis, Dr. Ben Coetzee (Promoter), Prof Jos Twisk (Co-promoter) and Prof. Andries Monyeki (Assistant-promoter) hereby give permission to the candidate, Mrs. Cindy Pienaar to include the three articles as part of the PhD thesis. The contribution (advisory and supportive) of the co-authors was kept within reasonable limits, thereby enabling the candidate to submit this thesis for examination purposes. This thesis, therefore, serves as fulfillment of the requirements for the degree Doctor of Philosophy within the School of Biokinetics, Recreation and Sport Science in the Faculty of Health Sciences at the North-West University (Potchefstroom campus).

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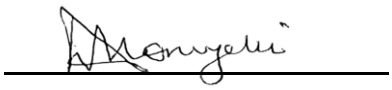

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SUMMARY

Developing $\dot{V}O_{2max}$ prediction functions from the physical, motor performance and anthropometric components of a cohort of adolescents: The PAHL-Study

The measurement of cardiorespiratory fitness has been extensively researched among adult populations, but very few researchers have focused their attention on the cardiorespiratory fitness of children and adolescents. Due to various constraints of direct $\dot{V}O_{2max}$ testing, various indirect testing methods have been developed of which the 20-m Shuttle Run Test is the most widely used testing method. The influence of various anthropometric, physical and motor performance components as well as certain demographic factors such as gender, race, living area, and sport participation as well as physical activity level on the $\dot{V}O_{2max}$ value of participants seems to suggest that $\dot{V}O_{2max}$ can be predicted by including these components in prediction models. It is against this background that the objectives of this study are provided.

The following four objectives of the study were achieved through a literature review: Firstly, to name and describe the various direct and indirect methods for determining $\dot{V}O_{2max}$; secondly, to provide a review on the findings with regard to the aerobic performances or $\dot{V}O_{2max}$ values of children and adolescents; thirdly, to discuss the possible influence of various anthropometric, physical and motor-performance components on the aerobic performances or $\dot{V}O_{2max}$ values of the last-mentioned groups of subjects. As part of this objective, other literature-identified factors such as certain demographic factors (living area, race and gender), sport and physical activity participation level which may also influence the aerobic performances or $\dot{V}O_{2max}$ values of the participants, were also discussed; fourthly, all literature identified models for the prediction of aerobic performances or $\dot{V}O_{2max}$ values in children, and in adolescents were mentioned and discussed. The next few objectives were achieved through a selected group, cross-sectional experimental research design; fifthly, to develop a valid $\dot{V}O_{2max}$ prediction function from several anthropometric measurements and demographic factors such as gender,

race and living area as well as sport participation level of a cohort of adolescents living in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa; sixthly, to develop a $\dot{V}O_{2max}$ prediction function from the physical and motor-performance components as well as demographic variables such as gender, race and living area as well as sport participation level of a cohort of adolescents living in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa; and finally, to determine the validity of the 20-m SRT to estimate the $\dot{V}O_2$ and $\dot{V}O_{2max}$ of a cohort of adolescent boys in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa.

In order to fulfil the fifth and sixth objectives of the study, a total of 214 grade 8 adolescents (boys: 88 and girls: 126) (age: 15.82 ± 0.68 years) of high schools in the Tlokwe Local Municipality (Potchefstroom area) of the Dr Kenneth Kaunda District of the North West Province, South Africa were purposefully selected from pre-acquired class lists, from six secondary schools. Data was collected by means of various questionnaires, anthropometric measurements and physical and motor-performance tests, which also included the 20-metre SRT. For the fulfilment of the final objective of the study, 52 boys were purposefully selected from the above-mentioned group that completed various questionnaires as well as the 20-m SRT while they were fitted with a portable gas analyser apparatus.

With regard to the anthropometric and demographic variable prediction model, the forward stepwise regression analysis results showed that muscle mass percentage, sport participation level, stature, hip circumference and ectomorphy act as significant predictors ($p \leq 0.05$) of the indirect, 20-m SRT $\dot{V}O_{2max}$ values of a cohort of adolescents. Muscle mass percentage emerged as the strongest predictor (59%) of adolescents' $\dot{V}O_{2max}$ values, followed by sport participation level (6%), ectomorphy (2%), stature (1%) and hip circumference (1%). The physical, motor-performance and demographic prediction model revealed that 10-metre speed, sit-up repetitions, sport participation level, handgrip strength, Vertical Jump Test (VJT) Tendo peak power, maximal heart rate (HR_{max}), living area, right shoulder external rotation flexibility (RPSERT), horizontal jump test distance (HJT) and right Modified Thomas iliopsoas flexibility (RMTIT) served as significant predictors ($p \leq 0.05$) of the indirect, 20m-SRT-derived $\dot{V}O_{2max}$ values of a cohort of adolescents. However, only 10-metre speed served as a major contributor (53.5%) to the indirect $\dot{V}O_{2max}$ values of the adolescents. The rest of the variables contributed 17.4% to the overall variance in $\dot{V}O_{2max}$ values. Overall, the last-mentioned anthropometric,

physical, motor performance and demographic variables were responsible for 70.5% of the variance in the $\dot{V}O_{2max}$ values of the adolescents. Cross-validations also revealed that both models are valid for predicting the 20-m SRT-derived indirect $\dot{V}O_{2max}$ values of this cohort of adolescents.

The 20-m SRT validity study showed that a significant difference ($p \leq 0.05$) existed between the predicted indirect $\dot{V}O_{2max}$ results (42.06 ± 4.53 ml/kg/min) as obtained from the 20-m SRT booklet and the direct $\dot{V}O_{2max}$ results (50.62 ± 7.11 ml/kg/min) as obtained from the gas analysis. Furthermore, significant differences ($p \leq 0.05$) were observed between the direct and indirectly predicted $\dot{V}O_2$ values at levels 1-9 of the 20-m SRT compared to no significant differences at levels 10 and 11 of the 20-m SRT.

In conclusion, to the researchers' knowledge, this is the first study to develop valid $\dot{V}O_{2max}$ prediction functions from the use of several anthropometric measurements, physical and motor-performance test results and demographic information for a group of South African adolescents. Furthermore, this is also the first study to reveal that the 20-m SRT is not a valid test for the accurate prediction of $\dot{V}O_2$ and $\dot{V}O_{2max}$ of a cohort of adolescent South African boys. The results of this study may possibly allow practitioners in the field of Human Movement Science to more accurately screen the indirect $\dot{V}O_{2max}$ values of adolescents by making use of easily obtainable measures and information, instead of the predicted $\dot{V}O_{2max}$ values of the 20-m SRT.

Keywords: adolescents, aerobic, $\dot{V}O_{2max}$, 20-m SRT, anthropometric, physical, motor, direct, indirect, gender

OPSOMMING

Die ontwikkeling van $\dot{V}O_{2maks}$-voorspellingsfunksies uit die fisiese, motoriese prestasie- en antropometriese komponente van 'n kohort adolessente: Die PAHL-studie

Die meting van kardiorespiratoriese fiksheid is al breedvoerig onder volwasse populasies nagevors, maar baie min navorsers het al hulle aandag geskenk aan die kardiorespiratoriese fiksheid van kinders en adolessente. Weens verskeie beperkings van direkte $\dot{V}O_{2maks}$-toetsing is verskeie indirekte toetsmetodes al ontwikkel waarvan die 20-m Heen en Weer Hardlooptoets (20-m Shuttle Run Test – SRT) die toetsmetode is wat die algemeenste gebruik word. Die invloed van verskeie antropometriese, fisieke en motoriesepresta sie-komponente asook sekere demografiese faktore soos geslag, ras, woongebied en sportdeelname asook fisieke aktiwiteitsvlak op die $\dot{V}O_{2maks}$-waarde van deelnemers blyk daarop te dui dat $\dot{V}O_{2maks}$ voorspel kan word deur hierdie komponente by voorspellingsmodelle in te sluit. Dit is teen hierdie agtergrond dat die doelstellings van hierdie studie voorsien word.

Die volgende vier doelstellings van die studie is bereik deur 'n literatuuroorsig: Eerstens om die verskeie direkte en indirekte metodes vir die bepaling van $\dot{V}O_{2maks}$ aan te dui en te beskryf; tweedens om 'n oorsig te verskaf van die bevindings rakende die aërobiese prestasies of $\dot{V}O_{2maks}$-waardes van kinders en adolessente; derdens om die moontlike invloed van verskeie antropometriese, fisieke en motoriesepresta sie-komponente op die aërobiese prestasies of $\dot{V}O_{2maks}$-waardes van laasgenoemde groepe proefpersone te bespreek. Ander literatuurgeïdentifiseerde faktore soos sekere demografiese faktore (woongebied, ras en geslag), sportdeelname- en fisieke aktiwiteitsvlak wat moontlik ook die aërobiese prestasies of $\dot{V}O_{2maks}$-waardes van die deelnemers kan beïnvloed, is ook bespreek as deel van hierdie doelstelling; vierdens is alle literatuurgeïdentifiseerde modelle vir die voorspelling van aërobiese prestasie of $\dot{V}O_{2maks}$-waardes by kinders en by adolessente uitgewys en bespreek. Die volgende doelstellings is bereik deur van 'n geselekteerde groep, dwars-deursnit eksperimentele

navorsingsontwerp gebruik te maak; vyfdens om 'n geldige $\dot{V}O_{2maks}$-voorspellingsfunksie uit etlike antropometriese metings en demografiese faktore soos geslag, ras en woonarea asook sportdeelnamevlak van 'n kohort adolessente woonagtig in die Tlokwe Plaaslike Munisipaliteit (Potchefstroomgebied) van die Noordwes Provinsie, Suid-Afrika te ontwikkel; in die sesde plek, om 'n $\dot{V}O_{2maks}$-voorspellingsfunksie uit die fisieke en motoriesepresta sie-komponente asook demografiese veranderlikes soos geslag, ras en woongebied en sportdeelnamevlak van 'n kohort adolessente woonagtig in die Tlokwe Plaaslike Munisipaliteit (Potchefstroomgebied) van die Noordwes Provinsie, Suid-Afrika, te ontwikkel; en ten slotte, om die geldigheid van die 20-m SRT te bepaal om die $\dot{V}O_2$ en $\dot{V}O_{2maks}$ van 'n kohort adolessenteseuns in die Tlokwe Plaaslike Munisipaliteit (Potchefstroomgebied) van Noordwes Provinsie, Suid-Afrika te beraam.

Om die vyfde en sesde doelstelling van die studie te behaal is 214 graad 8-adolessente (seuns: 88 en dogters: 126) (ouderdom: 15.82 ± 0.68 jaar) van hoërskole in die Tlokwe Plaaslike Munisipaliteit (Potchefstroomgebied) van die Noordwes Provinsie, Suid-Afrika doelbewus geselekteer uit vooraf bekomde klaslyste van ses sekondêre skole. Data is deur middel van verskeie vraelyste, antropometriese metings en fisieke sowel as motoriesepresta sie toetse wat ook die 20-meter SRT ingesluit het, ingesamel. Vir die bereiking van die finale doelstelling van die studie is 52 seuns doelbewus geselekteer uit bogenoemde groep wat verskeie vraelyste voltooi het asook die 20-m SRT terwyl hul toegerus is met 'n draagbare gasanaliseerapparaat.

Met betrekking tot die voorspellingsmodel vir antropometriese en demografiese veranderlikes, het die resultate van die vorentoe stapsgewyse regressie-analise getoon dat spiermassa-persentasie, sportdeelnamevlak, liggaamslengte, heupomtrek en ektomorfie as betekenisvolle voorspellers ($p \leq 0.05$) van die indirekte, 20-m SRT $\dot{V}O_{2maks}$-waardes van 'n kohort adolessente dien. Spiermassa-persentasie het na vore gekom as die sterkste voorspeller (59%) van adolessente se $\dot{V}O_{2maks}$-waardes, gevolg deur sportdeelnamevlak (6%), ektomorfie (2%), liggaamslengte (1%) en heupomtrek (1%). Die fisieke, motoriesepresta sie- en demografiese voorspellingsmodel het aan die lig gebring dat 10-meter-speed, opsit-herhalings, sportdeelnamevlak, handgreepkrag, Vertikalesprong-toets (Vertical Jump Test – VJT) Tendo piek-krag, maksimale harttempo (HRmaks), woongebied, regter eksterne-skouerrotasie-soepelheid (right shoulder external rotation flexibility – RPSERT), afstand vir die horisontalesprong-toets (Horizontal Jump Test – HJT) en *Right Modified Thomas iliopsoas*-soepelheidstoets (RMTIT) as betekenisvolle voorstellers ($p \leq 0.05$) van die indirekte, 20m-SRT-

afgeleide $\dot{V}O_{2maks}$-waardes van die kohort adolessente gedien het. Slegs 10-meter-spoed het egter gedien as 'n belangrike bydraer (53.5%) tot die adolessente se indirekte $\dot{V}O_{2maks}$-waardes. Die oorblywende veranderlikes het 17.4% tot die totale variansie in $\dot{V}O_{2maks}$-waardes bygedra. In die geheel was laasgenoemde antropometriese, fisieke, motoriese-prestasie- en demografiese veranderlikes vir 70.5% van die variansie in die $\dot{V}O_{2maks}$-waardes van die adolessente verantwoordelik. Kruisvalidasie het ook aan die lig gebring dat beide modelle geldig is vir die voorspelling van die 20-m SRT-afgeleide indirekte $\dot{V}O_{2maks}$-waardes van hierdie kohort adolessente.

Die 20-m SRT geldigheidstudie het getoon dat 'n betekenisvolle verskil ($p \leq 0.05$) bestaan tussen die voorspelde indirekte $\dot{V}O_{2maks}$-resultate (42.06 ± 4.53 ml/kg/min), soos verkry van die 20-m SRT-pamflet, en die direkte $\dot{V}O_{2maks}$-resultate (50.62 ± 7.11 ml/kg/min), soos verkry van die gasanalise. Voorts is betekenisvolle verskille ($p \leq 0.05$) waargeneem tussen die direk- en indirekvoorspelde $\dot{V}O_{2maks}$-waardes op vlakke 1-9 van die 20-m SRT, teenoor geen betekenisvolle verskille op vlakke 10 en 11 van die 20-m SRT nie.

Ten slotte, na die navorsers se wete, is hierdie die eerste studie wat geldige $\dot{V}O_{2maks}$-voorspellingsfunksies ontwikkel het vir 'n groep Suid-Afrikaanse adolessente deur gebruikmaking van etlike antropometriese metings, fisieke, en motoriesеprestasie toetsresultate en demografiese inligting. Hierbenewens is dit ook die eerste studie wat aan die lig gebring het dat die 20-m SRT nie 'n geldige toets is vir die akkurate voorspelling van $\dot{V}O_2$ en $\dot{V}O_{2maks}$ in 'n kohort Suid-Afrikaanse adolessenteseuns nie. Die resultate van hierdie studie kan moontlik praktisyns op die gebied van Menslike Bewegingskunde in staat stel om die direkte $\dot{V}O_{2maks}$-waardes van adolessente meer akkuraat te sif deur gebruik te maak van maklik bekombare metings en inligting, in plaas daarvan om die voorspelde $\dot{V}O_{2maks}$-waardes van die 20-m SRT daarvoor aan te wend.

Sleutelwoorde: adolessente, aërobiese, $\dot{V}O_{2maks}$, 20-m SRT, antropometriese, fisieke, motoriesеprestasie, direkte, indirekte, geslag

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LIST OF ABBREVIATIONS

20-m SRT	20-m Shuttle Run Test
ACSM	American Council of Sports Medicine
ASLRT	Active Straight Leg Raise Test
AST	Abdominal Strength Test
ATP-CP	Adenosine Triphosphate-Creatine Phosphate
ATT	Agility T-Test
BD	Body Density
BMI	Body Mass Index
bpm	beats per minute
CAFT	Canadian Aerobic Fitness Test
cm	centimetre
CMJ	Counter Movement Jump
ES	Effect Size
FFM	Fat Free Mass
g/cm3	gram per cubic centimetre
ISAK	International Society for the Advancement of Kinanthropometry
HJT	Horizontal Jump Test
HRR	Heart Rate Reserve
HR	Heart rate
HR_{max}	Heart Rate max
HRr_{est}	Resting Heart rate
J	Joules

kg	kilogram
L/min	Litre per minute
LL	Last level
LS	Last shuttle
MBPT	Medicine Ball Put Test
mi/h	miles per hour
min	minutes
ml/kg/min	millilitre per kilogram per minute
mm	millimetre
MRC	Medical Research Council
MTIT	Modified Thomas Iliopsoas Test
MTQT	Modified Thomas Quadriceps Test
n	Number of subjects in each subgroup
NRF	National Research Foundation
NWU	North-West University
O_2/min	Oxygen uptake per minute
p	statistical significance
PAHLS	Physical Activity and Health Longitudinal Society
PE	Physical Education
PHV	Peak Height Velocity
RPE	Rating of Perceived Exertion
PSLRT	Passive Straight Leg Raise Test
PWV	Peak Weight Velocity
***r* or R^2**	correlation
R	correlation coefficients
REE	Resting Energy Expenditure
RER	Respiratory Exchange Ratio
rev/min	revolutions per minute
RPSERT	Right Passive Shoulder External Rotation Test
RPSIT	Right Passive Shoulder Internal Rotation Test
RPSLRT	Right Passive Straight Leg Raise Test

RM	Repetition Maximum
RMTIT	Right Modified Thomas Iliopsoas Test
RMTQT	Right Modified Thomas Quadriceps Test
s	seconds
SD	Standard Deviation
SEC	Series Elastic Component
SEE	Standard Error of Estimate
SF	Skinfold
SUM6SF	Sum of the 6 Skinfolds
TEM	Technical Error of Measurement
$\dot{V}CO_2$	Carbon Dioxide Production
$\dot{V}_E$	Minute Ventilation
VJ	Vertical Jump
VJT	Vertical Jump Test
$\dot{V}O_2$	Oxygen Uptake
$\dot{V}O_{2max}$	Maximal Oxygen Uptake
$\dot{V}O_{2peak}$	Peak Oxygen Uptake
W	Watt
W_{max}	Maximal power output
WHPR	Waist to hip ratio
WHTR	Waist to height ratio
yr	years

CHAPTER 1

1 INTRODUCTION

1. **Problem Statement**
2. **Objectives**
3. **Hypotheses**
4. **Structure of the Dissertation**
5. **References**

1. Problem Statement

The measurement of cardiorespiratory fitness has been extensively researched among adult populations (Aziz *et al*., 2005; Bale *et al*., 1986; Boileau *et al*., 1982; Brandon & Boileau, 1992; Brandon & Boileau, 1987; Cunningham, 1990; O'Gorman *et al*., 2000; Paliczka *et al*., 1987; Pate & O'Neill, 2007), but very few researchers have focused their attention on the cardiorespiratory fitness of children (Chatterjee *et al*., 2006; Cunningham, 1990; Meckel *et al*., 2009; Mero *et al*., 1990). Furthermore, despite the use and availability of direct and indirect tests for determining the $\dot{V}O_{2max}$ values of children, certain constraints make these tests unaffordable and inaccessible to schools hosting children living in developing countries, especially in rural areas. The development and use of $\dot{V}O_{2max}$ prediction functions compiled by making use of the results from simple, affordable physical and motor performance tests, as well as anthropometric measurements, may provide a solution to this problem. This is especially true in view of the fact that the early indication of talent or potential for aerobic performance would allow coaches, trainers and sport scientists much more time to identify and develop potential athletes, since running experience is a distinctive marker of elite endurance and distance runners (Bale *et al*., 1986:172).

Maximal oxygen consumption, or $\dot{V}O_{2max}$, as it is more commonly known, is regarded by most researchers as the best single measurement of cardiorespiratory endurance and aerobic fitness (Boutcher, 1990:236; Brandon & Boileau, 1992:7). The direct measurement of $\dot{V}O_{2max}$, by indirect calorimetry and specifically by open-circuit spirometry as well as computerized instrumentation in the laboratory, is the most reliable and accurate method for assessing $\dot{V}O_{2max}$ (Chatterjee *et al*., 2008:176; Cooper *et al*., 2005:1). However, the direct measurement of $\dot{V}O_{2max}$ requires the use of specialised, sophisticated equipment which is very expensive; needs well-trained personnel to operate; requires a huge amount of time to conduct and does not allow for a large number of participants to be tested at the same time (Bonen *et al*., 1979:24; Cooper *et al*., 2005:1). Consequently, laboratory tests are impractical for use in large epidemiological field studies and are therefore not suitable for use by most public schools, especially in rural areas (Buono *et al*., 1991:250).

These and other constraints have given rise to the development of indirect $\dot{V}O_{2max}$ tests of which the 20-m Multistage Shuttle Run Test (20-m SRT) is the most widely used test among sport scientists, coaches and teachers for the prediction of $\dot{V}O_{2max}$ values (Aziz *et al*., 2005; Cooper *et al.,* 2005). Although this field test has been found to be practical, valid and reliable for predicting the $\dot{V}O_{2max}$ values of groups of adult subjects and athletes (Aziz *et al*., 2005; Cooper *et al.,* 2005), research findings with regard to children and adolescents have not received much attention in the research literature. The existing research with regard to children and adolescents seems to suggest that significant and insignificant correlations of between $r = 0.77$ and 0.87 ($p < 0.001$), and $r = 0.72$ ($p > 0.05$), respectively exist between the directly measured $\dot{V}O_{2max}$ and the estimated, predicted $\dot{V}O_{2max}$ values of the 20-m SRT among 8 to 17 -year-old children and adolescents (Liu *et al*., 1992:362; Matsuzaka *et al*., 2004:121). In other instances it has been found that the 20-m SRT significantly ($p < 0.05$) under-predicted the direct $\dot{V}O_{2max}$ values in adult males and females (Stickland *et al.*, 2003:274), with the magnitude of under-prediction being larger for males than for females. From their study results Stickland *et al*. (2003:280-281) highlighted the necessity of gender-specific prediction equations and the importance of also considering other components in prediction equations to more accurately determine $\dot{V}O_{2max}$.

Various components seem to play a role in the prediction of children's $\dot{V}O_{2max}$ values. In this regard Fonseca *et al*. (2008:46) for example found a high negative correlation ($r = -0.8$, $p < 0.001$) between fat mass and the $\dot{V}O_{2max}$ values of adolescent Brazilian boys (16.29 ± 0.96 years) and girls (15.86 ± 1.1 years). In addition, McVeigh *et al*. (1995:77) indicated that the inclusion of triceps skinfold thickness of girls (13.68 ± 0.3 years) and boys (13.68 ± 0.3 years) respectively strengthened the prediction of $\dot{V}O_{2max}$ values, which were derived from the 20-m SRT. Several researchers have also provided proof that triceps skinfold thickness is a good indicator of body fat percentage in children and adolescents (Lohman *et al*., 2008:1164; McVeigh *et al*., 1995:77), which may provide a reason for the identification of triceps skinfold thickness as a predictor of 20-m SRT-

derived $\dot{V}O_{2max}$ values (Buono *et al*., 1991:254; McVeigh *et al*., 1995:75). Furthermore, the changes in $\dot{V}O_{2max}$ values of boys (5%) and girls (29%) over a time period of 5 years are attributed to the increase in body fat percentage for girls and a decline in body fat percentage for the boys (Rowland *et al*., 1997:270).

Body weight and stature has also been proven to influence the $\dot{V}O_{2max}$ values of adolescents as Ruiz *et al*. (2008:282) found body weight and stature to be significant contributors to 20-m SRT performance in a group of adolescents. Negative and statistically significant correlations were reported for the relationships between body weight and $\dot{V}O_{2max}$ values in boys ($r = -0.517$, $p < 0.001$) and girls ($r = -0.241$, $p < 0.043$) respectively (Ruiz *et al*., 2008:242). Similarly, Body Mass Index (BMI) also influences 20-m SRT performances as children with lower BMI scores outperform those with higher BMI values (Cairney *et al.*, 2008:135). Dumith *et al*. (2010:647) reported that BMI status had the strongest correlation with the level of cardiorespiratory fitness of Brazilian adolescents (7 - 15 years). Not much attention has been focused on the influence of muscle mass on the $\dot{V}O_{2max}$ values of children and adolescents but results of 129 pre-pubertal children do show a strong and significant correlation ($r = 0.87$, $p < 0.001$) (Goran *et al*., 2000:843) between muscle mass and $\dot{V}O_{2max}$ values of this group. In adolescents, Fonseca *et al.* (2008:46) reported a significant negative correlation ($r = -0.80$, $p < 0.01$) between the fat-free mass and $\dot{V}O_{2max}$ in Brazilian adolescents.

Physical and motor performance components identified as possible predictors of 20-m SRT-derived $\dot{V}O_{2max}$ values among 84 schoolboys (13.6 ± 0.3 years) include 50 yard dash times, mile-run time, sit-and-reach distance, flamingo balance time, standing broad jump distance, hand grip strength and sit-up repetitions (Koutedakis, & Bouziotas, 2003:313). In a study by Buono *et al.* (1991:254) it was demonstrated that the mile-run time together with the triceps and subscapular skinfold values contributed 70.56% to the $\dot{V}O_{2max}$ prediction of 90 children and adolescents between ages 10 and 18 years. Other anaerobic-related performance variables such as speed, agility and explosive leg

power have also been shown to be possible predictors of aerobic performance (Brandon & Boileau, 1987:161; Grant *et al*., 1995:151; Koutedakis & Bouziotas, 2003:312)

Although the above-mentioned research seems to suggest that the 20-m SRT-derived $\dot{V}O_{2max}$ values of children and adolescents can be predicted by making use of certain physical, motor performance and anthropometric measurements, researchers have eluded to the fact that various factors may influence the prediction power of these variables. For example, Chillón *et al*. (2011:421) showed that Spanish children and adolescents (7 - 16 years) living in rural areas displayed significantly higher ($p < 0.001$) cardiorespiratory fitness as well as lower body mass and body mass index (BMI) values than children in urban areas. Previous research findings by Felton *et al*. (2002:254) that girls in rural areas showed higher physical activity participation levels, together with the statement of Machado-Rodrigues *et al.* (2011:482) that activities other than organised sport participation may lead to increased activity levels among children in rural areas, may serve as a possible explanation for the higher cardiorespiratory fitness levels among this population than those of the urban population.

With regard to the possible influence of race on the factors that may influence the $\dot{V}O_{2max}$ values aerobic performance of children and adolescents, Lee (1980:498) showed that black children outperformed white children of Louisiana in speed and standing broad jump tests. This is in contrast with later studies by Sirard *et al*. (2008:198) and Felton *et al*. (2002:250) which reported greater BMI values, together with lower physical activity participation ($p < 0.001$) values for African-American girls than for their white peers (12 – 14 years). African boys, on the other hand, showed higher physical activity scores with a lower decline in sport participation level than Portuguese boys (6 - 16 years) (Prista *et al*., 2009:397). Prista *et al*. (2009:397) stated that the fact that Portuguese children used private and public transport in contrast to walking long distances to school, as seen in the African children, might explain the differences in physical activity ratings between the two groups. Prista *et al*. (2009:397) also found that both African and Portuguese girls engaged in much less physical activity than boys of the same age groups. These differences in physical activity and sport participating levels may also explain the differences in $\dot{V}O_{2max}$ values between children and adolescents. In this regard, research showed that sport participating Greek (Koutedakis & Bouziotas, 2003:312) and Spanish children (Ara *et al*., 2007:1922; Chillón *et al*., 2011:241)

displayed significantly higher ($p < 0.05$) $\dot{V}O_{2max}$ values than their non-sport participating peers. The above-mentioned findings, together with the statement of Kelly *et al*. (2010:191) that the race of participants must be considered when working with especially adolescents, underline the need to include factors such as race, gender and sport participation in $\dot{V}O_{2max}$ prediction models.

The above-mentioned discussion suggests that 20-m SRT-derived $\dot{V}O_{2max}$ values can possibly be predicted by making use of anthropometric, physical and motor performance components such as body mass, fat mass, BMI, agility, speed and explosive power. However, it is also clear that other factors such as race, gender, living area and sport participation levels may also influence the 20-m SRT-derived $\dot{V}O_{2max}$ of adolescents. Various prediction models for use in sport-participating adults (Bale *et al*., 1986; Brandon & Boileau, 1992), children and adolescents (Chatterjee *et al*., 2006; Lamb & Rogers, 2007; Meckel *et al*., 2009) as well as non-sport-participating adults (Cao *et al*., 2010; Coquart *et al*., 2010; Matsuzaka *et al*., 2004), children and adolescents (Adegboye *et al*., 2010; Arngrímsson *et al*. 2008; Ortega *et al*., 2011; Zakeri *et al*., 2010) have been developed. However, until now no researchers have made an attempt to develop $\dot{V}O_{2max}$ prediction functions for adolescents in South Africa. Most of the existing models also do not consider factors such as gender, race, living area or sport participation levels of the participants. Considering the various ethnicities in the country it is possible that more than one prediction model may apply to South African adolescents, as research has confirmed variances in $\dot{V}O_{2max}$ as a result of race and ethnicity (Kelly *et al*., 2010:191; Lohman *et al*., 2008:1169).

It is against this background that the following research questions are posed: Firstly, is it possible to develop a valid $\dot{V}O_{2max}$ prediction function from several anthropometric measurements and demographic factors such as gender, race and living area as well as sport participation level of a cohort of adolescents living in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa? Secondly, is it possible to develop a $\dot{V}O_{2max}$ prediction function from the physical and motor performance components as well as demographic variables such as gender, race and living area and sport participation level of a cohort of adolescents living in the Tlokwe

Local Municipality (Potchefstroom area) of North West Province, South Africa? And thirdly, what is the validity of the 20-m SRT to estimate the $\dot{V}O_2$ and $\dot{V}O_{2max}$ of a cohort of adolescent boys in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa? Answers to these questions may provide coaches, sport scientists and other sport-related professionals with information regarding the prediction of aerobic endurance in adolescents and concerning the validity of $\dot{V}O_{2max}$ prediction models for South African adolescents.

2. Objectives

The objectives of this study are to:

- Develop a valid $\dot{V}O_{2max}$ prediction function from several anthropometric measurements and demographic factors such as gender, race and living area as well as sport participation level of a cohort of adolescents living in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa.
- Develop a $\dot{V}O_{2max}$ prediction function from the physical and motor performance components as well as demographic variables such as gender, race and living area as well as sport participation level of a cohort of adolescents living in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa.
- Determine the validity of the 20-m SRT to estimate the $\dot{V}O_2$ and $\dot{V}O_{2max}$ of a cohort of adolescent boys living in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa.

3. Hypotheses

The study is based on the following hypotheses:

- A valid $\dot{V}O_{2max}$ prediction function can be developed by making use of the fat percentage, body mass and muscle mass as well as BMI and demographic variables such as gender, race and living area as well as sport participation level of a cohort of adolescents living in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa.

- A valid $\dot{V}O_{2max}$ prediction function can be developed by making use of the speed, agility, explosive power, strength and flexibility measurements as well as demographic variables such as gender, race and living area and sport participation level of a cohort of adolescents living in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa.
- The 20-m SRT is not a valid test for estimating the $\dot{V}O_2$ and $\dot{V}O_{2max}$ of a cohort of adolescent boys in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa.

4. Structure of Dissertation

The thesis will be submitted in article format as approved by the Senate of the North-West University and will be structured as follows:

Chapter 1: Introduction. A bibliography will be provided at the end of the chapter in accordance with the guidelines of the North-West University.

Chapter 2: Literature overview: Predictors and prediction models/equations of aerobic power in children and adolescents. A bibliography will be provided at the end of this chapter in accordance with the guidelines of the North-West University.

Chapter 3: Article 1 – The use of anthropometric measurements and the influence of demographic factors on the prediction of $\dot{V}O_{2max}$ in a cohort of adolescents: The PAHL study. This article will be submitted to the *Journal of Human Movement Science*. This chapter and the bibliography presented at the end of this chapter will be compiled in accordance with the guidelines of the journal. Although not according to the guidelines of the journal, tables and figures will be included within the text so as to make the article easier to read and understand. Furthermore, the line spacing of the article will be set at 1.5 lines as the journal has set no guidelines for authors in this respect.

Chapter 4: Article 2 – Developing a $\dot{V}O_{2max}$ prediction function from the physical, motor performance and demographic components of a group of adolescents: The PAHL study. This article will be submitted to the *Journal of Pediatric Exercise Science*. This chapter and the bibliography presented at the end of the chapter will be compiled in

accordance with the guidelines of the journal. Although not according to the guidelines of the journal, tables and figures will be included within the text so as to make the article easier to read and understand. Furthermore, the line spacing of the article will be set at 1.5 lines instead of the prescribed 2 lines.

Chapter 5: Article 3 – The validity of the 20-m Shuttle Run Test to determine the $\dot{V}O_2$ and $\dot{V}O_{2max}$ of a cohort of adolescent boys: The PAHL study. This article will be submitted to the *Journal of Science and Medicine in Sport.* This chapter and the bibliography presented at the end of this chapter will be compiled in accordance with the guidelines of the journal. Although not according to the guidelines of the journal, tables and figures will be included within the text so as to make the article easier to read and understand. Furthermore, the line spacing of the article will be set at 1.5 lines instead of the prescribed 2 lines.

Chapter 6: Summary, conclusions, limitations and recommendations.

Appendix A: Ethical approval.

Appendix B: The demographic, general information questionnaire and informed consent forms.

Appendix C: Physical activity questionnaire, anthropometric, physical and motor performance data collection forms.

Appendix D: The instructions for authors from the Journal of Human Movement Science, Pediatric Exercise Science and the Journal of Science and Medicine in Sport respectively.

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CHAPTER 2

2 LITERATURE OVERVIEW: PREDICTORS AND PREDICTION MODELS/EQUATIONS OF AEROBIC POWER IN CHILDREN AND ADOLESCENTS

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1. Introduction

The physiological parameter, maximal aerobic power, or $\dot{V}O_{2max}$ as it is more commonly known, was introduced by Hill and colleagues in 1923 and has since been under much investigation by researchers the world over (Basset & Howley, 2000:70-72; Midgley *et al*., 2007:1020-1023). Hill *et al*.*'s* original work, which has been criticized, revered and expanded on, has set the foundation for much of the sport physiological research found in literature today (Basset & Howley, 2000:70). The concept of $\dot{V}O_{2max}$ has allowed researchers and practitioners in the area of sport science, to better understand, evaluate and interpret athletic ability and performance (Basset & Howley, 1997:594-596; Basset & Howley, 2000:77-79; Midgley *et al*., 2007:1023-1026). A number of mental and physical performance components can all significantly contribute to success (as measured by competitive performance) in sport (Birrer & Levine, 1987:215-220). Although $\dot{V}O_{2max}$ is not the only performance indicator, it is one of the strongest indicators of success in long-distance and endurance events (Bompa & Haff, 2009). It is, therefore, no surprise that $\dot{V}O_{2max}$ is one of the most extensively measured indicators by exercise physiology laboratories and generally regarded as the best functional measurement of cardiorespiratory fitness (Howley *et al*., 1995:1292).

A large number of exercise tests which involve the large muscle groups of the body are used to determine a participant's $\dot{V}O_{2max}$ (Åstrand *et al*., 2003:273). These tests, of which some include treadmill walking or running, bench stepping or cycle ergometry, need to be performed continuously with a gradual, incremental increase in intensity or tempo until the participant reaches complete exhaustion or terminates the test (McArdle *et al*., 2010:235). The significance of $\dot{V}O_{2max}$ as a determinant of endurance running performance (Bompa & Haff, 2009) has led many researchers to investigate the cardiorespiratory fitness of children and adolescents (Chatterjee *et al*., 2009; Cunningham, 1990; Meckel *et al*., 2009; Mero *et al*., 1990; Wennlöff *et al*., 2006) as well as adult populations (Aziz *et al*., 2005; Bale *et al*., 1986; Boileau *et al*., 1982; Brandon & Boileau, 1992; Brandon & Boileau, 1987; Cunningham, 1990; O'Gorman *et al*., 2000; Paliczka *et al*., 1987; Pate & O'Neill, 2007) by using direct and/or indirect $\dot{V}O_{2max}$ tests. Results of these studies have highlighted the importance of different factors in determining the $\dot{V}O_{2max}$ values of participants (Cureton *et al*., 1978; Glenmark *et al*., 1993; Goran *et al*., 2000; Vehrs *et al*., 2007:69; Westerstahl *et al*., 2003). The influence of various anthropometric, physical and motor performance

components on aerobic performance has further prompted researchers to develop prediction models or functions which incorporate the named components in order to estimate participants' $\dot{V}O_{2max}$ values, especially when direct testing is not a viable option (Akalan *et al*., 2008; Binyildiz, 1980; Cureton *et al*., 1995; Ruiz *et al*., 2008; Siconolfi *et al*., 1985, Wier *et al*., 2006). These prediction models can either be used to screen large groups of potential talented individuals, quickly and efficiently (Bale *et al*., 1986:172; Bonen *et al*., 1979:29); give an indication of participants' current aerobic fitness levels (Jurca *et al*., 2005:191; Takeshima & Tanaka, 1995:23) or ascertain the fitness levels of participants during large epidemiological studies (Nes *et al*., 2011:2029; Siconolfi *et al*., 1985:390). However, studies which have investigated aerobic performance vary greatly with regard to participant groups, testing methods used and the criteria set for the attainment of maximal aerobic power or $\dot{V}O_{2max}$, making the comparison of study results difficult (Kline *et al*., 1987:258; Latin *et al*., 1993:973; Matthews *et al*., 1999:492). The existence of a wide variety of $\dot{V}O_{2max}$ prediction models complicate matters even further due to the specificity of these models (Binyildiz, 1980:218). Therefore each prediction model is only relevant to the specific participant group, from and for which it was developed, making it inaccurate for use in the broader population (Ebbeling *et al*., 1991:970; Matthews *et al*., 1999:492).

It is against this background that the following literature review was compiled. The first aim of the literature review was to name and describe the various direct and indirect methods cited in the scientific literature and used to determine $\dot{V}O_{2max}$. In cases where the reliability and validity of the different methods have been investigated, findings with regard to results will also be reported. The second aim was to provide a review on the findings with regard to the aerobic performances or $\dot{V}O_{2max}$ values of children and adolescents. Thirdly, the aim was to discuss the possible influence of various anthropometric, physical and motor performance components on the aerobic performances or $\dot{V}O_{2max}$ values of children and adolescents - in cases where literature did not focus on the last-mentioned populations, studies on adults were used. As part of this aim other literature-identified factors, such as sport participation level, living area as well as race and gender, which may also influence the aerobic performances and $\dot{V}O_{2max}$ values of participants, will be discussed. Lastly, all literature-identified models for the prediction of aerobic performances or $\dot{V}O_{2max}$ values in children and adolescents will be mentioned and discussed.

Searches for the identification of literature relevant to this review were narrowed down to only include articles from the last 15 years (1997-2012) which made use of children and adolescent populations between ages 6 and 18 years that were either non-active or active individuals as well as recreational or professional athletes. Furthermore, only papers which included direct or indirect methods for the determination of participants' aerobic performances or $\dot{V}O_{2max}$ values as part of the testing protocol were considered. Both male and female participants were included and no distinction was drawn between either, individual or team sports. The search criteria were also set up to locate literature which has investigated the $\dot{V}O_{2max}$ values or aerobic performances of participants from different ethnic backgrounds.

The terms $\dot{V}O_{2max}$ (ACSM, 2010:72; Heyward, 2010:65; McArdle *et al*., 2010:235-236), $\dot{V}O_{2peak}$ (McArdle *et al*., 2010:235-236; Rowland, 2005:90-94), cardiorespiratory fitness/endurance (ACSM, 2010:71), aerobic power (Howley *et al*., 1995:1292) and aerobic capacity/ability are all used interchangeably in the literature to refer to a person's ability to maximally utilize oxygen to supply energy needs. However, for the remainder of this thesis the only terms that will be used to refer to these last-mentioned variables, are aerobic power or $\dot{V}O_{2max}$.

2. Measurement of aerobic performance

Aerobic power or $\dot{V}O_{2max}$ can be defined as the ability of the mitochondria to extract oxygen from the body's working muscles to supply and meet the energy demands of exercise (Bompa & Haff, 2009:287; Haff & Dumke, 2012:210, Plowman & Smith, 2011:93). The measurement of $\dot{V}O_{2max}$ also gives sport scientists an indication of the ability of the body's cardiovascular, pulmonary, vascular and muscular systems to work in unison (Boutcher, 1990:236, Haff & Dumke, 2012:210) so that oxygen can be optimally absorbed and used during exercise. Maximal oxygen uptake or $\dot{V}O_{2max}$ is measured during incrementally prolonged exercise and is the highest amount of oxygen absorbed and utilized by the body (Bompa & Haff, 2009:287). $\dot{V}O_{2max}$ is quantified in litres per minute with healthy individuals that show average values of between 3 and 4 litres a minute and endurance runners that can obtain values of between 5 and 6 litres per minute (Greenberg *et al*., 2004:112). $\dot{V}O_{2max}$ is regarded by most researchers as the best single measurement of

cardiorespiratory endurance and aerobic fitness (Boutcher, 1990:236; Brandon & Boileau, 1992:7) and is therefore vital in establishing and quantifying endurance fitness as well as cardiorespiratory health in all individuals from the sedentary side of the spectrum all the way to elite athletes (Akalan *et al*., 2008:2).

Various testing methods have been used over the years to assess maximal aerobic capacity and usually consist of the execution of a progressive incremental testing protocol which involves running on a treadmill, cycling on a cycle ergometer or some form of bench stepping (Åstrand *et al*., 2003:273; Boutcher, 1990:236; Grant *et al*., 1995:147; McArdle *et al*., 2010:235). These testing methods are normally regarded as valid methods due to the large number of muscle groups involved during execution (Åstrand *et al*., 2003:273; Boutcher, 1990:236; Grant *et al*., 1995:147; McArdle *et al*., 2010:235). Participants need to perform these tests until complete exhaustion in order to obtain $\dot{V}O_{2max}$ values (Boutcher, 1990:236). To ensure the attainment of maximal values during aerobic power testing, Åstrand and colleagues (2003:280) suggested that the following criteria be applied to ensure accurate collection of data: firstly, administrators should ensure that a large number of muscle groups are involved in the testing method; secondly, the work rate needs to be measureable and must be reproducible in future testing; thirdly, testing conditions should allow for the results to be comparable as well as reproducible; fourthly, all healthy individuals should be able to complete the test, and finally, the skill necessary to be able to complete the test should be uniform and met by all participants involved in the testing.

The direct measurement of $\dot{V}O_{2max}$ by indirect calorimetry and specifically by open-circuit spirometry as well as computerized instrumentation in the laboratory is the most reliable and accurate way of assessing $\dot{V}O_{2max}$ (Chatterjee *et al*., 2008:176; Cooper *et al*., 2005:1). However, the direct measurement of $\dot{V}O_{2max}$ requires the use of specialized, sophisticated equipment which is very expensive; needs well-trained personnel to operate; requires a huge amount of time to conduct; is confounded to laboratory settings and does not allow for a large number of participants to be tested at the same time (Bonen *et al*., 1979:24; Cairney *et al*., 2008; Cooper *et al*., 2005:1). Consequently, laboratory tests are impractical for use in large epidemiological field studies and are therefore not suitable for use by most public schools, especially in rural areas (Buono *et al*., 1991:250). These and other constraints have given rise to the development of indirect $\dot{V}O_{2max}$ tests such as the 20-m Multistage Shuttle Run Test (20-m SRT) (Aziz *et al*., 2005:106; Cooper *et al.,* 2005:1), 12-minute walk/run Cooper Test (Boutcher, 1990:238; Grant *et al*., 1995:148;

McNaughton *et al*., 1998:578), Queens College Step Test (McArdle *et al*., 1973:159), timed distance run (Buono *et al*., 1991:252), 3-minute step test (Buono *et al*., 1991:252), 2.4 km running test (Hergenroeder & Schoene, 1989:674), 1 mile walk/run test (Cureton *et al*., 1995:450), and 1.5 mile run test (Grant *et al*., 1999:348; McNaughton *et al*., 1998:578).

In view of this background the following section will focus on a discussion on each of the direct and indirect tests used to measure $\dot{V}O_{2max}$.

2.1 Direct measurement of $\dot{V}O_{2max}$

Although the direct measurement of $\dot{V}O_{2max}$ is regarded as the golden standard for the measurement of maximal aerobic capacity, this measurement method is often impractical, expensive and time consuming to perform (Cooper *et al*., 2005:1; Grant *et al*., 1995:147; Howley *et al*., 1995:1292; Sanada *et al*., 2007:143). Despite these shortcomings, direct measurement methods are still widely used by researchers, especially in studies of elite athletic populations (Jones, 2002:41; Kenney & Hodgens, 1985:207; Legas-Arrese & Manguia-Izquierdo, 2006:4; McLaughlin *et al*., 2010:992; Noakes *et al*., 1990:36). One of the primary goals of this type of testing is to indirectly determine the amount of energy required to perform a given activity (Plowman & Smith, 2011:94). Aerobic metabolism requires oxygen and leads to the production of metabolic heat, but it is the aerobic metabolism's requirement for oxygen that interests researchers most and which is measured by means of indirect open circuit spirometry (Plowman & Smith, 2011:93). In this method the amount of oxygen consumed ($\dot{V}O_2$) and the amount of carbon dioxide expired ($\dot{V}CO_2$) are calculated from the amount of air expired (Plowman & Smith, 2011:94). This method can then be used to calculate the energy requirements of any mode of physical activity which may include treadmill running (McNaughton *et al*., 1998:578; Morgan *et al*., 1989:79), or ergometer cycling (Patton *et al*., 1982:133; Storer *et al*., 1990:705; Swain & Wright, 1997:269).

Researchers make use of the following criteria to determine whether a participant has reached his/her $\dot{V}O_{2max}$: The exercise-testing protocol must be performed until the participant is unable to continue with the test due to complete exhaustion (McArdle *et al*., 2010:235). Therefore testing protocols are normally set up in such a manner that 8-10 minutes of activity is ensured for moderately to highly trained participants (Yoon *et al*., 2007:1190). Furthermore, Bentley *et al*.

(2007:583) suggested that test stages should be at least 3 minutes in duration for trained populations. However, despite the fact that participants may reach full exhaustion during execution of an exercise-testing protocol, researchers must still use the following criteria to evaluate the attainment of a $\dot{V}O_{2max}$ value during or after execution of a maximal exercise-testing protocol:

- Despite a progressive increase in exercise or testing intensity the $\dot{V}O_2$ increases by no more than 150 ml/min or reaches a plateau (Flouris *et al*., 2005:167, McNaughton *et al*., 1998:578; O'Gorman *et al*., 2000:63).
- A maximal heart rate (HR) of more than 90% (Davies, 2006:15) or 95% (O'Gorman *et al*., 2000:63) of the age-predicted maximum HR or greater than 185 bpm (Flouris *et al*., 2010:71) is achieved at the end of the test.
- A respiratory exchange ratio (RER) of greater than 1.00 (Davies, 2006:15) or 1.1 (Flouris *et al*., 2010:71, McNaughton *et al*., 1998:578; O'Gorman *et al*., 2000:63) or 1.15 (McArdle *et al*., 2010:235) is achieved at the end of the test.
- A Rating of Perceived Exertion (RPE) of greater than 17 on the Borg scale is achieved at the end of the test (Borg, 1982:378).
- A blood lactate concentration of greater than 8 (Davies, 2006:15) or 9 mmol/L blood (O'Gorman *et al*., 2000:63) is achieved during the first 5 minutes after the test

In cases where the last-mentioned criteria are not met, researchers rather refer to the $\dot{V}O_{2max}$, as the $\dot{V}O_{2peak}$. However, $\dot{V}O_{2peak}$ is also the preferred term in cases where a participant did not demonstrate a plateau in the $\dot{V}O_2$ curve despite an increased intensity, but this has been questioned by some researchers (Noakes, 1988:319). However, the majority of researchers still use the term $\dot{V}O_{2max}$ in cases where 2 or 3 of the above-mentioned criteria are met, with $\dot{V}O_{2peak}$ being the preferred term used in some studies on the aerobic performances of children and adolescents. However, for this literature review the term $\dot{V}O_{2max}$ will be used for all populations.
The following section will shed light on some of the most common direct maximal testing protocols for determining $\dot{V}O_{2max}$.

2.1.1 Treadmill protocols

Testing is usually conducted on a variety of motor-driven treadmills at different speeds and inclines (Heyward, 2010:72). The rate of work performed is usually expressed as kilometres per hour

(km/h) or miles per hour (mi/h) and/or as the degree of the treadmill incline used during completion of the testing protocol (Heyward, 2010:72). Testing commences with a warm-up period after which a gradual increase in workload will occur by either increasing the speed or the incline level of the treadmill. Expired gas is then analysed for 1 to 5 second periods and the HR values recorded throughout the testing period. The test will normally be stopped when the participant indicates that he/she can no longer continue. Various standard treadmill protocols have been compiled to enable researchers to duplicate the testing procedures on various populations of participants (Heyward, 2010:74-78). The use of non-standardized testing protocols and various testing methodologies remain one of the biggest challenges in establishing $\dot{V}O_{2max}$ norms and profiles for different populations of participants (Midgley *et al*., 2007:1027).

a. Bruce treadmill protocol

For this protocol, the treadmill speed and incline are changed continuously throughout the test (Bruce *et al*., 1973:547). During the 1st and 3rd minute of the test the pace is set at 1.7 mi/h and an incline of 10%. During the 4th and 6th minute of the test, the incline is increased to 12% and the speed to 2.5 mi/h, where after the incline is increased by 2% and the speed to either 0.8 or 0.9 mi/h every minute, until complete exhaustion (Bruce *et al*., 1973:547; Pollock *et al*., 1976:44). A high correlation (R) of R = 0.99 was obtained when the reproducibility of results was investigated. Furthermore, a Standard Error of Estimate (SEE) of 1.9 ml/kg/min was reported for the $\dot{V}O_{2max}$ values of healthy men and women (Bruce *et al*., 1973:552).

b. Balke treadmill protocol

The treadmill starting speed is set at 3.4 mi/h (91.1 m/min) and the initial incline at 0% for the first 2 minutes of testing (Heyward, 2010:74). After the first 2 minutes the incline is increased to 2% and every minute thereafter by an additional 1%, while the running speed is kept constant (McArdle *et al*., 1972:183; McArdle *et al*., 1973:157). McArdle *et al*. (1972:183) reported a test-retest reliability coefficient of R = 0.95 for the $\dot{V}O_{2max}$ values of college participants.

c. Ellestad treadmill protocol

In the test protocol Pollock *et al*. (1976:40) described, the test starts at a 10% incline and a 1.7 mi/h speed for a 3-minute duration. After the 3rd minute the speed is adjusted to 3.0 mi/h for another 2 minutes. After 5 minutes the speed is again increased by 1.0 mi/h for 2 minutes and at the end of the 7th minute the speed is adjusted to 5.0 mi/h for an additional 3 minutes. At the end of the 10th minute, the incline is adjusted to 15% and the speed adjusted by another 1 mi/h. Every

minute thereafter the speed will increase by 1 mi/h at the incline kept constant at 15% until complete exhaustion (Pollock *et al*., 1976:40). A correlation value of R = 0.90 was reported between time spent on the treadmill and $\dot{V}O_{2max}$ values, indicating that a longer run resulted in the attainment of higher $\dot{V}O_{2max}$ values. A SEE of ± 0.080 was reported for the $\dot{V}O_{2max}$ values of healthy men and women (Pollock *et al*., 1976:43).

d. Modified Åstrand treadmill protocol

In this protocol a 5-minute warm-up during which a participant walks at 3.5 mi/h at a 2.5% incline is followed by a continuous run at a constant speed of between 5 and 8 mi/h (depending on each participant's ability to run) with the incline increasing 2.5% every 2 minutes until complete exhaustion (Pollock *et al*., 1976:40). Due to the variable running speeds by different participants, indirect prediction equations have not been developed.

2.1.3 Cycle ergometer protocols

The cycle ergometer is often the preferred testing equipment when working with non-athletes as it is safer and more comfortable to perform a test on this apparatus (Howley & Franks, 2007:69-71). Work rate is expressed as watts (W) and is adjusted by applying resistance to the flywheel. Participants will be required to maintain a certain pedalling cadence (revolutions per minute or rpm) as the resistance gradually increases throughout the testing period (Heyward, 2010:79-81; Howley & Franks, 2007:69). Expired gas and heart rate are recorded during the testing period and the test is terminated when participants fail to maintain the required pedalling cadence (Heyward, 2010:79; Howley & Franks, 2007:69-70).

a. Åstrand-Ryhming Cycle Ergometer Maximal Test Protocol

Initial power output is set at 50 W for females and 100 W for males and a pedalling cadence must be maintained at 50 rpm for the duration of the test (Glassford *et al*., 1965:510; Patton *et al*., 1982:133). After 2 minutes at the initial workload the power output is increased every 2 to 3 minutes with 25 W for females and 50 W for males and the increase in workload will continue until complete exhaustion or until the pedalling cadence of 50 rpm is not maintained (Glassford *et al*., 1965:510; Patton *et al*., 1982:133). Test-retest reliability coefficients of R = 0.95 and R = 0.81 have been reported for males and females respectively (Patton *et al*., 1982:137).

b. Fox's Single Stage Cycle Ergometer Protocol

This test involves a series of 5-minute exercise sessions with a 10-minute resting period in

between each exercise session (Fox, 1973:914). The initial workload is 150 W and a pedalling cadence of 60 rpm must be maintained. The workload of subsequent sessions is made progressively heavier until the participant cannot maintain the required pedalling cadence for at least 3 minutes at a work load which is 10-15 W higher than the previous exercise session's workload. Participants' $\dot{V}O_{2max}$ values are determined by open circuit spirometry (Fox, 1973:914).

2.2 Indirect measurement of $\dot{V}O_{2max}$

Due to the previously mentioned constraints of direct $\dot{V}O_{2max}$ testing, researchers have developed less expensive and more easily administered indirect $\dot{V}O_{2max}$ testing methods (Akalan *et al*., 2008:15; Boutcher *et al*., 1990:237). Indirect testing methods are similar to those of direct testing methods but differ due to the fact that specialized equipment is not needed; it can be submaximal in nature; it can be terminated at a predetermined heart rate or intensity/workload and is easily administered to large numbers of participants (Buono *et al*., 1991:250; Cairney *et al*., 2008:137; Cooper *et al*., 2005:1). These tests are used to predict a participant's $\dot{V}O_{2max}$ values by compiling regression equations, normograms and other mathematical models from the data obtained from direct $\dot{V}O_{2max}$ tests (Adegboye *et al*., 2011:724; Arngrímsson *et al*., 2008:68; Chatterjee *et al*., 2009:116; Goran *et al*., 2000:845; Mahar *et al*., 2006:S37; Matsuzaka *et al*., 2004:116; Pfeiffer *et al*., 2007:2238; Ruiz *et al*., 2008:240; Tong *et al*., 2001:320). However, indirect $\dot{V}O_{2max}$ prediction models not specifically developed for a certain population will show a curtailed ability to accurately predict $\dot{V}O_{2max}$ (Ebbeling *et al*., 1991:973; Hermiston & Faulkner, 1971:837; Matthews *et al*., 1999:491; Pober *et al*., 2002:586; Siconolfi *et al*., 1982:338).

Subsequently, the most popular indirect $\dot{V}O_{2max}$ tests will be discussed.

2.2.1 Treadmill protocols

a. Ebbeling Treadmill Walking Test

This test is a single-stage walking test for males and females between ages 20 and 59 years (Ebbeling *et al*., 1991). The test starts with a warm-up period of 4 minutes at a comfortable self-selected walking speed of either 2, 3, 4 or 4.5 mi/h and a 0% incline. This is followed by another 2

stages of 4 minutes each during which the walking speed is increased (maintaining a comfortable walk or slow jog) and the treadmill incline is raised from 0 to 5% and then from 5 to 10%. Subsequently, participants can decide to maintain a constant walking or running pace with the incline being increased every 2 minutes by 2.5% until complete exhaustion. Each participant's $\dot{V}O_{2max}$ value is then calculated by applying the following equation (Ebbeling *et al*., 1991:972):

$\dot{V}O_{2max}$ = 15.1 + (21.8 x treadmill speed in mi/h) – (0.327 x HR) – 0.263 x (treadmill speed x age in years) + 0.00504 x (HR x age in years) + 5.98 x (gender: 0 = female; 1 = male)

The regression model showed a reliability coefficient of R = 0.96 to predict the $\dot{V}O_{2max}$ values of 20 to 59-year-old participants and had a SEE = 4.85 ml/kg/min (Ebbeling *et al*., 1991:972)

b. Incremental Treadmill Jogging Test

This test commences at a comfortable jogging pace of between 4.3 and 7.5 mi/h for 3 minutes. For female participants the treadmill speed will be set at less than 6.5 mi/h. HR, and Rating of Perceived Exertion (RPE) is recorded (Vehrs *et al*., 2007). $\dot{V}O_{2max}$ is then predicted by applying the following equation:

$\dot{V}O_{2max}$ (ml/kg/min) = 58.687 + (7.520 x gender: female = 0, male = 1) + (4.334 x jogging speed) – (0.211 x kg) – (0.148 x HR) – (0.107 x age in years)

The equation had a significant correlation of R = 0.91 with a SEE = 2.52 ml/kg/min in predicting the $\dot{V}O_{2max}$ results of 400 male and female participants between ages 18 and 40 years.

c. Bruce treadmill protocol

This protocol is executed in the exact same manner as the protocol explained under the direct measurement of aerobic performance heading. The following $\dot{V}O_{2max}$ prediction equation was developed by Bruce *et al*. (1973:554) to be used for healthy participants in cases where direct open circuit spirometry is not available:

$\dot{V}O_{2max}$ (ml/kg/min) = 6.70 – 2.82 (gender: 1 = male, 2 = female) + 0.056 (duration of test in seconds)

The Bruce treadmill protocol obtained a reliability coefficient of R = 0.920 for the prediction of

$\dot{V}O_{2max}$ values among healthy adult males and females.

d. Balke treadmill protocol

This protocol is executed in the exact same manner as the protocol explained under the direct measurement of aerobic performance heading. A nomogram is used to calculate participants' $\dot{V}O_{2max}$ values (Heyward, 2010:75). Pollock *et al*. (1982:363) reported a correlation of R = 0.94 for the prediction of $\dot{V}O_{2max}$ values of 49 healthy active and sedentary females (27.0 ± 5.2 years) from the Blake treadmill protocol with a SEE = 2.2 ml/kg/min when applying the following prediction equation :

$\dot{V}O_{2max}$ = 0.023 (treadmill walking/running time in seconds) + 5.2

e. Ellestad treadmill protocol

This test protocol is also executed in the exact same manner as the test protocol explained under the direct measurement of aerobic performance heading (Pollock *et al*., 1976:40). The following equation is then used to predict healthy males' $\dot{V}O_{2max}$ values (Pollock *et al*., 1976:44):

$\dot{V}O_{2max}$ = 3.933 (treadmill walking/running time in seconds) + 4.46 (SEE = ± 0.080 ml/kg/min)

2.2.2 Cycle ergometer protocols

a. Åstrand-Ryhming Cycle Ergometer Submaximal Exercise Test Protocol

For trained, physically active males and females a workload of 75-100 W and 100-150 W is used respectively. HR is recorded at every minute and the average HR at the 5th and 6th minute is calculated. In cases where the HR, at the 5th and 6th minutes of the test, differs more than 5 or 6 bpm from the previous stage, the workout is extended until a steady state HR is achieved. In cases where a participant's HR is less than 130 bpm the workload is increased by 50 W and another 6 minutes of exercise follows (Glassford *et al*., 1965:510; Heyward, 2010:87; Patton *et al*., 1982:133). A nomogram is used to predict $\dot{V}O_{2max}$ by using the HR response to the one 6-minute submaximal workload. The submaximal HR is then plotted together with the power output to obtain $\dot{V}O_{2max}$. A correlation coefficient of R = 0.79 was reported for the prediction of $\dot{V}O_{2max}$ values when compared with results obtained from direct testing methods of healthy adult males between ages 17 and 33 years (Glassford *et al*., 1965:510).

b. YMCA Bicycle Ergometer Test

The protocol involves 3 to 4 consecutive intervals of 3-minute workloads each. The workload should raise the steady-state HR to 85% of the age predicted maximal HR of the participants for at least two consecutive stages of the test. The pedalling cadence should be maintained at 50 rpm and HR is recorded during the last 15 - 30 seconds of each minute-interval of the test. In cases where the HR differs by more than 6 bpm within a stage it is noted that a steady-state has not been reached and the workload will need to be adjusted accordingly (Howley & Franks, 2007:78).

In the first step, the metabolic equation of the American Council of Sports Medicine (ACSM) is used to calculate $\dot{V}O_2$ after which the multistage model equation is used to determine $\dot{V}O_{2max}$ (ACSM, 2010:317; Haff & Dumke, 2012:179; Heyward, 2010:88). Garatachea *et al*. (2007:145) reported correlation coefficients of R = 0.677 for men and R = 0.726 for women when the $\dot{V}O_{2max}$ values obtained from the YMCA testing protocol was compared with the values obtained from the maximal cycle ergometer test. The Åstrand-Ryhming nomogram can also be used to predict the $\dot{V}O_{2max}$ values.

c. Fox Single-Stage Cycle Ergometer Test Protocol

This protocol is executed in the exact same manner as the protocol explained under the direct measurement of aerobic performance heading (Fox, 1973:914*)*. The following equation is used to predict the $\dot{V}O_{2max}$ values of participants (Fox, 1973:914):

$\dot{V}O_{2max}$ (L/min) = 6 300 – 19.26 (HR bpm at 5 min)

A correlation coefficient of R = 0.76 and a SEE = ± 246 mL/min were reported between the directly measured and predicted $\dot{V}O_{2max}$ values of 87 healthy, untrained college males (19.5 ± 2.3 years) from this test (Fox, 1973:914).

d. Swain Cycle Ergometer Submaximal Exercise Test Protocol

The protocol was designed to predict the $\dot{V}O_{2max}$ values for participants between ages 18 and 44 years that are either active or inactive (Swain *et al*., 2004). However, test protocols are performed differently for each of the mentioned populations:

For active clients weighing less than 90 kg:
The initial workload is 0.25 kg and increases by 0.25 kg every minute until a target HR of 45% of the heart rate reserve (HRR) is reached. At the point where the target HR is reached the current workload will be maintained for an additional 5 minutes and the average HR recorded for the final minute of the final stage.

For active clients weighing more than 90kg:
The initial workload is 0.5 kg and increases by 0.5 kg every minute until a target HR of 55% of the HRR is reached. At the point where the target HR is reached the current workload is maintained for an additional 5 minutes and the average HR recorded for the final minute of the final stage.

For inactive clients weighing less than 90kg:
The initial workload is 0.25 kg and increases by 0.25 kg every minute until a target HR of 45% of the HRR is reached. At the point where the target HR is reached the current workload is maintained for an additional 2 minutes. In cases where the HR reached during the first 3 minutes of the test is greater than 55% of the HRR, participants will cycle for an additional 3 minutes to complete a 6-minute stage. In cases where participants reach an HR of less than 55% of the HRR during the 3rd minute of the test the workload will be increased by an additional 0.25 kg/min until the participant reaches 55% of the HRR. At this point the participant will continue the test for an additional 5 minutes to complete a 6-minute stage.

For inactive clients weighing more than 90kg:
The initial workload is 0.5 kg and increases by 0.5 kg every minute until a target HR of 45% of the HRR is reached. At the point where the target HR is reached the current workload will be maintained for an additional 2 minutes. In cases where the HR reached is greater than 55% of the HRR during the first 3 minutes of the test, participants will cycle for an additional 3 minutes to complete a 6-minute stage. In cases where participants reach an HR of less than 55% of HRR during the 3rd minute of the test the workload will be increased by an additional 0.5 kg/min until the participant reaches 55% of the HRR. At this point the participant will continue the test for an additional 5 minutes to complete a 6-minute stage.

During the execution of the above-mentioned protocols, the participants will be required to maintain a pedal cadence of 60 rpm. HR is recorded during the last 15 sec of each 1-minute stage. Maximal workload and $\dot{V}O_{2max}$ are then predicted by following the subsequent steps:

Step 1: Calculate power (W) for the workload of the final 6 minutes:
Power = Workload (kg) x 60 rev/min x 9.81
Step 2: Calculate age predicted HR_{max} (maximal heart rate) by determining the average HR values for the 5^{th} and 6^{th} minutes of the final test stage.
Step 3: Calculate the percentage of HRR (%HRR) for the final stage:
%HRR = (HR_{6min} – HR_{rest}) / (HR_{max} – HR_{rest} (resting heart rate))
Step 4: Calculate maximum power ($Power_{max}$) (W) by dividing the workload of the final 6 minutes ($Power_{6min}$) (step 1) by the %HRR (step 3)
$Power_{max}$ (W) – $Power_{6min}$ / %HRR

Step 5: Use the ACSM's metabolic equation to convert maximum power to $\dot{V}O_{2max}$: $\dot{V}O_{2max}$ = 7 + [10.8 x $Power_{max}$ (W) / Body mass (kg)]

Test-retest correlations of R = 0.91 (pilot study) and R = 0.89 (modified protocol) were reported for the prediction of $\dot{V}O_{2max}$ for participants between ages 18 and 44 years (Swain *et al*., 2004:1424).

2.2.3 Bench-stepping protocols
The least desirable method to use when calculating maximal aerobic capacity is that of bench stepping due to the fact that the step ups are performed at different heights and at different rates (Rowland, 1996:34). Most protocols entail that the stepping rate or stepping height is gradually increased throughout the test and $\dot{V}O_{2max}$ is usually determined by using the individual's HR and HR recovery (Heyward, 2010:89-91; Rowland, 1996:34).

a. Åstrand-Ryhming Step Test Protocol
The test makes use of a bench with a height of 33 cm for females and 40 cm for males. A step-up pace of 90 steps/min is used for the duration of 5 minutes. Immediately after completion of the 5-minute test, HR is recorded (Marley & Linnerud, 1976:76). Siconolfi *et al*. (1985:386) reported a correlation coefficient of R = 0.92 and a SEE = 0.3 when the predicted $\dot{V}O_{2max}$ values of the step-up test were compared with the directly determined $\dot{V}O_{2max}$ results of 48 males and females (19 – 70 years). The Åstrand-Ryhming nomogram and the following equations are used to calculate the participants' $\dot{V}O_{2max}$ values:

Males: $\dot{V}O_2$ (L/min) = 0.348 ($\dot{V}O_2$ from nomogram not corrected for age) – (0.035 x age in years) + 3.011

Females: $\dot{V}O_2$ (L/min) = 0.302 ($\dot{V}O_2$ from nomogram not corrected for age) – 0.19 (age in years) + 1.593

b. Queens College Step Test

This test also uses the HR recovery to determine aerobic power. HR_{rest} is recorded prior to commencement of the test. For females the stepping rate is set at 88 steps/min and for males at 96 steps/min. The test is usually performed for a duration of 3 minutes, immediately after which HR is recorded (McArdle *et al*., 1972:185). $\dot{V}O_{2max}$ is then calculated as follows:

Males: $\dot{V}O_{2max}$ (ml/kg/min) = 111.33 – (0.42 x HR)

Females: $\dot{V}O_{2max}$ (ml/kg/min) = 65.81 – (0.1847 x HR)

McArdle *et al*. (1972:185) reported reliability coefficients of R = 0.78 – 0.92 when comparing step test scores of college females and the results of various physical work capacity tests.

The following section will discuss some of the most common field tests used in the measurement of $\dot{V}O_{2max}$ values.

2.2.4 Field tests

Field tests are inexpensive, very easy to administer as well as less time consuming than the treadmill and cycle ergometer tests and can easily be administered to large groups of participants (Heyward, 2010:92). The tests usually involve walking, running, swimming or bench stepping (Heyward, 2010:93).

a. 20-m Multi-Stage-Shuttle Run Test (20-m SRT)

During the 20-m SRT participants are required to run back and forth between a 20-metre stretch of marked lines or cones and pace themselves so that the arrival at the end of the 20-metre stretch coincides with a beep signal emitted from a commercially available pre-recorded compact disc (20-m Shuttle Run Test CD, Australian Sports Commission, 1998). Participants need to touch the marked lines at either end of the 20-metre stretch with one foot as a signal sounds from the CD.

The beep sounds at a progressively increasing pace with every minute of the test. This increase in running speed is described as a change in test level. The test is terminated when a participant voluntarily drops out or cannot make it to either end marks of the 20-metre distance within the given beep time in 2 successive shuttles. Both lines therefore need to be monitored by testers at either end. The results recorded will be the last number (level) called and the shuttle reached before dropping out. The $\dot{V}O_{2max}$ is determined from a booklet that comes with the test CD by using the last level and shuttle reached during the 20-m SRT (Léger & Lambert, 1982).

Léger and Lambert (1982) reported a correlation coefficient of R = 0.975 in their validity studies of the 20-m SRT when they tested and retested 50 males and females (aged 18 – 37 years). In this regard significant correlations of between R = 0.53 and 0.76 ($p < 0.001$ and $p < 0.05$) and non-significant correlations of between R = 0.66 and 0.72 ($p > 0.05$ and $p > 0.1$) have been reported for the relationship between direct $\dot{V}O_{2max}$ and the estimated, 20-m SRT-predicted $\dot{V}O_{2max}$ values of adolescents (Chatterjee *et al*., 2009:119; Liu *et al*., 1992:362; Mahar *et al*., 2006:S39; Mahar *et al*., 2011:S119; Matsuzaka *et al*., 2004:121; Pitetti *et al*., 2002:130; Williford *et al*., 1999:13).

b. Cooper 1.5 mile Run/Walk Test

For this test of Cooper participants are required to cover 1.5 miles in the quickest possible time (Heyward, 2010:94; ACSM, 2010:313). The $\dot{V}O_{2max}$ of each participant is calculated by using the time required to cover the set distance with participants covering the set distance in the fastest times that will obtain the highest $\dot{V}O_{2max}$ values (Heyward, 2010:94; ACSM, 2010:313). Zwiren *et al*. (1991:75) reported a correlation coefficient of R = 0.79 for the relationship between the Cooper 1.5 mile Run/Walk Test predicted and the directly determined $\dot{V}O_{2max}$ values of healthy females between ages 30 and 39 years. The following equations are used to determine participants' $\dot{V}O_{2max}$ values from the Cooper 1.5 mile Run/Walk Test results (ACSM, 2010:313):

Males: $\dot{V}O_{2max}$ (ml/kg/min) = 91.736 – (0.1656 x body mass (kg)) – (2.767 x 1.5 mile run time in minutes)

Females: $\dot{V}O_{2max}$ (ml/kg/min) = 88.020 – (0.1656 x body mass (kg)) – (2.767 1.5 mile run time in minutes)

Or

$\dot{V}O_{2max}$ (ml/kg/min) = 65.404 + (7.707 x gender: male = 1; female = 0) – (0.159 x body mass (kg)) – (0.843 x 1.5 mile run time in minutes)

c. Cooper 12-minute Run/Walk Test

During execution of this test participants must run as far as possible on a flat surface course or oval track in 12 minutes and at the end of the test the total distance covered in the set time period is used to calculate the participants' $\dot{V}O_{2max}$ values (Cooper, 1968:136; McCutcheon *et al*., 1990:280). Correlation coefficients of R = 0.897 (Cooper, 1968:137), R = 0.9 (McCutcheon *et al*., 1990:282) and R = 0.92 (Grant *et al*., 1995:150) have been reported for the relationship between the Cooper 12-minute Run/Walk Test predicted and the directly determined $\dot{V}O_{2max}$ values of graduate and undergraduate students, healthy male participants as well as male Air Force officers between ages 17 and 52 years.

$\dot{V}O_{2max}$ values are then calculated by applying the following equation:

$\dot{V}O_{2max}$ (ml/kg/min) = 0.0268 x (Cooper 12-minute Run/Walk Test distance in metres) – 11.3

d. Rockport Fitness Walking Test

During this Rockport test participants must walk 1 mile in the quickest possible time (Fenstermaker *et al*., 1992:323; Kline *et al*., 1987:255). The following equations are then used to calculate $\dot{V}O_{2max}$ values (Fenstermaker *et al*., 1992:323):

$\dot{V}O_{2max}$ (L/min) = 6.9652 + (0.0091 x body mass in lbs) – (0.0257 x age in years) + (0.5955 x gender: male = 1, female = 0) – (0.2240 x Rockport Fitness Walking Test time) – (0.0115 x HR directly after completion of test)

$\dot{V}O_{2max}$ (ml/kg/min) = 132.853 – (0.0769 x body mass in lbs) – (0.3877 x age in years) + (6.3150 x gender: male = 1, female = 0) – (3.2649 x Rockport Fitness Walking Test time) – (0.1565 x HR directly after completion of test)

Fentermaker *et al*. (1992:324) reported a test-retest reliability coefficient of R = 0.67 – 0.97 for females over 60 years of age whereas Kline *et al*. (1987:257) found a reliability coefficient of R = 0.92 when comparing predicted and directly determined $\dot{V}O_{2max}$ values of males and females between ages 30 and 69 years. A later study by Greenhalgh *et al.* (2001:145) revealed

correlations of R = 0.81 – 0.84 when comparing predicted and directly determined $\dot{V}O_{2max}$ values of college males and females.

e. 1 Mile Track Jog

The test was designed due to the fact that the 1-mile walk test was not appropriate for use among college-aged or fit individuals (Heyward, 2010:94). The test requires participants to run sub-maximally at a steady, self-selected pace at an HR lower than 180 bpm (Heyward, 2010:94). Running speed is established by determining the HR after completion of a 2 to 3-minute warm-up jog. In cases where the HR is higher than 180 bpm at the end of the warm-up jog the speed will be adjusted accordingly (George *et al*., 1993:402; Kline *et al*., 1987:255). Correlation coefficient values of R = 0.87 and R = 0.94 have been reported for the relationship between the above-mentioned test predicted and the directly determined $\dot{V}O_{2max}$ values of 18 to 29-year-old, fit, college students (George *et al*., 1993:403). Quail *et al*. (1999:9) reported reliability coefficients of R > 0.98 for the prediction of $\dot{V}O_{2max}$ values in African American and Caucasian populations between ages 18 and 38 years. $\dot{V}O_{2max}$ values are calculated by applying the following equation (George *et al*., 1993:401):

$\dot{V}O_{2max}$ (ml/kg/min) = 100.5 + (8.344 x gender: male = 1, female = 0) – (0.1636 x body mass in kg) - (1.438 x 1 Mile Track Jog Test results in mi/h) – (0.1928 x Steady state HR in bpm)

The various testing methods discussed above allow researchers to determine either direct or indirect $\dot{V}O_{2max}$ values of participants. The relationship between these two methods of determining a participant's $\dot{V}O_{2max}$ will be discussed in the section to follow.

2.3 Relationship between the direct and indirect measurements of $\dot{V}O_{2max}$

The indirect assessment of maximal aerobic capacity has received a huge amount of attention in the literature, with studies either investigating the best and most accurate available indirect testing methods (Aziz *et al.*, 2005; Buckley *et al*, 2004; Castro-Piñero *et al.*, 2010; Cooper *et al.*, 2005; Flouris *et al.*, 2005; Grant *et al.*, 1999; McNaughton *et al.*, 1998; O'Gorman *et al.*, 2000; Stickland *et al.*, 2003) while others tested the validity of existing methods by comparing the indirect $\dot{V}O_{2max}$ test results with the results of direct tests (Davies *et al.*, 2008; Flouris *et al.*, 2010; Matsuzaka *et al.*,

2004; Metsios *et al.*, 2008; Ruiz *et al*, 2009). Common to all the mentioned studies, is that researchers investigated ways of making $\dot{V}O_{2max}$ testing more accessible to a wider group of participants and sport practitioners alike.

In most cases participants will undergo indirect open circuit spirometry tests by using one of the above-mentioned testing protocols (section 2.1 and 2.2) after which these directly determined $\dot{V}O_{2max}$ results will be compared with the indirectly predicted $\dot{V}O_{2max}$ results of tests such as the 20-m SRT, 12-minute Cooper run test and 1-mile walk/run test, amongst others. In this regard Stickland *et al.* (2003:274) for example studied the accuracy of the 20-m SRT to predict $\dot{V}O_{2max}$ in adult males and females by comparing the 20-m SRT-predicted to the directly treadmill testing protocol-determined $\dot{V}O_{2max}$ values. Their results suggested that the original equations of Légar *et al*. (1988) and Léger and Gadoury (1989) significantly under-predicted ($p < 0.05$) the $\dot{V}O_{2max}$ values of both male and female groups, with the magnitude of under-prediction being larger for males than for females. From their study results Stickland *et al*. (2003:280-281) highlighted the necessity of gender-specific prediction equations and the importance of also considering 20-m SRT-obtained half stages in the prediction equations to more accurately determine $\dot{V}O_{2max}$. Similarly, Ruiz *et al.* (2009:903) also recommended the inclusion of 20-m SRT-obtained half stages as variables in $\dot{V}O_{2max}$ prediction equations to increase the accuracy of predicting $\dot{V}O_{2max}$ values. They also found the equation of Léger *et al*. (1988) to be the least accurate of the 5 prediction equations evaluated for the prediction of $\dot{V}O_{2max}$ from the 20-m SRT results (Ruiz *et al*., 2009:903).

Moreover, Lamb and Rogers (2007:291) disputed the use of the 20-m SRT as a tool to predict $\dot{V}O_{2max}$ and regarded the 20-m SRT results to be a better indicator of sport-specific endurance than $\dot{V}O_{2max}$. Lamb and Rogers (2007:291) used the Léger equation and the table of Brewer to predict $\dot{V}O_{2max}$ from the 20-m SRT results and found significantly higher values (mean difference of 5.7 ml/kg/min) for the Léger equation than the values obtained by using the table of Brewer (Lamb & Rogers, 2007:290). A surprising finding of this study was that different values were obtained from 3 different testing occasions with those of trials 2 and 3 being significantly higher

than those of trial 1 but not significantly different from each other (Lamb & Rogers, 2007:290).

Several researchers suggested that sport type can greatly affect the outcome of all-out exercise tests (Aziz *et al*., 2005:311). In this regard Aziz *et al*. (2005:311) demonstrated that endurance runners obtained significantly lower 20-m SRT-predicted $\dot{V}O_{2max}$ values than direct $\dot{V}O_{2max}$ values from treadmill running. The opposite results were found for team sport participants that obtained higher 20-m SRT-predicted $\dot{V}O_{2max}$ values than direct $\dot{V}O_{2max}$ values from treadmill running (Aziz *et al.*, 2005:311). A possible reason for these differences in $\dot{V}O_{2max}$ values between the two testing methods is possibly that team sport participants are more accustomed to performing running activities that include accelerations, decelerations and turning which are activities performed during execution of the 20-m SRT (Aziz *et al.*, 2005:312). Dissimilarly, running on the treadmill is continuous and linear which suites endurance runners better (Aziz *et al.*, 2005:312). These findings suggest that test protocols need to resemble the sporting event of an athlete in order to deliver accurate $\dot{V}O_{2max}$ results (Aziz *et al.*, 2005:313; Ruiz *et al*., 2009:903). In contrast to the last-mentioned results, Chatterjee *et al.* (2009:118) found the 20-m SRT to be accurate in predicting the $\dot{V}O_{2max}$ values of football players due to the fact that no significant differences were obtained between the 20-m SRT-predicted and directly determined $\dot{V}O_{2max}$ values. The more favourable results with regard to the validity of the 20-m SRT may possibly be related to the nature of football that involves frequent changes in direction and short turns, which are similar to movements of the 20-m SRT.

One of the problems researchers are faced with when validating the predicted $\dot{V}O_{2max}$ results of the 20-m SRT, is that the biomechanical requirements and musculature involvement during execution of the 20-m SRT are very different from those of the direct treadmill running test. The metabolic energy contribution pathways also differ extremely between the two tests, with the anaerobic energy system that contributes more to the energy requirements of the 20-m SRT than does the treadmill running test (Metsios *et al.,* 2008:215). These mentioned differences have compelled researchers to change the design of the 20-m SRT in such a manner that the test is performed in a square sequence where participants perform 90° turns instead of the traditional test in which 180° turns are performed (Metsios *et al.*, 2008). Correlation values of r = 0.95 and r = 0.63, respectively were found for the relationship between the predicted $\dot{V}O_{2max}$ square shuttle

test (SST), the 20-m SRT and the direct $\dot{V}O_{2max}$ values from treadmill running of 74 males (age: 21.6 ± 2 years) (Metsios *et al.* 2008:216). The SST obtained a prediction error of –0.3 ± 3.3 ml/kg/min compared to the 20-m SRT, which obtained a value of 4.2 ± 7.3 ml/kg/min. The researchers also reported re-test coefficients of 0.85 and 0.72 respectively for the two last-mentioned tests (Metsios *et al.*, 2008:216). However, the SST proved to be a more valid test than the 20-m SRT, although both tests were considered reliable and valid tests for the prediction of $\dot{V}O_{2max}$ in this population (Metsios *et al.*, 2008:216).

In another attempt to improve the validity of the original 20-m SRT, Flouris *et al.* (2010:73) modified the 20-m SRT to a 15 m square shuttle run test that only required 90° turns instead of the normal 180° turns. Forty-five men between ages 18 and 29 years volunteered to take part in the study to validate the new test. Comparisons between the $\dot{V}O_{2max}$ scores from direct treadmill testing and the directly measured or predicted SST showed no significant differences (Flouris *et al*., 2010:73). Both the predicted and directly measured $\dot{V}O_{2max}$ results from the SST were higher than the values of the direct treadmill test (Flouris *et al*., 2010:73). The SST showed no differences in test and re-test measured and predicted $\dot{V}O_{2max}$ values and was therefore deemed a valid and reliable alternative to the 20-m SRT (Flouris *et al*., 2010:73). Furthermore, the $\dot{V}O_{2max}$ values from the treadmill test correlated significantly with the directly measured and predicted $\dot{V}O_{2max}$ values of the 20-m SRT ($r = 0.72$; $p < 0.001$ and $r = 0.68$; $p < 0.05$) as well as with the directly measured and predicted $\dot{V}O_{2max}$ values of the SST ($r = 0.92$; $p < 0.001$ and $r = 0.87$; $p < 0.001$) (Flouris *et al*., 2010:72). These results confirm earlier findings of Flouris *et al*. (2005:167) who predicted 20-m SRT $\dot{V}O_{2max}$ values correlated significantly ($r = 0.96$, $p < 0.001$) with directly measured 20-m SRT $\dot{V}O_{2max}$ values.

Due to the high correlation reported between the 20-m SRT- and directly determined $\dot{V}O_{2max}$ values of participants, researchers agree that the 20-m SRT is a good tool for determining aerobic performance in children, adolescents ($r = 0.75$ - 0.76; $p < 0.001$) (Matsuzaka *et al.*, 2004) and adults ($r = 0.88$); $p < 0.001$) (Matsuzaka *et al.*, 2004) but warned that caution needs to be taken when testing sport participants (Cooper *et al.*, 2005:6; Matsuzaka *et al.*, 2004:121). Sport

participation may influence the 20-m SRT results and the 20-m SRT may not be sensitive enough to detect very slight increases in cardiorespiratory fitness as is often the case with elite athletes (Cooper *et al.*, 2005:6). However, Davies *et al.* (2008:1009) were able to improve the prediction power of the 20-m SRT for physically active females by considering ratings of perceived exertion (RPE) experienced during execution of the 20-m SRT. A high ($p \leq 0.05$) linear relationship was observed between each participant's $\dot{V}O_2$ and RPE values (Davies *et al.*, 2008:1009).

In another study (Ruiz *et al*., 2009:903) the prediction power of various 20-m SRT-derived equations were evaluated by comparing the directly measured $\dot{V}O_{2max}$ values during execution of the 20-m SRT with predicted $\dot{V}O_{2max}$ values derived from 5 different equations for 13 to 19-year-old participants. All the equations, except that of Barnett, significantly ($p < 0.001$) underestimated the $\dot{V}O_{2max}$ values from the directly obtained assessment (Ruiz *et al*., 2009:902). Correlations ranged between 0.59 for the Léger equation to 0.76 for the Barnett equation (Ruiz *et al*., 2009:903). The lowest percentage error was observed for the Ruiz equation and the highest error for the Leger equation (Ruiz *et al*., 2009:903). Previous research by Pitetti *et al.* (2002:231) also found a moderate, but significant correlation between the predicted $\dot{V}O_{2max}$ values of the Léger ($r = 0.57$) and Fernhall ($r = 0.66$) equations and the directly determined $\dot{V}O_{2max}$ values of treadmill testing in a group of 15 to 18-year-old adolescents. These studies suggest that researchers must ensure that the most accurate $\dot{V}O_{2max}$ prediction equation is used when determining the indirect $\dot{V}O_{2max}$ values of different groups of participants.

Comparisons have also been drawn between the direct assessment of $\dot{V}O_{2max}$ and the predicted $\dot{V}O_{2max}$ values of other indirect tests than the 20-m SRT among different populations of participants in order to determine the preferred indirect testing method. For example, McNaughton *et al.* (1998:580-583) compared the predicted $\dot{V}O_{2max}$ values obtained from of a submaximal treadmill jogging test, the Cooper 1.5-mile run test, the Cooper 12-minute run test and the 20-minute SRT with the directly determined $\dot{V}O_{2max}$ values obtained through an incremental treadmill jogging test. The highest correlation ($r = 0.87$; $p < 0.001$) was reported for the relationship between

the 12-minute Cooper run predicted $\dot{V}O_{2max}$ and the directly determined $\dot{V}O_{2max}$ values. The next highest non-significant correlations were reported for the relationships between the 1.5-mile run (r = 0.87), the 20-m SRT- (r = 0.82) predicted $\dot{V}O_{2max}$ and the directly determined $\dot{V}O_{2max}$ values. O'Gorman *et al.* (2000:63) studied the validity of 3 indirect $\dot{V}O_{2max}$ measurement tests to predict the endurance capacity of 22 young males (7 international rugby players and 15 competitive sports men) compared with the directly determined $\dot{V}O_{2max}$ values obtained from an incremental treadmill run. The predicted $\dot{V}O_{2max}$ values of the 3000 m (r = -0.67) and 12-minute Cooper run (r = 0.67) were significantly ($p < 0.05$) related to the direct $\dot{V}O_{2max}$ values of the incremental treadmill run (completed by only 15 sportsmen). In contrast the 20-m SRT $\dot{V}O_{2max}$-predicted values of the 15 sportsmen (r = 0.41) and 7 rugby players (r = 0.42) did not reveal any significant correlations with the direct $\dot{V}O_{2max}$ values of the incremental treadmill run (O'Gorman *et al.*, 2000:65). However, the named researchers obtained a significant correlation (r = 0.61; $p < 0.05$) between the two last-mentioned test results when the data for both groups of athletes were combined. This significant result was attributed to the larger sample size and the greater range of results obtained when both groups' $\dot{V}O_{2max}$ values were pooled (O'Gorman *et al.*, 2000:65-67). O'Gorman and colleagues (2000:65) also stated that the 20-m SRT might be better suited for court-related sport participants and that the 3 000 m and the 12-minute Cooper run are better indirect tests for rugby players. In addition, rugby players that execute the 20-m SRT will probably experience fatigue much earlier than other sport participants due to their greater body mass values which are detrimental to turning and sprinting continuously during the last-mentioned test (O'Gorman *et al.*, 2000:66).

In a much larger study of various $\dot{V}O_{2max}$ indirect tests, Grant *et al.* (1999:347) compared 7 different indirect $\dot{V}O_{2max}$ tests with a direct $\dot{V}O_{2max}$ testing method in a group of 30 males and females (ages: 18 to 35 years). The indirect $\dot{V}O_{2max}$ tests included the following: Bruce treadmill protocol; 85% Bruce treadmill protocol; Åstrand-Ryhming cycle ergometer protocol as well as an HR extrapolated test on a cycle ergometer; 20-m SRT; Cooper 1.5 mile run test and the Canadian Aerobic Fitness Test (step test) (CAFT) (Grant *et al.,* 1999:347-348). The researchers found no

significant differences between the predicted $\dot{V}O_{2max}$ values of the mentioned indirect tests and the $\dot{V}O_{2max}$ values of the direct test (Grant *et al.,* 1999:348). Results also showed that the Åstrand-Ryhming cycle ergometer and the Bruce treadmill protocol produced the least number of errors with the CAFT showing the lowest validity and highest number of errors for especially the female participants (Grant *et al.,* 1999:349). In the females, all the other indirect tests (except the CAFT) obtained significant ($p \leq 0.01$) validity coefficients of $R = 0.8$ or greater (Grant *et al.,* 1999:349). However, data for males revealed errors of less than 10% and very low validity coefficients which led the researchers to conclude that the study results were inconclusive (Grant *et al.,* 1999:349).

Various other indirect tests have also been investigated by researchers. For example, Buckley *et al.* (2004:204) found that the Chester step test produced less favourable results as an indicator of $\dot{V}O_{2max}$ but seemed to be a good measuring tool for monitoring aerobic fitness. Similarly, Pober *et al.* (2002:584) reported that the Rockport Walking Test (RWT) was not an appropriate test for predicting $\dot{V}O_{2max}$ in a group of older individuals (ages: 40 – 79 years) as opposed to the direct $\dot{V}O_{2max}$ as obtained by using the Balke treadmill protocol. More recently the Yo-Yo Intermittent Recovery Test has also received attention by researchers. Although the Yo-Yo Intermittent Recovery Test's primary purpose is not to serve as an indirect test for estimating participants' $\dot{V}O_{2max}$ values, Bangsbo *et al.* (2008:47) developed a prediction equation that uses the Yo-Yo Test performance to determine indirect $\dot{V}O_{2max}$ values. They found a significant correlation ($r = 0.7$; $p < 0.05$) between the predicted $\dot{V}O_{2max}$ and directly determined $\dot{V}O_{2max}$ values of 141 participants from various sporting codes. Although the mentioned Yo-Yo Test performance-related prediction equation can be used to give an estimate of participants' $\dot{V}O_{2max}$ values, it should be used with caution. The Yo-Yo Test relies more on the anaerobic energy system and the recovery of this system to execute the test and is therefore better suited to monitor changes in training status than to estimate $\dot{V}O_{2max}$ (Bangsbo *et al.*, 2008:48).

Despite uncertainty with regard to the validity of the 20-m SRT, a systematic review of 50 high quality studies on field-based fitness testing in children and adolescents revealed that the 20-m SRT can be regarded as a valid test to estimate the aerobic fitness of this population (Castro-

Piñero *et al*., 2010:942). Castro-Piñero *et al*. (2010:942) also pointed out that the 1-mile walk/run could be used as an alternative indirect $\dot{V}O_{2max}$ test, except for the prediction of trained children's $\dot{V}O_{2max}$ values. In the case of obese adolescents the 12-minute walk/run is preferred to the 9-minute walk/run for determining aerobic fitness (Drinkard *et al*., 2001:1895). The practicality, ease of use and availability of the 20-m SRT for use in testing large populations' aerobic fitness, make this an invaluable indirect measuring tool, especially in school settings and where testing is conducted both indoors and outdoors (Ruiz *et al.*, 2009:905).

The choice of the most suitable indirect test for predicting $\dot{V}O_{2max}$ should be based on the participants' primary mode of training, equipment availability as well as the group size and age of the participants (Grant *et al.*, 1999:351). In cases where athletes need to be tested the sport of participation must also be considered, as this may influence the indirect test selection (Aziz *et al.*, 2005:311). Indirect tests of a longer duration are better suited to predict the $\dot{V}O_{2max}$ values of participants that are active or train frequently (McNaughton *et al.*, 1998:582). However, at present the literature contains insufficient data with regard to the use and validity of indirect tests to determine the $\dot{V}O_{2max}$ values of trained participants. Therefore it is imperative for researchers to further investigate this aspect in order to provide athletes with more accurate information concerning their aerobic fitness levels so that performance prediction and talent detection can take place (Bentley *et al.*, 2007:583).

The following section will be dedicated to a discussion on research that has reported on children's and adolescents' aerobic performances ($\dot{V}O_{2max}$) as well as on the various testing protocols used to evaluate these performances. Furthermore, the possible influence of other factors such as the gender, age and race of participants (demographic variables) as well as their physical activity and sport performance levels on the $\dot{V}O_{2max}$ results will also be highlighted.

3. The aerobic performance ($\dot{V}O_{2max}$) of children and adolescents:

The literature-reported aerobic performances of children and adolescents are presented in Table 1. Overall the table shows that the $\dot{V}O_{2max}$ results of sport-participating children and adolescents are

significantly higher than those of healthy and/or non-sport participating adolescents. The highest $\dot{V}O_{2max}$ results were reported for 12 to 14-year-old cross-country runners (61.7 ± 4.4 ml/kg/min) (Malison *et al*., 2003:385), 9 to 19-year-old competitive distance runners (51.8 ± 6.4 - 67.8 ± 5.6 ml/kg/min) (Eisenmann *et al*., 2001:701), 13 to 15-year-old adolescent soccer players (65.3 ± 5.0 – 70.7 ± 4.3 ml/kg/min) (Chamari *et al*., 2005:25) and 14 to 18-year-old internationally ranked tennis players (58.9 ± 5.3 – 63.8 ± 5.7 ml/kg/min) (Girard *et al*., 2006:794). The next best $\dot{V}O_{2max}$ values observed were for moderate to vigorously active 9-year-old children that achieved values between 36.7 ± 5.3 and 42.3 ± 6.9 ml/kg/min and for 15-year-old adolescents that achieved values between 40.2 ± 5.9 and 51.0 ± 6.7 ml/kg/min (Ortega *et al*., 2010:258).

Research pertaining to the possible influence of race on the aerobic or cardiorespiratory fitness of participants concluded that grade 9 ($p < 0.05$) and 12 ($p < 0.05$) white girls displayed significantly higher aerobic fitness levels than African American girls (Pfeiffer *et al*., 2007). It was also shown that a significantly higher proportion of white girls were moderate to vigorously active and participated in sport than the proportion of their African American peers (Pfeiffer *et al*., 2007:2237). These researchers also showed that physical activity; Body Mass Index (BMI) together with race and sport participation were significant contributors to the girls' weight-relative cardiorespiratory fitness (Pfeiffer *et al*., 2007:2239). However, physical activity, race and sport participation emerged as significant contributors to the girls' absolute cardiorespiratory fitness (Pfeiffer *et al*., 2007:2239). Most researchers have also reported higher cardiorespiratory fitness values for white or Caucasian children and adolescents than for black or African American children and adolescents (Gutin *et al*., 2005:80; Johnson *et al*., 2000:5; Lohman *et al*., 2008:1168; Pivarnik *et al*., 1998:26; Trowbridge *et al*., 1997:E811).

Gender also seems to be a determining factor in the aerobic fitness levels children and adolescents obtain. For example, Arngrímsson *et al.* (2008:66) indicated that 9-year-old boys generally reached higher $\dot{V}O_{2max}$ values than girls of the same age, but that the differences in $\dot{V}O_{2max}$ values were only significant ($p < 0.0.5$) when expressed relative to body weight. Similarly, the absolute and relative $\dot{V}O_{2max}$ values were also significantly higher ($p < 0.05$) for the 15-year-old boys than for the girls (Arngrímsson *et al*., 2008:66). Older studies by Rowland *et al*. (1997:270) as well as Rowland *et al*. (2000:631) also noted gender differences in aerobic performance with differences of between 9 and 29% between the two gender groups when their

$\dot{V}O_{2max}$ values were observed over a period of 5 years (Rowland *et al*., 1997:270). Rowland *et al*. (2000:632) reported 16.8% higher $\dot{V}O_{2max}$ values for 11 to 13-year-old boys than for girls. The gender differences in $\dot{V}O_{2max}$ values seem to stay similar in the growth period among adolescents. Janz *et al*. (2000:1252) proved this contention when they tracked a group of boys and girls from pre- to early puberty during a 5-year period to monitor changes in $\dot{V}O_{2max}$ values.

Regardless of maturity level, the $\dot{V}O_{2max}$ values of boys were higher than those of girls. However, $\dot{V}O_{2max}$ normalized for body size remained stable for boys, but decreased in girls during the 5-year period (Janz *et al*., 2000:1255). For boys, the greatest improvements in $\dot{V}O_{2max}$ values were seen between years 3 and 4 of the tracking period with the advancement to late or post-puberty whereas for girls, the greatest decline in fat-free mass adjusted $\dot{V}O_{2max}$ values took place between years 4 and 5 of the tracking period with the advancement to late puberty (Janz *et al*., 2000:1255). Pivarnik *et al*. (1998:23-25) also observed a significant decline ($p < 0.01$) of 12% in $\dot{V}O_{2max}$ values from the 6th to 8th grade for a group of African American girls. In another study of 2 041 English children between ages 11 to 15 years, Sandercock *et al.* (2008:956) found an increase in the aerobic performance of boys throughout the mentioned period, whereas the girls experienced an increase over the first two years after which a levelling off occurred with the onset of puberty.

Researchers attribute these changes in absolute and relative $\dot{V}O_{2max}$ values during the growth period to an increase in fat-free mass for boys and an increase in fat mass for girls (Janz *et al*., 2000:1255). This shift in body composition could directly affect the ability of the two gender groups to transport and utilize oxygen (Janz *et al*., 2000:1255). Another factor that may also contribute to the gender differences in $\dot{V}O_{2max}$ values is the physical activity levels of boys, which are generally higher than those of girls (Kolle *et al*., 2010:e44; McMurray *et al*. 2002:149; Mota *et al*., 2002:710; Nevill *et al.,* 2009:225; Ortega *et al*., 2010:258; Rowland *et al*., 1997:271; Rowland *et al*., 2000:632; Westerstahl *et al*., 2003:132).

Two systematic reviews have suggested that aerobic fitness in children and adolescents have

declined over time with Swedish adolescents that have shown a significant decline ($p < 0.001$) in their 9-minute walk/run test results from 1974 to 1995 (Westerstahl *et al*., 2003:132). The decrease in aerobic fitness over the 5-year period coincided with significant increases in both BMI ($p < 0.001$) and body weight ($p < 0.05$ (girls) and $p < 0.01$ (boys)) (Westerstahl *et al*., 2003:133). These results were also confirmed by Volkbekienė and Griciūtė (2007:240) who found a significant decline ($p < 0.001$) in the 20-m SRT results of 12 to 16-year-old boys and girls from 1992 to 2002. Despite the last-mentioned study results, a review by Armstrong *et al*. (2011:856) suggests that no clear evidence exists to confirm the $\dot{V}O_{2max}$ value decline of children and adolescents over the last two decades. However, the use of different test instruments and protocols to assess $\dot{V}O_{2max}$ values as well as a tendency to express the $\dot{V}O_{2max}$ values in different ways make the comparison of $\dot{V}O_{2max}$ results between older and more recent studies complicated (Eisenmann *et al*., 2001:2179; Kolle *et al*., 2010:e46).

Table 1. Directly or indirectly measured (predicted) aerobic performance values ($\dot{V}O_{2max}$) of children and adolescents

Study	Number, status gender and age of participants	Protocol	$\dot{V}O_{2max}$
Adegboye *et al.* (2011)	4500 Healthy school children of both genders between ages 9 and 15 years with some risk factors evident	*Maximum cycle ergometer test:* Workload reprogrammed to increase every minute. For 9-year-olds: An initial and incremental workload of 20 W for children with a body mass under 30 kg and 25 W for those with a body mass above 30 kg was used. For 15-year-olds: An initial and incremental workload of 40 W for girls and 50 W for boys was used. Maximal power output (W_{max}) calculated from power output during last completed workload.	$\dot{V}O_{2max}$ (ml/min/kg) for 9-year-olds: All = 48.0 ± 8.7 Girls = 45.4 ± 8.2 Boys = 50.5 ± 8.7 $\dot{V}O_{2max}$ (ml/kg/min) for 15-year-olds: All = 48.2 ± 9.7 Girls = 52.4 ± 8.2 Boys = 42.0 ± 6.8
Ara *et al.* (2007)	1068 Healthy, active and non-active school children between ages 7 and 12 years (31% was obese and 6% overweight)	*20-m SRT:* Participants were required to run back and forth between a 20-metre stretch of marked lines or cones and pace themselves so that the arrival at the end of the 20-metre stretch coincided with a beep signal emitted from a pre-recorded CD.	$\dot{V}O_{2max}$ (ml/kg/min) physically active: Girls = 46.02 ± 3.76 Boys = 48.31 ± 4.36 $\dot{V}O_{2max}$ (ml/kg/min) non-active: Girls = 44.67 ± 3.86 Boys = 46.59 ± 3.98

$\dot{V}O_{2max}$ = Maximal Oxygen Uptake; 20-m SRT = 20-metre Shuttle Run Test; W = Watt; W_{max} = Maximal power output

Table 1 (cont). Directly or indirectly measured (predicted) aerobic performance values ($\dot{V}O_{2max}$) of children and adolescents

Study	Number, status gender and age of participants	Protocol	$\dot{V}O_{2max}$	Prediction model/equation	R and SEE values
Arngrímsson *et al.* (2008)	23 Children: 10 boys (9.5 ± 0.2 years) and 13 girls (9.5 ± 0.3 years). 22 Adolescents: 13 boys (15.5 ± 0.3 years) and 9 girls (15.5 ± 0.3 years) that were overweight	*Maximal cycle ergometer test:* For 9-year-olds: An initial and incremental workload of 20 W for children with a body mass less than 30 kg and 25 W for those with a body mass above 30 kg was used; For 15-year-olds: An initial and incremental workload of 40 W for girls and 50 W for boys was used. Workload was increased every 3rd minute until volatile exhaustion or until the participants were unable to maintain a pedalling cadence of 40 rpm.	$\dot{V}O_{2max}$ (ml/kg/min) for 9-year-olds: Girls = 42.2 ± 6.8 Boys = 50.3 ± 6.8 $\dot{V}O_{2max}$ (ml/kg/min) for 15-year-olds: Girls = 41.9 ± 6.7 Boys = 54.4 ± 6.2	$\dot{V}O_{2max}$ = - 1.5986 + 0.0115 (W_{max}) + 0.0109 (body mass in kg) + 0.1313 (gender: 1 = boys, 0 = girls) + 0.0085 (HR_{max})	R^2 = 0.98 SEE = 0.18 L/min Cross validated group to test validity of model: R^2 = 0.98 SEE = 0.17 L/min
Berndtsson *et al*. (2007)	219 Obese children of both genders between ages 8 and 16 years	*Åstrand-Ryhming submaximal cycle ergometer test:* Workload adjusted to 50, 75, 100, 150 or 200 W every minute, depending on every child's age, gender and health. HR was recorded every minute.	$\dot{V}O_{2max}$ values (ml/kg/min) (no exact values are given – only a bar graph): Girls: 8-10 years = ± 26 11-13 years = ± 25 14-16 years = ± 24 Boys: 8-10 years = ± 28 11-13 years = ± 26 14-16 years = ± 26		

$\dot{V}O_{2max}$ = Maximal Oxygen Uptake; R = Correlation; SEE = Standard Error of Estimate; W = Watt; W_{max} = Maximal Watts; HR_{max} = Maximal Heart Rate

Table 1 (cont). Directly or indirectly measured (predicted) aerobic performance values ($\dot{V}O_{2max}$) of children and adolescents

Study	Number, status gender and age of participants	Protocol	$\dot{V}O_{2max}$	Prediction model/equation	R and SEE values
Chamari *et al*. (2005)	18 Elite, male soccer players (14 ± 0.4 years)	*Maximal incremental treadmill test:* Ran at a speed of 7 km/h and an incline of 5.5% for 4 minutes, followed by 1 km/h increments until volitional exhaustion (test lasted 10 – 15 minutes for all players). HR was recorded every minute. Training: The participants also followed 8 weeks of soccer training.	$\dot{V}O_{2max}$ (ml/kg/min): Pre-training = 65.3 ± 5.0 Post-training = 70.7 ± 4.3		
Chatterjee *et al.* (2009)	35 Very active, male football players (15.2 ± 0.87 years)	*Maximal incremental treadmill test:* Warmed up for 5 minutes at 4 km/h and a 4.5° incline after which the speed was increased to 7 km/h for 5 minutes. Thereafter the incline was increased by 0.5° until volitional exhaustion. HR was recorded continuously. *20-m SRT:* Participants were required to run back and forth between a 20-metre stretch of marked lines or cones and pace themselves so that the arrival at the end of the 20-metre stretch coincided with a beep signal emitted from a pre-recorded CD.	Measured $\dot{V}O_{2max}$ (ml/kg/min) = 51.68 ± 5.25 Predicted $\dot{V}O_{2max}$ (ml/kg/min) = 51.36 ±5.36	*Y = 6.693 + 5.319X – 1.415A + 0.001AX Y = $\dot{V}O_{2peak}$ (ml/kg/min) X = Maximum shuttle run speed (km/h) A = age	None reported *New equation showed no significant difference (p > 0.10) between predicted and directly measured $\dot{V}O_{2max}$ values

$\dot{V}O_{2max}$ = Maximal Oxygen Uptake; 20-m SRT = 20-metre Shuttle Run Test; R = Correlation; SEE = Standard Error of Estimate; HR = Heart Rate

Table 1 (cont). Directly or indirectly measured (predicted) aerobic performance values ($\dot{V}O_{2max}$) of children and adolescents

Study	Number, status gender and age of participants	Protocol	$\dot{V}O_{2max}$
Chillón *et al.* (2011)	1 068 School children between ages 7 and 12 years and 1 501 adolescents of both genders between ages 13 and 16 years	*20-m SRT:* Participants were required to run back and forth between a 20-metre stretch of marked lines or cones and pace themselves so that the arrival at the end of the 20-metre stretch coincided with a beep signal emitted from a pre-recorded CD.	$\dot{V}O_{2max}$ (ml/kg/min) for girls: Children = 46.3 ± 3.5 Adolescents = 41.3 ±5.2 $\dot{V}O_{2max}$ (ml/kg/min) for boys: Children = 48.5 ± 4.0 Adolescents = 47.3 ± 5.9
Drinkard *et al*. (2001)	8 African American and 10 Caucasian overweight adolescents (14.5 ± 2.0 years)	*Maximal cycle ergometer test:* A 4-minute warm-up with no resistance, after which the load was progressively increase by 15-20 W/min until volitional exhaustion or until participants failed to maintain the required pedalling cadence of 60 – 70 rpm. HR was recorded every minute. *12*- minute *Walk/run test* Participants were required to cover as much distance as possible in 12 minutes. The total distance covered at 9 and 12 minutes was measured in metres. HR was recorded at 3, 6, 9 and 12 minutes.	$\dot{V}O_{2max}$ (ml/kg/min): = 17.4 ± 3.6 $\dot{V}O_{2max}$ (ml/kg lean body mass in kg/min): = 33.4 ± 4.9 Distance covered (m): 12 minutes = 1 174.4 ± 208.1 9 minutes = 883.3 ± 162.2

$\dot{V}O_{2max}$ = Maximal Oxygen Uptake; 20-m SRT = 20-metre Shuttle Run Test; HR = Heart Rate; W = Watt

Table 1 (cont). Directly or indirectly measured (predicted) aerobic performance values ($\dot{V}O_{2max}$) of children and adolescents

Study	Number, status gender and age of participants	Protocol	$\dot{V}O_{2max}$
Eisenmann *et al*. (2001)	124 competitive distance runners consisting of 75 boys and 49 girls between ages 9 and 19 years	*Maximal incremental treadmill test*: *Group1*: 3- minute work and 3-minute rest intervals. Warmed up at 6 mi/h at a 0% incline, after which the incline was increased to 5%. The speed and incline were then increased by 1 mi/h and 1%, respectively for each stage until volitional exhaustion. HR was recorded continuously. *Group 2*: Walked/jogged at 3 and 4.5 mi/h for 1 minute at each speed. This was followed by 4-minute stages at speeds of 6, 7.5 and 8 mi/h. After these stages the incline was increased by 2.5%/min until volitional exhaustion. The running or walking pace was determined by participants' 5km race time. HR was recorded continuously.	$\dot{V}O_{2max}$ (ml/kg/min): Girls: 9 – 10 years = 56.3 ± 6.6 11 years = 57.9 ± 5.2 12 years = 57.1 ± 5.3 13 years = 54.8 ± 6.3 14 years = 56.9 ± 8.4 15 years = 56.2 ± 7.0 16 years = 54.3 ± 6.8 17 – 18 years = 51.8 ± 6.4 Boys: 9 – 10 years = 62.7 ± 6.1 11 years = 63.6 ± 7.1 12 years = 63.3 ± 6.3 13 years = 60.8 ± 7.2 14 years = 63.5 ± 5.2 15 years = 62.7 ± 6.3 16 years = 64.8 ± 5.0 17 years = 67.8 ± 5.6 18 years = 67.3 ± 8.0
Ekelund *et al.* (2001)	42 Boys and 40 girls between ages 14 and 15 years	*Bruce treadmill protocol:* During the 1st and 3rd minute of the test the pace is set at 1.7 mi/h and an incline of 10%. During the 4th and 6th minute of the test, the incline is increased to 12% and the speed to 2.5 mi/h, where after, the incline is increased by 2% and the speed to either 0.8 or 0.9 mi/h every minute, until complete exhaustion. HR was recorded every minute.	$\dot{V}O_{2max}$ scaled for body size by using an allometric scaling technique: Girls = 166.0 ± 19.0 $ml/kg^{-2/3}/min$ Boys = 215.0 ± 29.0 $ml/kg^{-2/3}/min$

$\dot{V}O_{2max}$ = Maximal Oxygen Uptake; HR = Heart Rate

Table 1 (cont). Directly or indirectly measured (predicted) aerobic performance values ($\dot{V}O_{2max}$) of children and adolescents

Study	Number, status gender and age of participants	Protocol	$\dot{V}O_{2max}$
Eliakim *et al.* (1998)	43 Healthy adolescent boys (16 ± 0.7 years)	*Progressive cycle ergometer test:* Exercise until volitional exhaustion (no detailed explanation of protocol was given).	$\dot{V}O_{2max}$ (ml/kg/min) : = 39.3 ± 0.8
Fonseca *et al.* (2008)	144 Brazilian adolescents between ages 15 and 18 years	*1-Mile track walk/run test:* Time registered to complete the test was used in a prediction model.	$\dot{V}O_{2max}$ (ml/kg/min): Girls = 40.9 ± 2.31 Boys = 49.7 ± 3.05
Geithner *et al.* (2004)	105 Healthy, twin pairs between ages 10 and 18-years	*Bruce treadmill protocol:* During the 1st and 3rd minute of the test the pace is set at 1.7 mi/h and an incline of 10%. During the 4th and 6th minute of the test, the incline is increased to 12% and the speed to 2.5 mi/h, where after, the incline is increased by 2% and the speed to either 0.8 or 0.9 mi/h every minute, until complete exhaustion. HR was recorded every minute.	$\dot{V}O_{2max}$ (L/min): Girls = 1.86 ± 0.41 Boys = 2.99 ± 0.53
Girard *et al*. (2006)	9 Internationally ranked male tennis players (16.0 ± 1.6 years)	*Maximal incremental treadmill test:* Started at a speed of 9 km/h and a 0% incline after which the speed was increased by 0.5 km/h every minute until volitional exhaustion. Each minute consisted of 45 seconds of running and 15 seconds of active recovery at 5 km/h. HR was recorded every minute. *Tennis-specific field test*: Participants performed a tennis-specific field test designed to replicate the tennis game. HR was recorded every minute.	$\dot{V}O_{2max}$ (ml/kg/min): Treadmill test = 58.9 ± 5.3 Field test = 63.8 ± 5.7

$\dot{V}O_{2max}$ = Maximal Oxygen Uptake; R = Correlation; SEE = Standard Error of Estimate; HR = Heart Rate

Table 1 (cont). Directly or indirectly measured (predicted) aerobic performance values ($\dot{V}O_{2max}$) of children and adolescents

Study	Number, status gender and age of participants	Protocol	$\dot{V}O_{2max}$	Prediction model/equation
Ginty *et al*. (2005)	128 Healthy boys between ages 16 and 18 years	*20-m SRT:* Participants were required to run back and forth between a 20-metre stretch of marked lines or cones and pace themselves so that the arrival at the end of the 20-metre stretch coincided with a beep signal emitted from a pre-recorded CD.	Predicted $\dot{V}O_{2max}$ (ml/kg/min): = 48.8 ± 6.2	
Goran *et al.* (2000)	39 "Lean" children (8.6 ± 1.6 years) and 39 "obese" children (8.9 ± 1.2 years)	*Maximal incremental treadmill test*: Started test by walking at a speed of 4 km/h and an incline of 0% for 4 minutes after which the incline was increased to 10% for 2 minutes. Thereafter the incline was increased every 2 minutes by another 2.5% while the speed remained 4 km/h until an incline of 20% was reached. At this incline the speed was increased by 0.6 km/h until volitional exhaustion. HR was recorded every minute.	$\dot{V}O_{2max}$ (ml/kg/min): Lean group = 44.2 ± 3.2 Obese group = 32.0 ± 4.1	Regression between $\dot{V}O_{2max}$ and FFM: $\dot{V}O_{2max}$ (L/min) = 0.063 x FFM (kg) – 0.12 (L/min) Regression between $\dot{V}O_{2max}$ and body weight: $\dot{V}O_{2max}$ (L/min) = 0.021 x body weight (kg) + 0.56 (L/min)
Gutin *et al.* (2005)	398 Healthy Caucasian and non-Caucasian adolescents living in rural and urban areas (16.3 ± 1.19 years)	*Maximal incremental treadmill test:* Started test by warming up for 3 minutes at an incline of 0% and a speed of 2 mi/h after which the speed was increased by 0.5 mi/h every 2 minutes until 3.5 mi/h was reached. Thereafter the incline was increased by 2% every minute until an incline of 16% was reached. At this point the speed was increased by 0.5 mi/h every minute until volitional exhaustion. HR was recorded every minute.	$\dot{V}O_{2max}$ (ml/kg/min): Caucasian girls = 24.66 ±5.75 Non-Caucasian girls = 22.16 ±5.20 Caucasian boys = 33.23 ± 6.73 Non-Caucasian boys = 31.22 ± 7.38	

$\dot{V}O_{2max}$ = Maximal Oxygen Uptake; HR = Heart Rate; FFM = Fat-Free mass; L/min = litre per minute

Table 1 (cont). Directly or indirectly measured (predicted) aerobic performance values ($\dot{V}O_{2max}$) of children and adolescents

Study	Number, status gender and age of participants	Protocol	$\dot{V}O_{2max}$
Janz *et al*. (2000)	126 Pre- and early pubertal children: 61 boys (monitored between ages 8 and 12 years) and 62 girls (monitored between ages 7 to 11 years)	*Maximal cycle ergometer test:* Started with a 1-minute warm-up, followed by three 3-minute submaximal stages. Thereafter, a series of 30-second stages were completed until volitional exhaustion. HR was recorded every minute.	Girls' $\dot{V}O_{2max}$ (ml/kg/min): Year 1 = 40 ± 7 Year 2 = 39 ± 6 Year 3 = 37 ± 7 Year 4 = 38 ± 7 Year 5 = 33 ± 5 Boys' $\dot{V}O_{2max}$ (ml/kg/min): Year 1 = 49 ± 8 Year 2 = 47 ± 8 Year 3 = 44 ± 7 Year 4 = 47 ± 7 Year 5 = 46 ± 7
Johnson *et al.* (2000)	155 Children (4.6 to 11.0 years) that consisted of 72 Caucasian children (55 girls, 17 boys) and 43 Non-Caucasian children (24 girls, 19 boys)	*Maximal incremental treadmill test:* Started by walking for 4 minutes at an incline of 0% and a speed of 4 km/h. Thereafter the incline was increased to 10% for 2 minutes after which the incline was increased by 2.5% every 2 minutes until an incline of 22.5% was reached. At this point the speed was increased by 0.6 km/h until volitional exhaustion. HR was recorded every minute.	$\dot{V}O_{2peak}$ (L/min): Caucasian girls = 1.12 ± 0.29 Non-Caucasian girls = 1.22 ± 0.24 Caucasian boys = 1.46 ± 0.39 Non-Caucasian boys = 1.21 ± 0.29

$\dot{V}O_{2max}$ = Maximal Oxygen Uptake; HR = Heart Rate; L/min = Litre per minute

Table 1 (cont). Directly or indirectly measured (predicted) aerobic performance values ($\dot{V}O_{2max}$) of children and adolescents

Study	Number, status gender and age of participants	Protocol	$\dot{V}O_{2max}$
Kolle *et al*. (2010)	2 266 Healthy Norwegian children and adolescents (1 291 9-year-olds; 975 15-year-olds)	*Maximum cycle ergometer test:* For 9-year-olds: An initial and incremental workload of 20 W for children that weighed less than 30 kg; 25 W for children that weighed more than 30 kg or 30 kg. For 15-year-olds: An initial and incremental workload of 40 W for girls and 50 W for boys. The pedalling cadence was kept at 60 – 70 rpm and the workload increased every 3 minutes until volitional exhaustion. HR was recorded every minute.	$\dot{V}O_{2max}$ (ml/min/kg) for 9-year-olds: Girls = 42.9 ± 6.7 Boys = 48.2 ± 7.1 $\dot{V}O_{2max}$ (ml/kg/min) for 15-year-olds: Girls = 41.1 ± 6.0 Boys = 51.9 ± 8.0
Koutedakis & Bouziotas (2003)	84 Greek boys (13.6 ± 0.3): 43 Participated in physical education classes (PE group) while 41 participated in PE and organized sports (PE + sports group)	*20-m SRT:* Participants were required to run back and forth between a 20-metre stretch of marked lines or cones and pace themselves so that the arrival at the end of the 20-metre stretch coincided with a beep signal emitted from a pre-recorded CD.	$\dot{V}O_{2max}$ (ml/kg/min): PE group = 34.7 ± 3.7 PE and sports group = 43.9 ± 4.2

$\dot{V}O_{2max}$ = Maximal Oxygen Uptake; HR = Heart Rate; W = Watt; PE = Physical Education; 20-m SRT = 20-metre Shuttle Run Test

Table 1 (cont). Directly or indirectly measured (predicted) aerobic performance values ($\dot{V}O_{2max}$) of children and adolescents

Study	Number, status gender and age of participants	Protocol	$\dot{V}O_{2max}$
Le Mura *et al.* (2001)	48 Children between ages 5 and 6 years	*Modified Balke treadmill protocol:* They started the test by walking at a speed of 4.8 km/h and an incline of 0% for 1 minute, after which the speed increased to 8.0 km/h and the incline to 2.5% for another 1 minute. During the rest of the test the speed was maintained at 8.0 km/h while the incline was increased by 2.5% every minute until volitional exhaustion. HR was recorded every minute. *Maximal cycle ergometer test:* They started the test by pedalling at a cadence of 60 rpm with no resistance for 1 minute. Thereafter the workload was increased by 10, 15 or 20 W/min depending on each child's body stature until volitional exhaustion. HR was recorded every minute.	Treadmill $\dot{V}O_{2max}$ (ml/kg/min): Boys = ± 45 ml/kg/min Girls = ± 44 ml/kg/min Cycle ergometer $\dot{V}O_{2max}$ (ml/kg/min): Boys = ± 41 ml/kg/min Girls = ± 40 ml/kg/min
Leone *et al.* (2002)	100 Elite, female tennis players, swimmers, figure skaters and volleyball players (14.3 ± 1.3 years)	*Maximal incremental treadmill test:* They started the test at a speed of 10 km/h and no incline after which the incline was increased by 2.5% every 2.5 minutes until volitional exhaustion. HR was recorded every minute.	$\dot{V}O_{2max}$ (ml/kg/min): Tennis players = 49.5 ± 4.4 Skaters = 48.3 ± 4.0 Swimmers = 47.6 ± 3.1 Volleyball players = 48.9 ± 3.6

$\dot{V}O_{2max}$ = Maximal Oxygen Uptake; HR = Heart Rate; W = Watt

Table 1 (cont). Directly or indirectly measured (predicted) aerobic performance values ($\dot{V}O_{2max}$) of children and adolescents

Study	Number, status gender and age of participants	Protocol	$\dot{V}O_{2max}$
Lobelo *et al.* (2009)	1 247 Healthy adolescents between ages 12 and 19 years	*Submaximal incremental treadmill test:* They started the test with a 2- minute warm-up followed by two 3-minute work stages and a 2-minute cool down. Test conducted to elicit an HR of 80% of age-predicted HR_{max} for prediction of $\dot{V}O_{2peak}$.	$\dot{V}O_{2max}$ (ml/kg/min): 12 to15-year-olds: Females = 39.7 ± 7.5 Males = 47 ± 8.6 16 to19-year-olds: Females = 38.9 ± 8.6 Males = 48.1 ± 9.5
Lohman *et al.* (2008)	1 440 Healthy, Hispanic, non-Hispanic Black, non-Hispanic White and non-Hispanic other 13 to 15-year-old adolescents	*Submaximal cycle ergometer test:* They started the test at an initial workload of 0.25 or 0.5 kg depending on body weight (under 50 kg or equal to or above 50 kg). Each test stage was 2 minutes in duration and a pedalling cadence of 60 rpm was maintained. HR was recorded every minute to determine the resistance increase to the next stage until 165 bpm was reached.	$\dot{V}O_{2max}$ expressed as maximum workload obtained at the end of the test (kg/m/min/kg) during test : Hispanic = 11.5 ± 3.14 Non-Hispanic Black = 10.5 ± 3.88 Non-Hispanic White = 12.3 ± 3.52 Non-Hispanic other = 11.8 ± 3.39

$\dot{V}O_{2max}$ = Maximal Oxygen Uptake; HR = Heart Rate; HR_{max} = Maximal Heart Rate

Table 1 (cont). Directly or indirectly measured (predicted) aerobic performance values ($\dot{V}O_{2max}$) of children and adolescents

Study	Number, status gender and age of participants	Protocol	$\dot{V}O_{2max}$	Prediction model/equation	R and SEE values
Mahar *et al.* (2006)	74 Adolescents, between ages 12 and 14 years	*Maximal incremental treadmill test:* *Females*: They started the test and within the 1st minute the speed increased to 5 mi/h, where after the speed was maintained for the remainder of the test. The incline was increased at the 2nd minute to 2% and every minute thereafter until volitional exhaustion *Males*: They started the test and within the 1st minute the speed increased to 5.5 mi/h and the speed was maintained for the rest of the test. For 8 boys the speed of 5 mi/h was used to ensure safety and increased to 6 mi/h. For 5 boys the speed was increased to 6.5 mi/h, and for 2 boys to 7mi/h. The incline was raised at the 2nd minute to 2% and every minute thereafter until volitional exhaustion. *PACER 20-m SRT:* Participants were required to run back and forth between a 20-metre stretch of marked lines or cones and pace themselves so that the arrival at the end of the 20-metre stretch coincided with music emitted from a pre-recorded CD.	Measured $\dot{V}O_{2max}$ (ml/kg/min): = 44.4 ± 8.4 PACER 1 (body mass model) (ml/kg/min): = 45.2 ± 6.1 PACER 2 (BMI model) (ml/kg/min): = 45.2 ± 6.2 Léger equation (1988) (ml/kg/min): = 43.5 ± 6.0	$\dot{V}O_{2max}$ = 47.438 + (PACER laps completed) x (0.142)) + (Gender (1 = male, 0 = female) x (5.134) - (Body mass (kg) x (0.197)	R = 0.65 SEE = 6.38 ml/kg/min

$\dot{V}O_{2max}$ = Maximal Oxygen Uptake; R = Correlation; SEE = Standard Error of Estimate; HR = Heart Rate; 20-m SRT = 20-metre Shuttle Run Test

Table 1 (cont). Directly or indirectly measured (predicted) aerobic performance values ($\dot{V}O_{2max}$) of children and adolescents

Study	Number, status gender and age of participants	Protocol	$\dot{V}O_{2max}$	Prediction model/equation	R and SEE values
Malison *et al.* (2003)	9 adolescent male track and cross-country runners, (13.4 ± 0.6 years)	*Maximal incremental treadmill test:* Started test at 80.4 m/min and a 0% incline for 2 minutes after which the speed was increased to 134.0 m/min and the incline maintained at 0% for another 4 minutes. Thereafter the speed was increased by 26.8 m/min every 4 minutes until a speed of 187.6 m/min was reached. The speed was then maintained but the incline increased by 2.5% every minute until volitional exhaustion. HR was recorded every minute.	$\dot{V}O_{2max}$ (ml/kg/min) = 61.7 ± 4.4		
Matsuzaka *et al.* (2004)	134 Japanese sport participants between ages 8 and 17 years (62 boys, 72 girls)	*Maximal incremental treadmill test:* They started with a warm-up that consisted of walking or running followed by 3 submaximal stages of 4 minutes each. The first stage was completed at a speed of 3.6 – 6 km/h (depending on participant's size and age) and a 0% incline. Thereafter the speed was increased by 1.2 – 2.4 km/h for the 2nd and 3rd stages. Next the incline was increased to 4% and the speed by 0.6 – 1.2 km/h every minute until volitional exhaustion. HR was recorded every minute. *20-m SRT:* Participants were required to run back and forth between a 20-metre stretch of marked lines or cones and pace themselves so that the arrival at the end of the 20-metre stretch coincided with a beep signal emitted from a pre-recorded CD.	$\dot{V}O_{2max}$ (ml/kg/min) for girls: 8-10 years = 49.3 ± 5.5 11-13 years = 50.2 ± 5.4 14-17 years = 40.9 ± 4.5 Total group: Measured = 46.7 ± 6.7 Predicted = 46.4 ± 6.9 $\dot{V}O_{2max}$ (ml/kg/min) for boys: 8-10 years = 52.1 ± 6.2 11-13 years = 56.0 ± 5.0 14-17 years = 53.6 ± 6.9 Total group: Measured = 54.2 ± 6.2 Predicted = 52.5 ± 5.7	MRS $\dot{V}O_{2max}$ (ml/kg/min) = 25.9 – (2.21 x gender: 0 = male, 1 = female) – (0.449 x age (years)) – (0.831 x BMI) + (4.12 x MRS) TL $\dot{V}O_{2max}$ (ml/kg/min) = 61.1 – (2.20 x gender: 0 = male, 1 = female) – (0.462 x age (years)) – (0.862 x BMI) + (0.192 x TL) BMI = Body Mass Index MRS = maximal running speed at end stage TL = total number of levels in 20-m SRT	R = 0.81 SEE = 3.3 ml/kg/min R = 0.80 SEE = 3.4 ml/kg/min

$\dot{V}O_{2max}$ = Maximal Oxygen Uptake; R = Correlation; SEE = Standard Error of Estimate; HR = Heart Rate; 20-m SRT = 20-metre Shuttle Run Test

Table 1 (cont). Directly or indirectly measured (predicted) aerobic performance values ($\dot{V}O_{2max}$) of children and adolescents

Study	Number, status gender and age of participants	Protocol	$\dot{V}O_{2max}$
McMurray *et al.* (2002)	2540 African American and Caucasian 8 to 16-year-old children and adolescents living in urban and rural areas	*Submaximal cycle ergometer test*: Started test at pedalling cadence of 60 rpm for three, 3-minute stages. The initial workload was set at 30 or 60 W (depending on participant's body weight) and increased by either 30 or 60 W, depending on HR. HR was measured during the last 10 seconds of each minute to predict $\dot{V}O_{2max}$.	$\dot{V}O_{2max}$ (ml/kg/min): African American girls: 8 – 10 years = 39.9 ± 9.7 - 37.6 ± 8.9 11 – 13 years = 35.6 ± 8.3 33.2 ± 6.2 14 - 16 years = 31.9 ± 6.2 30.0 ± 6.0 Caucasian girls: 8 – 10 years = 41.3 ± 9.1 38.0 ± 9.5 11 – 13 years = 36.5 ± 6.9 34.6 ± 6.1 14 – 16 years = 33.5 ± 6.7 32.3 ±7.2 African American boys: 8 – 10 years = 45.1 ± 11.8 44.3 ± 9.2 11 – 13 years = 44.5 ± 10.9 40.3 ± 7.7 14 – 16 years – 41.3 ± 7.9 40.3 ± 12.7 Caucasian boys: 8 – 10 years = 45.5 ± 8.9 44.8 ± 9.8 11 – 13 years = 41.9 ± 9.4 41.4 ± 8.3 14 – 16 years = 42.8 ± 9.3 42.1 ± 10.9

$\dot{V}O_{2max}$ = Maximal Oxygen Uptake; HR = Heart Rate; W = Watt

Table 1 (cont). Directly or indirectly measured (predicted) aerobic performance values ($\dot{V}O_{2max}$) of children and adolescents

Study	Number, status gender and age of participants	Protocol	$\dot{V}O_{2max}$
Meckel *et al.* (2009)	33 Elite, male soccer players between ages 16 and 18 years	*20-m SRT:* Participants were required to run back and forth between a 20-metre stretch of marked lines or cones and pace themselves so that the arrival at the end of the 20-metre stretch coincided with a beep signal emitted from a pre-recorded CD.	$\dot{V}O_{2max}$ (ml/kg/min): = 54.1 ± 3.1
Monyeki *et al*. (2010)	59 Rural-living soccer players between ages 11 and 20 years	*20-m SRT:* Participants were required to run back and forth between a 20-metre stretch of marked lines or cones and pace themselves so that the arrival at the end of the 20-metre stretch coincided with a beep signal emitted from a pre-recorded CD.	$\dot{V}O_{2max}$ (ml/kg/min): Under 12 = 34.3 Under 14 = 40.5 Under 16 = 39.2 Senior = 44.5
Mota *et al.* (2002)	494 Healthy, Portuguese children between ages 8 and 16 years	*20-m SRT:* Participants were required to run back and forth between a 20-metre stretch of marked lines or cones and pace themselves so that the arrival at the end of the 20-metre stretch coincided with a beep signal emitted from a pre-recorded CD.	$\dot{V}O_{2max}$ (ml/kg/min) expressed in terms of maturity level: Boys (PH = pubic hair): PH1 = 48.2 ± 3.4 PH2 = 46.9 ± 4.7 PH3 = 48.6 ± 4.2 PH4 = 49.6 ± 4.7 PH5 = 50.9± 4.1 Girls (B = breast development): B1 = 46.7 ± 2.8 B2 = 45.7 ± 2.8 B3 = 47.3 ± 4.1 B4 = 44.9 ± 3.8 B5 = 42.1 ± 4.1

$\dot{V}O_{2max}$ = Maximal Oxygen Uptake; HR = Heart Rate; 20-m SRT = 20-metre Shuttle Run Test

Table 1 (cont). Directly or indirectly measured (predicted) aerobic performance values ($\dot{V}O_{2max}$) of children and adolescents

Study	Number, status gender and age of participants	Protocol	$\dot{V}O_{2max}$
Norman *et al*. (2005)	129 Obese and 34 healthy adolescents between ages 12 and 18 years	*Submaximal cycle ergometer test*: They started the test with a warm-up of 4 minutes with no added load. There after stages followed where the load was continuously increased by 15 – 20 W/min until volitional exhaustion. HR was recorded every minute. *12*-minute *walk/run test:* The participants had to cover as much distance as possible in 9 and 12 minutes. The total distance covered in 9 and 12 minutes was measured in metres. HR was recorded at 3, 6, 9 and 12 minutes.	$\dot{V}O_{2max}$ (mL/min): Healthy = 2 067 ± 571 Obese = 1942 ± 398 12 min Distance (metres): Healthy = 1 983 ± 323 Obese = 1 159 ± 194
Norman *et al*. (2005)	129 Obese and 34 healthy adolescents between ages 12 and 18 years	*Submaximal cycle ergometer test*: They started the test with a warm-up of 4 minutes with no added load. There after stages followed in which the load was continuously increased by 15 – 20 W/min until volitional exhaustion. HR was recorded every minute. *12*-minute *walk/run test* They had to cover as much distance as possible in 9 and 12 minutes. The total distance covered in 9 and 12 minutes was measured in metres. HR was recorded at 3, 6, 9 and 12 minutes.	$\dot{V}O_{2max}$ (mL/min): Healthy = 2 067 ± 571 Obese = 1942 ± 398 12-minute Distance (metres): Healthy = 1 983 ± 323 Obese = 1 159 ± 194

$\dot{V}O_{2max}$ = Maximal Oxygen Uptake; HR = Heart Rate; 20-m SRT = 20-metre Shuttle Run Test; W = Watt

Table 1 (cont). Directly or indirectly measured (predicted) aerobic performance values ($\dot{V}O_{2max}$) of children and adolescents

Study	Number, status gender and age of participants	Protocol	$\dot{V}O_{2max}$
Ortega *et al.* (2010)	557 Healthy, moderate to vigorously active children between ages 9 and 10 years and 518 adolescents between ages 15 and 16 years	*Maximal cycle ergometer test:* *Children*: An initial and incremental workload of 25 W every 3 minutes for children weighing more than 30 kg or 30 kg and 20 W every 3 minutes for children weighing less than 30 kg . *Adolescent boys*: Started at 50 W with a 50 W increase every 3 minutes. *Adolescent girls*: Started at 40 W with a 40 W increase every 3 minutes. HR was recorded every minute.	Hansen equation $\dot{V}O_{2max}$ (ml/kg/min): Children: Boys = 42.3 ± 6.9 Girls = 36.7 ± 5.3 Adolescents: Boys =51.0 ± 6.7 Girls = 40.2 ± 5.9
Ortega *et al.* (2011)	3 528 Healthy adolescent boys and girls between ages 14 and 16 years	*20-m SRT* Participants were required to run back and forth between a 20-metre stretch of marked lines or cones and pace themselves so that the arrival at the end of the 20-metre stretch coincided with a beep signal emitted from a pre-recorded CD.	$\dot{V}O_{2max}$ (ml/kg/min): Total group = 40.6 ± 7.5 Boys = 44.3 ± 7.5 Girls = 37.1 ± 5.6

$\dot{V}O_{2max}$ = Maximal Oxygen Uptake; HR = Heart Rate; W = Watt; 20-m SRT = 20-metre Shuttle Run Test

Table 1 (cont). Directly or indirectly measured (predicted) aerobic performance values ($\dot{V}O_{2max}$) of children and adolescents

Study	Number, status gender and age of participants	Protocol	$\dot{V}O_{2max}$	Prediction model/equation	R and SEE values
Pfeiffer *et al.* (2007)	274 Healthy adolescent girls (13.6 ± 0.6 years) of which 59% was African American girls	*Submaximal cycle ergometer test:* (*Predicted test at HR of 170 bpm (PWC_{170})*) Started test at an initial workload of 0.5 kg. Each test lasted 2 minutes and participants were required to maintain a pedalling cadence of 60 rpm. Girls completed 3 stages to obtain an HR of 160 bpm and an additional stage if necessary to reach an HR of 160 bpm. HR at the end of the last stage was used to establish the workload increment for the next stage. HR was recorded every minute. Sport participation and level of physical activity (moderate (MVPA) to vigorous (VPA)) was also recorded and monitored.	PWC_{170} absolute (kg/m/min) 8^{th} grade: 668.0 ± 162.6 9^{th} grade: 752.5 ± 195.8 12^{th} grade: 730.3 ± 207.0	Absolute PWC_{170} for MVPA: = 614.1 + 40.3 (race) + 2.5 (BMI) + 28.4 (MVPA) + 27.2 (type of sport) + 107.0 (time) – 22.6 ($time^2$) + 0.98 (time x BMI) Absolute PWC_{170} for VPA: = 624.8 + 40.7 (race) + 2.8 (BMI) 22.1 (VPA) + 28.4 (sport) + 106.5 (time) – 22.5 ($time^2$) + 0.90 (time x BMI) BMI = Body Mass Index	Correlations for MVPA and VPA and cardio respiratory fitness (CRF) absolute values: 8^{th} - 9^{th} grade : R = 0.53 9^{th} – 12^{th} grade: R = 0.63 8^{th} – 12^{th} grade: R = 0.55 SEE = non reported

$\dot{V}O_{2max}$ = Maximal Oxygen Uptake; R = Correlation; SEE = Standard Error of Estimate; 20-m SRT = 20-metre Shuttle Run Test W = Watt; HR = Heart Rate

Table 1 (cont). Directly or indirectly measured (predicted) aerobic performance values ($\dot{V}O_{2max}$) of children and adolescents

Study	Number, status gender and age of participants	Protocol	$\dot{V}O_{2max}$
Pitetti *et al*. (2002)	51 Healthy children and adolescents between ages 8 and 15 years	*Modified Bruce treadmill test:* The started the test at a speed of 3.3 to 5.8 km/h at an incline of 0%. Thereafter the incline increased 4% every 2 minutes until a 12% incline was reached. At this incline the speed was increased by 0.5 mi/h every minute until volitional exhaustion. HR was recorded every minute. *20-m SRT* Participants are required to run back and forth between a 20-metre stretch of marked lines or cones and pace themselves so that the arrival at the end of the 20-metre stretch coincides with a beep signal emitted from a pre-recorded compact disc. Participants need to touch the marked lines at either end of the 20-metre stretch with one foot as a signal sounds from the recording. The test is terminated when a participant voluntarily drops out or cannot make it to either end marks of the 20-metre distance within the given beep time in 2 successive shuttles.	Treadmill $\dot{V}O_{2max}$ (ml/kg/min): All = 46.2 ± 7.6 Females = 45.0 ± 7.2 Males = 49.4 ± 7.7 Léger *et al*. equation (ml/kg/min): All = 47.0 ± 3.7 Females = 46.8 ± 3.4 Males = 47.5 ± 4.4 Fernhall *et al.* equation (ml/kg/min): All = 44.4 ± 6.0 Females = 43.1 ± 6.0 Males = 48.0 ± 4.5
Pivarnik *et al.* (1998)	19 Healthy African-American girls of 6th to 8th grade (12.1 ± 0.5 - 14.6 ± 0.5 years)	*Maximal treadmill walk/run test:* They started the test at 67 m/min and increased the speed by 13.4 m/min up to a speed of 161 m/min. In cases where participants could still run, the incline was increased by 3% every minute until volitional exhaustion. HR was recorded every minute.	$\dot{V}O_{2max}$ (ml/kg/min): Fall 6th grade = 35.5 ± 4.9 Spring 6th grade = 33.2 ± 4.9 Fall 7th grade = 32.6 ± 4.7 Spring 7th grade = 33.3 ± 3.6 Fall 8th grade = 32.4 ± 4.4 Spring 8th grade = 31.4 ± 4.8

$\dot{V}O_{2max}$ = Maximal Oxygen Uptake; 20-m SRT = 20-metre Shuttle Run Test; HR = Heart Rate;

Table 1 (cont). Directly or indirectly measured (predicted) aerobic performance values ($\dot{V}O_{2max}$) of children and adolescents

Study	Number, status gender and age of participants	Protocol	$\dot{V}O_{2max}$
Rowland *et al.* (1995)	37 Healthy, active girls (24) and boys (13) between ages 10 and 13 years	*Submaximal incremental treadmill walking test:* They started with a 2-minute warm-up during which participants walked, after which the speed was increased to 3.25 mi/h and the incline to 6% for 4 minutes. Thereafter the speed was increased to 3.5 mi/h and the incline to 2% every minute to volitional exhaustion. HR was recorded every minute. Participants also followed a 12-week training programme.	$\dot{V}O_{2max}$ (ml/kg/min): 1 = 44.3 ± 5.8 2 = 44.7 ± 5.8 3 = 47.6 ± 6.4 1 = 12 weeks before training 2 = at start of training 3 = after 12 weeks of training
Rowland *et al.* (1997)	21 Healthy children between ages 7.9 and 10.3 years	*Maximal incremental treadmill test:* They started the test with a 2-minute warm-up at 3.25 mi/h and a 6% incline. Thereafter the incline was increased to 8% for 4 minutes and the speed to either 3.25 or 3.75 mi/h. After this the incline increased 2% every minute until volitional exhaustion. HR was recorded every minute. The participants repeated the test annually over a 5-year period.	$\dot{V}O_{2max}$ (L/min): Girls: Year 1 = 1.63 ± 0.37 Year 2 = 1.83 ± 0.47 Year 3 = 2.02 ± 0.54 Year 4 = 2.12 ± 0.53 Year 5 = 2.41 ± 0.61 Boys: Year 1 = 1.78 ± 0.19 Year 2 = 2.22 ± 0.30 Year 3 = 2.49 ± 0.39 Year 4 = 2.65 ± 0.49 Year 5 = 3.11 ± 0.61

$\dot{V}O_{2max}$ = Maximal Oxygen Uptake; HR = Heart Rate; L/min = Litre per minute

Table 1 (cont). Directly or indirectly measured (predicted) aerobic performance values ($\dot{V}O_{2max}$) of children and adolescents

Study	Number, status gender and age of participants	Protocol	$\dot{V}O_{2max}$
Rowland *et al.* (1999)	40 Healthy boys (12.2 ± 0.5 years)	*Maximal cycle ergometer test:* The test consisted of an initial and incremental workload of 25 W which increased every 3 minutes while maintaining a pedalling cadence of 50 rpm until volitional exhaustion. HR was recorded every minute. *1-mile walk/run test:* Participants were required to run a distance of one mile on a measured outdoor grass course. Time of completing the distance was recorded.	$\dot{V}O_{2max}$ (ml/kg/min) = 47.0 ± 5.8 1-Mile run time (min): = 9:07 Mean cycling velocity (m/sec): = 3.00 ± 0.48
Rowland *et al.* (2000)	25 Healthy, active, pre-pubertal boys (12 ± 0.4 years) and 24 pre-menarcheal girls (11.7 ± 0.5 years)	*Maximal cycle ergometer test:* The test consisted of an initial and incremental workload of 25 W which increased every 3 minutes while maintaining a pedalling cadence of 50 rpm until volitional exhaustion. HR was recorded every minute.	$\dot{V}O_{2max}$ (ml/kg/min): Boys = 47.2 ± 6.1 Girls = 40.4 ± 5.8

$\dot{V}O_{2max}$ = Maximal Oxygen Uptake; HR = Heart Rate; W = Watt

Table 1 (cont). Directly or indirectly measured (predicted) aerobic performance values ($\dot{V}O_{2max}$) of children and adolescents

Study	Number, status gender and age of participants	Protocol	$\dot{V}O_{2max}$	Prediction model/equation	R and SEE values
Ruiz *et al.* (2008)	122 Healthy boys and 71 girls between ages 13 and 19 years	*20-m SRT* Participants were required to run back and forth between a 20-metre stretch of marked lines or cones and pace themselves so that the arrival at the end of the 20-metre stretch coincided with a beep signal emitted from a pre-recorded CD. Participants were fitted with a portable gas analyser while completing the 20-m SRT. HR was recorded every minute.	Measured $\dot{V}O_{2max}$ (ml/kg/min): All = 47.7 ± 10.0 Females = 37.1 ± 5.0 Males = 53.9 ± 6.2 Predicted $\dot{V}O_{2peak}$ - Léger equation: All = 43.0 ± 6.8 Females = 36.2 ± 2.9 Males = 47.0 ± 5.0	$\dot{V}O_{2max}$ (ml/kg/min) = Equation available at http://www.helenastudy.com/scientific.php Ruiz *et al*. (2008); Artificial neural network-based equation for estimating $\dot{V}O_{2max}$ from the 20-metre shuttle run test in adolescents. *Artificial intelligence in medicine*, 44:233-245.	R = 0.96 SEE = 2.84 ml/kg/min
Ruiz *et al*. (2009)	26 Healthy, Caucasian girls (14.6 ± 1.5 years) and 22 boys (15.0 ± 1.6 years)	*20-m SRT* Participants were required to run back and forth between a 20-metre stretch of marked lines or cones and pace themselves so that the arrival at the end of the 20-metre stretch coincided with a beep signal emitted from a pre-recorded CD. Participants were fitted with a portable gas analyser while completing the 20-m SRT. HR was recorded every minute.	$\dot{V}O_{2max}$ (ml/kg/min) as per direct measurement and from various equations: Direct = 47.1 ± 8.1 Leger = 41.5 ± 5.2 Barnett (a)= 44.2 ± 5.6 Barnett (b) = 45.7 ±5.0 Matsuzaka = 43.8 ±5.5 Ruiz = 43.4 ± 8.8		

$\dot{V}O_{2max}$ = Maximal Oxygen Uptake; R = Correlation; SEE = Standard Error of Estimate; 20-m SRT = 20-metre Shuttle Run Test; HR = Heart Rate

Table 1 (cont). Directly or indirectly measured (predicted) aerobic performance values ($\dot{V}O_{2max}$) of children and adolescents

Study	Number, status gender and age of participants	Protocol	$\dot{V}O_{2max}$
Schneider *et al.* (2007)	122 Healthy, adolescent girls (10th or 11th grade)	*Maximal cycle ergometer test:* The test was done on an electronically braked cycle ergometer which increased the resistance throughout the test (no indication of starting or incremental load) while participants had to maintain a pedalling cadence of 70 rpm until volitional exhaustion. Participants were fitted with a portable gas analyser and HR was recorded every minute. The intervention period consisted of 60 minutes of Physical Education classes for 5 days a week.	$\dot{V}O_{2max}$ (ml/min/kg): Intervention group: Baseline = 23.19 ± 4.81 Semester 1 = 23.2 ± 4.59 Semester 2: 24.17 ± 4.53 Comparison group (no classes): Baseline = 23.71 ± 4.49 Semester 1 = 22.11 ± 4.14 Semester 2 = 22.85 ± 3.61
Sirard *et al.* (2008)	1 903 Healthy, active adolescent girls (13.6 ± 0.63 years) of which 48% were Caucasian	*Submaximal cycle ergometer test:* (*Predicted test at HR of 170 bpm (PWC_{170})*) The started the test at an initial workload of 0.5 kg and each stage lasted 2 minutes. 3 Stages were completed to obtain an HR of 120, 150 and 170 bpm at the end of each 2-minute stage. Participants had to maintain a pedalling cadence of 60 rpm throughout the test and if HR was lower than 160 bpm at the end of the 3rd stage, a 4th stage was completed. HR at the end of each stage was used to establish the work increment for the next stage HR recorded to extrapolate with workload to predict PWC_{170} (kg/min/kg).	PWC_{170} (kg/min/kg): All = 11.5 ± 3.36 Caucasian: All = 11.7 ± 3.15 No sport = 10.9 ± 3.0 One sport = 11.7 ± 3.02 Multi-sport = 12.5 ± 3.3 African American: All = 11.4 ± 3.57 No sport = 11.1 ± 3.77 One sport = 11.4 ± 3.32 Multi-sport = 12.0 ± 3.40

$\dot{V}O_{2max}$ = Maximal Oxygen Uptake; 20-m SRT = 20-metre Shuttle Run Test; HR = Heart Rate

Table 1 (cont). Directly or indirectly measured (predicted) aerobic performance values ($\dot{V}O_{2max}$) of children and adolescents

Study	Number, status gender and age of participants	Protocol	$\dot{V}O_{2max}$
Sirard *et al.* (2008)	1 903 Healthy, active adolescent girls (13.6 ± 0.63 years) of which 48% were Caucasian	*Submaximal cycle ergometer test:* (*Predicted test at HR of 170 bpm (PWC_{170})*) They started the test at an initial workload of 0.5 kg and each stage lasted 2 minutes. 3 Stages were completed to obtain an HR of 120, 150 and 170 bpm at the end of each 2-minute stage. Participants had to maintain a pedalling cadence of 60 rpm throughout the test and if HR was lower than 160 bpm at the end of the 3rd stage, a 4th stage was completed. HR at the end of each stage was used to establish the work increment for the next stage HR recorded to extrapolate with workload to predict PWC_{170} (kg/min/kg).	PWC_{170} (kg/min/kg): All = 11.5 ± 3.36 Caucasian: All = 11.7 ± 3.15 No sport = 10.9 ± 3.0 One sport = 11.7 ± 3.02 Multi-sport = 12.5 ± 3.3 African American: All = 11.4 ± 3.57 No sport = 11.1 ± 3.77 One sport = 11.4 ± 3.32 Multi-sport = 12.0 ± 3.40
Sveinsson *et al.* (2009)	270 Healthy Icelandic children and adolescents between ages 9 and 15 years	*Maximal cycle ergometer test:* For 9-year-olds: An initial and incremental workload of 20 W for children with a body mass under 30 kg and 25 W for those with a body mass above 30 kg was used. For 15-year-olds: An initial and incremental workload of 40 W for girls and 50 W for boys was used. Load increases occurred every 3 minutes until volitional exhaustion or until pedalling cadence could not be maintained at 40 rpm.	Fitness (w/kg): Girls: 15 years = 3.08 ± 0.38 9 years = 2.98 ± 0.58Boys: 15 years = 3.82 ± 0.57 9 years = 3.46 ± 0.65

$\dot{V}O_{2max}$ = Maximal Oxygen Uptake; W = Watt; HR = Heart Rate

Table 1 (cont). Directly or indirectly measured (predicted) aerobic performance values ($\dot{V}O_{2max}$) of children and adolescents

Study	Number, status gender and age of participants	Protocol	$\dot{V}O_{2max}$	Prediction model/equation	R and SEE values
Tambalis *et al.* (2011)	725 163 Healthy, Greek children between ages 8 and 9 years	*20-m SRT:* Participants were required to run back and forth between a 20-metre stretch of marked lines or cones and pace themselves so that the arrival at the end of the 20-metre stretch coincided with a beep signal emitted from a pre-recorded CD.	20-m SRT stages: 1997 Urban: Girls = 2.97 ± 1.5 Boys = 3.48 ± 1.9 1997 Rural: Girls = 2.98 ± 1.9 Boys = 3.54 ± 2.0 2007 Urban: Girls = 2.53 ± 1.7 Boys = 3.02 ± 2.1 2007 Rural: Girls = 2.99 ± 1.7 Boys = 3.51 ± 2.1		
Tong *et al.* (2001)	14 Healthy, adolescent boys between ages 16 and 18 years	*Maximal incremental treadmill test:* The test started at an incline of 0% and a self-selected speed to elicit an HR of 70% of predicted HR. Thereafter the incline increased by 2% every 2 minutes until an HR of more than 90% of the predicted HR was reached. The incline was then increased every minute by 2% until the increase in $\dot{V}O_2$ was smaller than 2.1 ml/kg/min or until the RER was higher than or equal to 1.15. HR was recorded every minute.	Measured $\dot{V}O_{2max}$ (ml/kg/min) = 55.5 ± 1.4 Predicted $\dot{V}O_{2peak}$ (ml/kg/min) (Léger *et al*.) = 52.09 ± 0.9	$\dot{V}O_{2max}$ = 4.95 + 3.31x x = maximal treadmill velocity	R^2 = 0.35 SEE = 5.64 ml/kg/min

$\dot{V}O_{2max}$ = Maximal Oxygen Uptake; R = Correlation; SEE = Standard Error of Estimate; 20-m SRT = 20-metre Shuttle Run Test; HR = Heart Rate

Table 1 (cont). Directly or indirectly measured (predicted) aerobic performance values ($\dot{V}O_{2max}$) of children and adolescents

Study	Number, status gender and age of participants	Protocol	$\dot{V}O_{2max}$
Trowbridge *et al.* (1997)	44 Healthy, African American children and 31 Caucasian children between ages 5 and 10 years	*Maximal incremental treadmill test:* The test started at a speed of 4 km/h and an incline of 0% for 4 minutes. Thereafter the incline was increased to 10% for 2 minutes after which the incline increased every 2 minutes until an incline of 22.5% was reached while the speed was kept constant. After reaching 22.5% the speed was increased 0.6 km/h every 2 minutes until volitional exhaustion. HR was recorded every minute.	$\dot{V}O_{2max}$ (L/min): Caucasian girls = 1.49 ± 0.31 Caucasian boys = 1.34 ± 0.28 African American girls = 1.23 ± 0.33 African American boys = 1.18 ± 0.31
Wennlöff *et al.* (2006)	935 Children and adolescents between ages 9 and 15 years	*Maximal cycle ergometer test:* This test was conducted according to the method of Hansen. Participants had to remain seated upright as the work load increased every 3 minutes (no mention of incremental work load given) while cycling until volitional exhaustion. HR was recorded every minute.	$\dot{V}O_{2max}$ (ml/kg/min): Girls: 9-year-old = 37.3 ± 5.5 15-year-old = 40.4 ± 5.6 Boys: 9-year-old = 42.8 ± 6.6 15-year-old = 51.5 ± 6

$\dot{V}O_{2max}$ = Maximal Oxygen Uptake; HR = Heart Rate; L/min = Litre per minute

4. Components that influence the aerobic performance of children and adolescents

The following section will focus on the influence of anthropometric, physical and motor performance components on the aerobic performance ($\dot{V}O_{2max}$) of children and adolescents. In cases where research did not provide data with regard to the last-mentioned themes for children and adolescents, the data of adults was used. Other factors such as race and sport participation that may also influence the aerobic performances of participants will also be discussed.

4.1 Anthropometric components that influence the aerobic performance of children and adolescents:

A certain body build or body type is more suited for certain sports and will make the participant less prone to injury, which means that an ideal anthropometric profile is vital for success in sport (Nevill *et al*., 2009:228). The importance of the anthropometric profile in achieving sport success has motivated researchers to not only identify the most optimal physique for a certain sport, but also to identify ways of developing and maintaining the most optimal physique (Carter & Ackland., 2009:55; Birrer *et al*., 1987:214). The measurement of a participant's anthropometric profile is rather simple and time efficient, which compelled researchers to also include these measurements as independent variables in $\dot{V}O_{2max}$ prediction models (Akalan *et al*., 2008:10; Cureton *et al*., 1995:447; Kline *et al*., 1987:257; Nes *et al*., 2011:2028). The influence of participants' anthropometric profile on aerobic performance has been widely researched (Carter & Ackland, 2009; Cureton *et al*., 1978; Housh *et al*., 1986; Nevill *et al*., 2009) and the following section will deal with the anthropometric components that influence aerobic performance.

4.1.1 <u>The influence of body mass and stature on aerobic performance</u>:

When evaluating aerobic fitness or potential in children it is important to correct for normal changes in body size which occur during growth (Rowland *et al.*, 1997:271-272). In general the biggest changes in children's $\dot{V}O_{2max}$ occur during the growth spurt phase which is characterised by a rapid increase in body stature, weight and muscle mass (Geithner *et al*, 2004:1622). Although the growth spurt occurs earlier in girls than in boys, the extent of the growth spurt is much more pronounced in boys than in girls at all ages from late childhood to adolescence (Geithner *et al*.,

2004:1622). The $\dot{V}O_{2max}$ values (corrected for changes in body size) of boys show an increase from childhood to adolescence and then early adulthood whilst the $\dot{V}O_{2max}$ values of girls increase up until puberty after which it levels off (Harris & Cale, 2006:207). On average the peak velocity of $\dot{V}O_{2max}$ coincides with the peak height velocity (PHV) and before peak weight velocity (PWV) in both genders (Geithner *et al*., 2004:1622). Mean ages at the peak velocity of $\dot{V}O_{2max}$ are reported to be 12.3 ± 1.2 years for girls and 14.1 ± 1.2 years for boys (Geithner *et al*., 2004:1622). Furthermore, Pearson *et al*. (2006:279) reported that the greatest improvements in boys' aerobic performances were between ages 11 and 15, which coincided with the attainment of PHV and PWV. However, for boys the increase in stature and body weight during puberty might have a greater influence on physical fitness performance than puberty itself (Jones, 2000:62, Ekelund *et al.*, 2001:199; Mota *et al.*, 2002:711)

With regard to the direct influence of anthropometric components on aerobic performance, Ruiz *et al*. (2008:282) found body weight and stature to be significant contributors to 20-m SRT performance in a group of adolescents. Negative and statistically significant correlations were reported for the relationships between body weight and $\dot{V}O_{2max}$ values in boys ($r = -0.517$, $p < 0.001$) and girls ($r = -0.241$, $p < 0.043$) respectively (Ruiz *et al*., 2008:242). However, non-significant correlations were found for the relationships between body stature and $\dot{V}O_{2max}$ in both genders (boys: $r = -0.170$, $p = 0.079$; girls: $r = 0.219$, $p = 0.066$) (Ruiz *et al*., 2008:242). While body stature was negatively associated with $\dot{V}O_{2max}$ values in boys, the opposite was true for girls (Ruiz *et al*., 2008:242). This finding may suggest that a certain body stature range may benefit 20-m SRT performance, but that body statures under or above this range may be detrimental to 20-m SRT performances (Ruiz *et al*., 2008:242). In an older study Goran *et al*. (2000:843) also demonstrated that children's (9.6 ± 1.3 years) body weight ($r = 0.78$, $p < 0.0001$) and stature ($r = 0.75$, $p < 0.001$) contributed significantly to their $\dot{V}O_{2max}$ scores. Other researchers also identified a body stature-related variable, namely ponderal index (weight/height^3) to be an important determinant of cardiorespiratory efficiency in Greek children and adolescents between ages 9 and 16 years with lower ponderal index scores showing to be more beneficial to performance (Nevill *et al*., 2009:228).

The results highlight the importance of an optimal stature to weight ratio to ensure that weight as a minimum influence on weight-bearing endurance type of activities (Nevill *et al*., 2009:228).

Studies regarding the influence of body stature and weight on the aerobic performances of adults, obtained results similar to those of children and adolescents. For example, Verma *et al*. (1998:108) found that men's body weight ($r = 0.229$, $p < 0.01$), stature ($r = 0.117$, $p > 0.01$) and age ($r = -0.144$, $p < 0.001$) correlated significantly and non-significantly respectively with $\dot{V}O_{2max}$ values. The highest multiple correlation for the prediction of aerobic performance was obtained from the combination of age and body weight ($r = 0.536$, $p < 0.001$) (Verma *et al*., 1998:105). Flouris *et al*. (2005:168-169) also demonstrated that body stature was a significant predictor of $\dot{V}O_{2max}$ differences between treadmill running and the 20-m SRT with the energy cost of variance ($r = 0.94$, $p < 0.001$) increasing as the participants' body stature increased. These results were attributed to the detrimental effect of a high stature 20-m SRT execution (Flouris *et al*., 2005:169). A study of highly trained middle- and long-distance (aerobic performance-related) athletes showed that body stature ($r = -0.86$, $p < 0.001$) and weight ($r = -0.77$, $p < 0.01$) had a significant negative correlation with energy cost of running (Maldonado *et al.*, 2002:270). These results suggest that taller and heavier middle to long-distance athletes' energy cost of running is higher than that of shorter and lighter athletes. Ackland and De Ridder (2009:95) also confirmed the last-mentioned conclusion by reporting that most middle-distance runners are characterised by a tall and linear body build with long legs and normal trunk lengths. On the other hand the same researchers also found that long-distance runners displayed progressively shorter body statures as the race distance increased (Ackland & De Ridder, 2009:96). In addition, the long-distance runners also displayed shorter lower limb lengths in relation to their trunk lengths (Ackland & De Ridder, 2009:96).

4.1.2 <u>The influence of body fat on aerobic performance:</u>

Research has shown that a body composition-related variable, namely fat percentage (as measured by the sum of 4 skinfolds) correlated negatively with adolescent boys' ($r = -0.48$, $p < 0.001$) and girls' $\dot{V}O_{2max}$ values ($r = -0.43$, $p = 0.004$) (Ekelund *et al.*, 2001:197-198).). In this regard, McVeigh *et al*. (1995:77) indicated that the inclusion of triceps skinfold thickness among girls (13.68 ± 0.3 years) and boys (13.68 ± 0.3 years) respectively strengthened the prediction of

$\dot{V}O_{2max}$ values, which were derived from the 20-m SRT. Researchers have also provided proof that triceps skinfold thickness is a good indicator of body fat percentage in children and adolescents (Lohman *et al*., 2008:1164; McVeigh *et al*., 1995:77), which may explain the identification of triceps skinfold thickness as a predictor of 20-m SRT derived $\dot{V}O_{2max}$ values (Buono *et al*., 1991:254; McVeigh *et al*., 1995:75). In a study by Buono *et al.* (1991:254) it was demonstrated that the mile-run time together with the triceps and subscapular skinfold values contributed 70.56% to the $\dot{V}O_{2max}$ prediction of 90 children and adolescents between ages 10 and 18 years. In the study by Ekelund *et al*., (2001) for the same group of boys, body fat and maturity accounted for 47% of the variation in $\dot{V}O_{2max}$ values whereas body fat together with activity energy expenditure accounted for 22% of the variation in $\dot{V}O_{2max}$ among girls (Ekelund *et al.*, 2001:199-200). A study on Portuguese children revealed similar results, with fat percentage resulting in a $\dot{V}O_{2max}$ variation of 10% for girls and 22% for boys (Mota *et al.*, 2002:710). The same authors also showed that $\dot{V}O_{2max}$ were inversely and significantly ($p < 0.001$) associated with percentage body fat for both gender groups in their study (Mota *et al.*, 2002:709). In another study on adolescents, Ortega *et al*. (2010:261) also found that $\dot{V}O_{2max}$ was inversely and significantly associated ($p = 0.002$) with abdominal adiposity.

As mentioned before, fat percentage changes directly related to the growth process in children may explain the changes in $\dot{V}O_{2max}$ variation among the two gender groups. In this regard Rowland *et al.* (1997:270) showed that the differences in $\dot{V}O_{2max}$ variations between boys and girls were initially 5% but after a period of five years it increased to 29%. These changes in the variation of $\dot{V}O_{2max}$ values corresponded directly with a decrease in the percentage body fat for boys and an increase in percentage body fat for girls as they entered puberty (Rowland *et al.*, 1997:270). The onset of puberty and resulting increase in body fat among Portuguese girls, also resulted in a decline in $\dot{V}O_{2max}$ values for this group of participants (Mota *et al.*, 2002 711). In this regard Johnson *et al*. (2000:4) reported that an increase of 0.081 kg of body fat per kilogram of lean body

mass would result in a 0.1 L/min decrease in $\dot{V}O_{2max}$ among 8 and 11-year-old Caucasian and non-Caucasian boys and girls. Furthermore, other researchers showed that fat mass alone was responsible for 31% of the variance in distance-running performance in a group of 12-year-old boys (Rowland *et al*., 1999:848). These results are also supported by the findings of other researchers (Ara *et al*., 2007:1921; Cairney *et al*., 2008:135; Gutin *et al*., 2005:81; Huotari *et al*., 2010:743; Nevill *et al*., 2009:228; Rowlands *et al*., 1999:1343; Sveinsson *et al*., 2009:147) who all agreed that low body fat levels benefit weight-bearing endurance activities due to a decrease in energy demand caused by the lower mass of metabolic inactive body tissue that needs to be displaced.

The lowest $\dot{V}O_{2max}$ values are reported for obese children (32.0 ± 4.1 ml/kg/min) (Goran *et al*., 2000). According to Goran *et al*. (2000:846), the higher fat mass values for this population led to an increase in energy expenditure and $\dot{V}O_2$ during weight-bearing activities, which negatively affected aerobic capacity. Therefore the $\dot{V}O_{2max}$ results of the obese children are poorer than those of lean and healthy children of more or less the same age (Adegoye *et al*., 2011; Ara *et al*., 2007; Arngrímsson *et al*., 2008; Berndtsson *et al*., 2007:568; Drinkard *et al*., 2001:1892: Dumith *et al*., 2010:644; Ekelund *et al*., 2001; Fonseca *et al*., 2008:43; Ortega *et al*., 2010; Rowland *et al*., 1999:847; Wennlöff *et al*., 2006). In contrast, Norman *et al*. (2005:e694) found similar absolute $\dot{V}O_{2max}$ values for overweight and non-overweight adolescents at the lactate threshold and maximal exertion points. These results indicate that overweight adolescents' $\dot{V}O_{2max}$ values are impaired due to the increased effort required to move a heavier body during treadmill running, rather than due to cardiorespiratory impairment (Norman *et al*., 2005:e694).

Higher percentage body fat values also negatively influence the aerobic performances of adult populations (Wier *et al.*, 2006:559). In this regard the last-mentioned researchers showed that the inclusion of fat percentage in a non-exercise regression model to predict $\dot{V}O_{2max}$ in 26 to 78-year-old males and females resulted in the highest correlation and lowest standard error of estimate (R = 0.82, SEE = 4.72 ml/kg/min) when compared with either including BMI (R = 0.80, SEE = 4.90 ml/kg/min) or waist girth (R = 0.81, SEE = 4.80) in the respective prediction regression models (Wier *et al.*, 2006:556-557).

4.1.3 The influence of BMI on aerobic performance:

BMI also influences 20-m SRT performances as children with lower BMI scores outperform those with higher BMI values (Cairney *et al.*, 2008:135). Furthermore, the BMI status of Brazilian adolescents (7 - 15 years) had the strongest correlation with the level of cardiorespiratory fitness, indicating that a higher BMI score results in lower aerobic fitness results independent of a participant age (Dumith *et al*., 2010:647).

4.1.4 The influence of muscle mass on aerobic performance:

Up until now only a small number of researchers have investigated the possible influence of muscle mass on the aerobic performance of children and adolescents, which compelled the author of this chapter to also discuss publications that have focussed on this theme in adult populations. Research that has investigated the relationship between muscle mass and the $\dot{V}O_{2max}$ values of 129 pre-pubertal children reported a strong and significant correlation ($r = 0.87$, $p < 0.001$) (Goran *et al*., 2000:843). Furthermore, Fonseca *et al.* (2008:46) found a significantly negative correlation between the fat-free mass and $\dot{V}O_{2max}$ in Brazilian adolescents ($r = -0.80$, $p < 0.01$). A study on 15 to 17-year-old female adolescents also revealed that 40% of the training response as measured by increased $\dot{V}O_{2max}$ values could be explained by the increase in the thigh muscle volume (Eliakim *et al.*, 1996:540). Linear regressions revealed a strong correlation between thigh muscle volume and $\dot{V}O_{2max}$ before the exercise intervention of 5 weeks (1.42 ± 0.20 ml O_2/min per cubic centimetre muscle volume). After the intervention the $\dot{V}O_{2max}$ increase was much greater than the increase in thigh muscle volume with results improving to 4.78 ± 1.46 ml O_2/min per cubic centimetre (Eliakim *et al.*, 1996:540). In contrast, an increase in muscle mass among 19 to 30-year-old cross-country skiers did not lead to improved $\dot{V}O_{2max}$ values in a study undertaken by Østerås *et al.* (2002:261).

Despite a scarcity of research that has investigated the possible influence of muscle mass on the $\dot{V}O_{2max}$ of especially children and adolescent populations, the research that exists would suggest that muscle mass will have a significance influence on the $\dot{V}O_{2max}$ values of these populations.

4.1.5 The influence of bone mineral density and skeletal mass on aerobic performance:

Fonseca *et al.* (2008:47) indicated that body mass, muscle mass and aerobic fitness were directly related to the bone mass in adolescent boys. Muscle mass was also identified as the main indicator of bone mass in a group of adolescent girls at the end of adolescents (Fonseca *et al.*, 2008:47). Falk *et al*. (2007:452) also showed that higher bone mineral densities occurred in the presence of lower body fat percentage and higher muscle mass values among a group of 8 to 23-year-old children, adolescents and adults. A positive association between bone mineral density as well as bone mineral content at specific bone sites, and the aerobic performance of 16 to 18-year-old adolescents was also reported by Ginty *et al*. (2005:108).

4.1.6 The influence of somatotype on aerobic performance:

Another anthropometric indicator, namely somatotype, which is an indicator of the muscle, fat and lean mass, and its possible influence on aerobic performance has not received much attention in literature. Somatotyping allows scientists to categorise individuals into ectomorphic (tall and slender), endomorphic (large or fat) or mesomorphic (muscular) categories (McArdle *et al*., 2010:760). In this regard research would also suggest that the trainability of $\dot{V}O_{2max}$ is highly dependent on a participant's somatotype. For example, Chaouachi *et al*. (2005:956) found that participants that displayed a mesomorphic ectomorph or a more mesomorphic somatotype showed the biggest improvements in $\dot{V}O_{2max}$ after a training period when compared with participants with other somatotypes. Furthermore, Bolonchuk *et al.* (2000:172) found that mesomorphy was significantly positively correlated with peak power, ventilation rate and $\dot{V}O_2$ measured during a progressive, continuous, maximal exercise test on a cycle ergometer among eighty-five men. From these results, the importance of somatotype as an anthropometric variable, which may possibly influence the aerobic performance of children and adolescents, cannot be ignored.

The following section will discuss the influence of various physical and motor performance components on the aerobic performance of children and adolescents.

4.2 Physical and motor performance components as well as running economy's influence on the aerobic performance of children and adolescents

Motor performance components can be best described as components or elements that will influence an individual's current level of performance and will allow that individual to best perform a certain movement or skill (Gallahue & Ozman, 2006:16). Motor performance components include speed, agility, balance, muscle strength and explosive power (Gallahue & Ozman, 1995:73). Physical components on the other hand relate to muscle endurance and flexibility (Haywood, 1986:203). Although, researchers have not given much attention to the possible influence of physical and motor performance components such as speed, agility, strength, power and flexibility on the aerobic performance of especially children and adolescents, the available literature in this regard will be discussed. However, due to the limited availability of children- and adolescent-related research, research on adult populations will also be included.

4.2.1 The influence of speed, agility, strength, explosive power and flexibility on aerobic performance

Some studies have determined the relationship between the above-mentioned variables and $\dot{V}O_{2max}$ whereas others have used aerobic performance as a measure. For instance, Sinnet *et al*. (2001:406) investigated the relationship between 10 km distance-running (aerobic) performance and several anaerobic field tests in 36 recreational distance runners (age: 27.9 ± 5.7 years). The anaerobic tests included 50 m sprint, vertical jump from a static position (VJ) and with a countermovement (CMJ), a plyometric leap and a 300 m sprint test (Sinnet *et al.*, 2001:406). The 10 km performance measured as run time was significantly correlated ($p \leq 0.05$) with the following variables in the total group of male and female runners: 50 m sprint time ($r = 0.444$), 300 m sprint time ($r = 0.79$), VJ height ($r = -0.618$), CMJ height ($r = -0.605$), VJ power ($r = -0.533$), CMJ power ($r = -0.549$) and plyometric leap distance ($r = -0.86$) (Sinnet *et al.*, 2001:408). Stepwise regression analysis also revealed that 73.9% ($r^2 = 0.739$) of the variance in run time was explained by the plyometric leap distance and, when combined with the 300 m sprint, the value increased to 77.9% ($r^2 = 0.779$) (Sinnet *et al.*, 2001:408). These results indicate that anaerobic power is significantly related to distance-running performance and can therefore be used to predict aerobic running performance (Sinnet *et al.*, 2001:408). Another anaerobic component, namely maximal running speed, also obtained a strong, significant correlation with $\dot{V}O_{2max}$ ($r = 0.91$, $p < 0.05$) in elite male and female netball and lacrosse players (22.6 ± 3.4 years) (Wilkinson *et al.*, 1999:417). Maximal

running speed also showed a strong and significant correlation (r = 0.92, p < 0.01) with 10 km running performance in elite runners (Petit *et al.*, 1997:563). However, maximal speed over 40 m showed a lower correlation coefficient with 20-m SRT-derived $\dot{V}O_{2max}$ values (r = 0.542, p < 0.001) in Greek school children between ages 10 and 13 years (Nevill *et al*., 2009:225). Researchers also found that maximal 20-m SRT running speed correlated significantly with the $\dot{V}O_{2max}$ values (r = 0.95, p < 0.01) of adolescent football players from Nepal (Chatterjee *et al*., 2009:119). The last-mentioned two studies are, however, the only studies that investigated the possible influence of the above-mentioned components on the aerobic performance of children and adolescents.

Studies investigating the influence of strength and power on aerobic performance have been limited to the adult population. In this regard, thirty-eight healthy males (21.6 ± 2.5 years) participated in three different $\dot{V}O_{2max}$ tests: the 20-m SRT, a 20-m SST and a maximal treadmill test (Flouris *et al*., 2006:198). In addition, knee flexor/extensor strength was measured at 60°/sec on a Cybex Isokinetic machine. Leg strength accounted for 9% (r= 0.63, p < 0.001) of the 20-m SRT performance and 4% (r = 0.44, p < 0.05) of the SST performance (Flouris *et al.*, 2006:200). Other researchers found that 9 weeks of strength training in a group of cross-country skiers led to improved skiing performance (decrease in time to exhaustion) without a corresponding increase in $\dot{V}O_{2max}$ values (Østerås *et al.*, 2002:262). The authors attributed this result to the fact that the cross-country skiers were highly trained, which made it difficult to elicit further improvements in $\dot{V}O_{2max}$ values (Østerås *et al.*, 2002:262). It is therefore possible that improved time to exhaustion was the result of higher lower-body strength values and a better economy of movement (Østerås *et al.*, 2002:262). Similarly, Hoff *et al*. (2002:291) reported improvements in the aerobic endurance performance of cross-country skiers after 8 weeks of strength training which led to significant increases ($p \leq 0.05$) in 1 Repetition Maximum (RM) values of cable pulley pull-down values (used to simulate the double poling movements in cross-country skiing).

The possible influence of flexibility on the aerobic performance of participants is not a component that has drawn the attention of many researchers. Surprisingly, researchers are of the opinion that stiffer musculotendinous structures will reduce the aerobic demand of submaximal running by facilitating greater elastic energy return during the shortening phase of the stretch-shortening cycle

(Jones, 2002:42; Trehearn & Buresh, 2009:161). Some researchers even suggest that endurance runners should completely alter their stretching routines or even discontinue stretching in order to prevent reductions in running economy (Nelson *et al*., 2001:264).

The above-mentioned findings clearly underline the importance of considering various physical and motor performance components for the prediction of aerobic performance. However, various other factors that do not resort under the category of anthropometric, physical and motor performance components may also influence the aerobic performance of participants.

4.3 Other factors that influence the aerobic performance of children and adolescents:

Demographic and other factors also seem to influence participants' aerobic performance and include, but are not limited to, participants' race, living area, sport participation and physical activity level (Harris & Cale, 2006:212; McHunu & Le Roux, 2010:96-97; McMurray *et al*., 2002:149-151; McNaughton *et al*., 2006:578). In the subsequent section the possible influence will be discussed of each of these factors on the aerobic performance of participants.

4.3.1 The influence of race on aerobic performance:

Differences in ethical and racial backgrounds need to be considered when interpreting and comparing participants' aerobic results (Chaouachi *et al.*, 2005:958; McMurray *et al*., 2002:149) and may help to increase the accuracy of $\dot{V}O_{2max}$ prediction models (Matthews *et al*., 1999:491; Wier *et al.*, 2006:560). Several researchers investigated the effect of race on children's and adolescents' aerobic performances (Felton *et al.*, 2002; Gutin *et al*., 2005; Johnson *et al*., 2000; Kimm *et al*., 2002; Lohman *et al.*, 2008; McHunu & Le Roux, 2010; McMurray *et al.*, 2002; Pivarnik *et al.*, 1998; Prista *et al.*, 2009; Sirard *et al.*, 2008; Trowbridge *et al.*, 1997) and agreed that African American or black children and adolescents displayed lower aerobic performance scores than their Caucasian peers. In this regard a group of 5 to 10-year-old African American children obtained $\dot{V}O_{2max}$ values, which were significantly lower (15%, $p < 0.01$) than those of Caucasian children (Trowbridge *et al.*, 1997:E811). The children's $\dot{V}O_{2max}$ values were independent of fat mass and lean body mass, but ethnicity remained a significant independent predictor of $\dot{V}O_{2max}$ ($p < 0.01$) (Trowbridge *et al.*, 1997:E811). In another study, African American girls between ages 11 and 15

years also obtained lower (level of significance was not indicated) $\dot{V}O_{2max}$ values than Caucasian girls and the values showed significant declines (12%) from grades 6 to 8 (Pivarnik *et al.*, 1998:25). McMurray *et al.* (2002:150) concluded that the higher relative $\dot{V}O_{2max}$ values of the Caucasian children and adolescents compared to that of African American children and adolescents (8 - 16 years) were the result of lower weight and skinfold values for Caucasian population. This notion was also verified by the lower increases in sum of skinfolds values for the Caucasian boys and girls (28% and 33% respectively) than the increases that was observed for the African American children and adolescents with age (47% and 43.8% respectively) (McMurray *et al.*, 2002:150). This is in contrast with an earlier finding by Johnson *et al*. (2000:4) who reported no significant relationship between ethnicity and $\dot{V}O_{2max}$. This group of researchers also found that adiposity was similar both in black and white children (Johnson *et al*., 2000:4).

The influences of differences in race in conjunction with gender on aerobic performance have also been noted. For example, Felton *et al.* (2002) and Lohman *et al.* (2008) confirmed that race had the strongest influence on physical activity patterns for girls and as a result African American adolescent girls showed lower aerobic fitness levels than Caucasian girls of the same age. These results were also substantiated by Sirard *et al*. (2008:202) who found that 12% more Caucasian girls participated in at least one team sport than did African American girls ($p < 0.05$), which may account for the $\dot{V}O_{2max}$ differences between different racial groups. Pfeiffer *et al.* (2007:2235) studied aerobic fitness changes in girls from grades 8 to 12 (middle to high school) and also reported that white girls displayed significantly higher aerobic fitness values in grades 9 ($p < 0.05$) and 12 ($p < 0.01$) than African American girls. These results were explained by the significantly higher proportion of white girls that were moderately to vigorously active, than were the proportion of African American girls ($p < 0.01$) (Pfeiffer *et al.*, 2007:2237). Furthermore, significantly more ($p < 0.05$) white girls participated in sport at all stages than the African American girls (Pfeiffer *et al.*, 2007:2237). In a more recent study, Kelly *et al.* (2010:188) also showed that white girls were more engaged in physical activity, when results were compared with Hispanic and black middle-school girls. The decline in physical activity also seems to be racially related (Kimm *et al*., 2002:71).

Hence the last-mentioned results would suggest that race has a significant influence on children and adolescents' aerobic performance and should be considered in $\dot{V}O_{2max}$ prediction functions.

4.3.2 The influence of living area on aerobic performance:

Living area (rural or urban) may have an influence on the aerobic performance and must therefore be considered when investigating the aerobic performance of children and adolescents (Dumith *et al.*, 2010:646). In especially South Africa, inadequate facilities in rural areas may lead to physical inactivity, which will in the long run translate to poor aerobic performances (McHunu & Le Roux, 2010:97). However, a study on Spanish children and adolescents showed that rural-living participants had a healthier anthropometric profile and displayed significantly higher aerobic fitness values ($p < 0.001$) than their urban-living peers (Chillón *et al.*, 2011:421). Possible reasons for the significant differences in aerobic fitness values between rural and urban-living children and adolescents are that children and adolescents living in rural areas usually walk to and from school (Chillón *et al.*, 2011:421; Sjolie *et al.*, 2002:24) and participate in sport as a recreational activity instead of a structured, competitive activity (Chillón *et al.*, 2011:421). Similarly, Machado-Rodrigues *et al.* (2011:481) reported that Portuguese adolescents living in rural areas were 76% more likely to be classified as being aerobically fit than those living in urban areas. Researchers also demonstrated that the time spent outdoors is positively associated with participants' aerobic capacity (Felton *et al.*, 2002:254; Machado-Rodrigues *et al*, 2011:482). Results of Greek children mirror the previously mentioned results as rural-living children showed significantly better ($p < 0.01$) 20-m SRT-obtained aerobic values than their urban-living peers (Tambalis *et al.*, 2011:274). These results were unexpected in view of the increasing levels of obesity among the rural-living children (Tambalis *et al.*, 2011:274).

The influence of sport and/or physical activity participation on aerobic performance will be further discussed in the following section.

4.3.3 The influence of sport participation and physical activity level on aerobic performance:

Sport participation and sufficient physical activity are necessary for improved aerobic performance (Ara *et al*., 2007; Koutedakis & Bouziotas, 2003; Lohman *et al*., 2008; Pfeiffer *et al.*, 2007; Rowlands *et al.*, 1999; Sirard *et al.*, 2008). The trend of a decrease in aerobic fitness among children and adolescents over time is most likely the result of a decrease in physical activity (and

sport participation level) (Albon *et al*., 2010:268; Volkbekienė & Griciūtė, 2007:241; Westerstahl *et al*., 2003:135). Furthermore, it would seem that school physical education programmes have not been able to address this problem (Volkbekienė & Griciūtė, 2007:241). Evidence for this statement was provided by Pfeiffer *et al.* (2007:2237) who showed that aerobic performance was significantly better ($p < 0.05$) among middle-school girls that participated in sport than among non-participants. At all three measurement time points (8th, 9th and 12th grades), sport team participants displayed significantly higher ($p \leq 0.05$) absolute as well as relative aerobic fitness levels than non-participants (Pfeiffer *et al.*, 2007:2237). Koutedakis and Bouziotas (2003:312) also reported significantly better ($p \leq 0.001$) cardiovascular fitness and $\dot{V}O_{2max}$ values for Greek boys that participated in organised sport activities in addition to their normal school physical education classes and habitual physical activities than the boys that only participated in physical education classes at school. Similarly, Chillón *et al*. (2011:241) and Ara *et al*. (2007:1922) found higher aerobic fitness values for sport participating Spanish children than the values of non-sport participating Spanish children. These results confirmed previous findings by Rowlands *et al.* (1999:1433) who observed a direct relationship between the aerobic fitness of 8 to 10-year-old children and their physical activity levels. The results of sport participating 12 to 17-year-old adolescents (47.6 ± 3.1 – 49.5 ± 4.4 ml/kg/min) (Leone *et al*., 2002: 444) are also much higher than those reported for non-sport participating adolescent females (22.11 ± 4.14 – 24.17 ± 4.53 ml/kg/min) (Schneider *et al*., 2007: 23).

Some researchers also investigated the possible effect of race on children's and adolescents' physical activity levels. In this regard, Kimm *et al*. (2002:712) showed that a decline in physical activity levels was significantly influenced ($p < 0.001$) by race due to the fact that black girls experienced a decline in physical activity levels from ages 9/10 to 18/19 years, which was twice as much as those of white girls. However, by ages 16 and 17 years, 56% of the black and 31% of the white girls were not participating in any physical activities (Kimm *et al*., 2002:714). The level of parental education was inversely associated with a decline in physical activity levels among white adolescents but became less of a factor at an older age. In black girls this relationship was only observed at an older age (Kimm *et al*., 2002:713). Kolle *et al*. (2010:e43) also indicated a significant decline ($p \leq 0.001$) in physical activity levels from the age of 9 years up until the age of 15 years among Norwegian adolescent boys and girls. In this regard Koutedakis and Bouziotas (2003:313) stated that despite the aerobic fitness levels ($p \leq 0.001$) of adolescents that regularly participate in

school physical education programmes being significantly higher than the levels of adolescents that do not regularly participate in such programs, the level of physical activity was not sufficient to achieve adequate aerobic fitness levels

Researchers have also analysed the interaction between race and living area as well as the possible influence of this interaction on participants' physical activity levels. In this regard Felton *et al.* (2002:253) reported that black girls living in a rural setting were physically more active than girls of the same race group living in urban areas. In contrast, white girls living in urban areas were physically more active than their peers in rural areas (Felton *et al*., 2002:253). It therefore seems that black rural-living girls and white urban-living girls would achieve greater aerobic fitness values than their peers in other living areas. However, when researchers controlled for race in their analyses, for both groups of girls, those living in a rural area had higher intentions of being physically active (Felton *et al*., 2002:253). On the other hand, Prista *et al*. (2009:393) reported that both rural and urban-living Mozambican children and adolescents displayed significantly higher ($p \leq 0.001$) physical activity levels than their Portuguese peers.

The above-mentioned findings highlight the influence of demographic factors such as race, gender and living area as well as sport participation and physical activity levels on the aerobic performances and $\dot{V}O_{2max}$ values of children and adolescents. It is also evident that these factors (variables) are not always considered when setting up functions for the prediction of aerobic performance. These findings further emphasise the importance of tailoring $\dot{V}O_{2max}$ prediction models specifically according to the demographics of a certain population.

5. Current $\dot{V}O_{2max}$ prediction models/equations for children and adolescents:

$\dot{V}O_{2max}$ prediction models are based on the fact that various factors influence the aerobic performance or power of participants and that a very delicate, expensive and time-consuming measurement such as $\dot{V}O_{2max}$ can be predicted by using a few measurements (Akalan *et al*., 2008:4). Prediction models are simple and easy to use and therefore necessary to especially

predict the $\dot{V}O_{2max}$ values of children and adolescents (Ruiz *et al*., 2008:234). However, $\dot{V}O_{2max}$ performance is influenced by various factors and cannot only be predicted by using one single component. In this regard Sanada *et al*. (2007:147) highlighted the importance of including both central and peripheral factors in $\dot{V}O_{2max}$ prediction models to improve the prediction power of these models. In the next section the various $\dot{V}O_{2max}$ prediction models provided in literature and presented in Table 1 will be discussed.

Probably the most frequently used $\dot{V}O_{2max}$ prediction model is the original 20-m SRT $\dot{V}O_{2max}$ prediction model of Léger and Lambert (1982) and Léger *et al*. (1988). However, as mentioned before, the accuracy of this prediction model for use in different types of populations has been questioned (Liu *et al*., 1992:632; Mahar *et al*., 2006:S43; Mahoney, 1992:45; Pitetti *et al*., 2002:131). This has led researchers to develop more specific and accurate $\dot{V}O_{2max}$ prediction models for use in a wide variety of populations. For example, Mahar *et al*. (2006:S40) included data from the PACER test together with the body mass and BMI results as well as the gender grouping of 12 to 14-year-old boys and girls to develop a new $\dot{V}O_{2max}$ prediction model. They found that the $\dot{V}O_{2max}$ values predicted by using this new model, delivered higher correlation coefficients for the relationship between the predicted and directly determined $\dot{V}O_{2max}$ values of this age group than the model of Léger *et al*. (1988) (Mahar *et al*., 2006:S45). Ruiz *et al*. (2008:241) also developed a new artificial neural network-based model for the prediction of adolescents' $\dot{V}O_{2max}$ values in view of their finding that the equation of Léger *et al.* (1988) under-predicted the average $\dot{V}O_{2max}$ value of this population by 4.9 ml/kg/min and showed an error of 17.13%. The new model underestimated the average $\dot{V}O_{2max}$ value by only 0.5 ml/kg/min and showed an error of 7.38% (Ruiz *et al*., 2008:241). The primary differences between the last-mentioned model and that of Léger *et al*. (1988) were that the new model also considered participants' gender and instead of using the last level reached during execution of the 20-m SRT, used the 20-m SRT-obtained maximal speed (Ruiz *et al*., 2008:243).

Another $\dot{V}O_{2max}$ prediction model for use on Japanese children and adolescents was developed by Matsuzaka *et al*. (2004:121). This prediction model also included 20-m SRT performance (total number of laps completed as well as maximal running speed of the completed stage), gender, BMI and age as predictors of $\dot{V}O_{2max}$ (Matsuzaka *et al*., 2004:121). These last-mentioned variables were responsible for 80% of the variance in the predicted $\dot{V}O_{2max}$ of the Japanese population (Matsuzaka *et al*., 2004:121). Matsuzaka *et al*. (2004:121) also highlighted the fact that $\dot{V}O_{2max}$ prediction models must be specifically developed for each of the populations targeted for testing when they showed that previous $\dot{V}O_{2max}$ prediction models were inaccurate for use on Japanese children and adolescents. Different body proportions of Japanese children and adolescents, when compared with other populations, may possibly serve as a reason for this finding. The specificity of $\dot{V}O_{2max}$ prediction models were also substantiated by Matthews *et al*. (1999:492) who stated that ethnically diverse populations with different activity and fitness levels will yield different predicted $\dot{V}O_{2max}$ values and therefore need their own prediction models.

The prediction model of Pfeiffer *et al*. (2007:2239) considered race and sport participation level, and the interaction of these variables with physical activity and BMI. They found that these last-mentioned variables were significant contributors ($p \leq 0.01$) to weight-relative $\dot{V}O_{2max}$ performance (Pfeiffer *et al*., 2007:2239). Physical activity, race and sport participation level were identified as significant contributors to absolute cardiorespiratory fitness (Pfeiffer *et al*., 2007:2239). In their model, sport participation level was a significant contributor to $\dot{V}O_{2max}$ for the moderately active girls but not for the vigorous physically active group, where the race and sport participation interaction was significant (Pfeiffer *et al*., 2007:2238). In the weight-relative prediction models, higher $\dot{V}O_{2max}$ values were observed for girls with lower BMI values, higher physical activity levels as well as higher sport participation scores (Pfeiffer *et al*., 2007:2238). For the absolute $\dot{V}O_{2max}$ prediction models, race as well as sport participation level were significant contributors (Pfeiffer *et al*., 2007:2238). The complex interaction between race, physical activity, body composition and

$\dot{V}O_{2max}$ values (Pfeiffer *et al*., 2007:2240) clearly indicated that these variables need to be included in models aimed at predicting the $\dot{V}O_{2max}$ of adolescents.

Although a $\dot{V}O_{2max}$ prediction model for 9 to 15-year-old Icelandic children and adolescents did not include race or sport participation level as possible predictors, gender, age, sum of the skinfolds, HR_{max} and the resting energy expenditure (REE) were considered (Arngrímsson *et al*., 2008:71). However, a better prediction of $\dot{V}O_{2max}$ was obtained by the exclusion of REE, probably due to the fact that REE is highly variable in this age group of participants (Arngrímsson *et al*., 2008:71). Gender contributed significantly ($p \leq 0.01$) to the $\dot{V}O_{2max}$ prediction model as opposed to age as well as sum of the skinfolds which did not ($p > 0.01$). Notwithstanding these findings, their proposed $\dot{V}O_{2max}$ prediction model allows the use of easily measured variables to predict $\dot{V}O_{2max}$ in this population.

In another study Chatterjee and colleagues (2009:119) developed a new and improved model to increase the accuracy of 20-m SRT-obtained $\dot{V}O_{2max}$ results of 14 to 16-year-old football players from Nepal. Their improved model included the participants' 20-m SRT maximal running speed as possible predictors of $\dot{V}O_{2max}$ (Chatterjee *et al*., 2009:119). An earlier model by Tong *et al*. (2001:321) also included maximal running treadmill speed of a direct $\dot{V}O_{2max}$ assessment in their prediction model but due to the small participant group (n = 14) of adolescent boys (ages 16 to 18 years), the use of the model is limited. The $\dot{V}O_{2max}$ prediction model of Goran *et al*. (2000:843) also has limited use as half of their study participants were obese children (8.9 ± 1.2 years). Despite this shortcoming their proposed model highlighted the influence of fat-free mass on the prediction of $\dot{V}O_{2max}$ (Goran *et al*., 2000:844).

Overall, the above-mentioned research findings would suggest that a wide range of variables need to be included to increase the accuracy of $\dot{V}O_{2max}$ prediction models for children and adolescents.

Examples of variables that have been included in new prediction models, are participants' PACER test results, the 20-m SRT-obtained maximal speed, body and fat-free mass, BMI, gender, race, sport participation and physical activity level. However, various studies have also identified the following variables for possible inclusion as predictors in $\dot{V}O_{2max}$ prediction models: fat percentage (Ara *et al*., 2007; Ekelund *et al*., 2001; McMurray *et al*., 2002; Mota *et al*., 2002; Rowland *et al*., 1999:848; Rowlands *et al*., 1999; Sveinsson *et al*., 2009:144; Trowbridge *et al*., 1997:E811), BMI (Cairney *et al*., 2008; Dumith *et al*., 2010; Mahar *et al*., 2006; Matsuzaka *et al*., 2004; Pfeiffer *et al*., 2007; Sveinsson *et al*., 2009:144); body weight (Goran *et al*., 2000; Jones *et al*., 2000; Machado-Rodrigues *et al*., 2011; Mahar *et al*., 2006; Mota *et al*., 2002; Ruiz *et al*., 2008); body stature (Geithner *et al*., 2004; Jones *et al*., 2000; Mota *et al*., 2002; Ruiz *et al*., 2008); maturity status (Dumith *et al*., 2010; Geithner *et al*., 2004; Harris & Cale, 2006; Hilland *et al*., 2011; Jones *et al*., 2000; Mota *et al*., 2002); maximal aerobic velocity/maximal running speed (Chatterjee *et al*., 2009; Malison *et al*., 2003; Ruiz *et al*., 2008:243; Tong *et al*., 2001:321); age (Cairney *et al*., 2008; Chatterjee *et al*., 2009; Matsuzaka *et al*., 2004; McMurray *et al*., 2002; Pearson *et al*., 2006; Pivarnik *et al*., 1998; Rowland *et al*., 1997; Ruiz *et al*., 2008; Sandercock *et al*., 2008; Sveinsson *et al*., 2009:144-146); gender (Adegboye *et al*., 2011; Arngrímsson *et al*., 2008; Chillón *et al*., 2011; Dumith *et al*., 2010; Ekelund *et al*., 2001; Geithner *et al*., 2004; Machado-Rodrigues *et al*., 2011; Mahar *et al*., 2006; Matsuzaka *et al*., 2004; McMurray *et al*., 2002; Rowland *et al*., 1997; Rowland *et al*., 2000; Ruiz *et al*., 2008; Sandercock *et al*., 2008); fat-free mass (Goran *et al*., 2000; McMurray *et al*., 2002); half stages of the 20-m SRT (Ruiz *et al*., 2008); 20-m SRT shuttles completed (Mahar *et al*., 2006); physical activity (Hilland *et al*., 2011; Huotari *et al*., 2010:745; Machado-Rodrigues *et al*., 2011; Mahar *et al*., 2006; Pfeiffer *et al*., 2007; Rowlands *et al*., 1999); sport participation level (Chillón *et al*., 2011; Huotari *et al*., 2010:745; Pfeiffer *et al*., 2007); ethnicity/race (Chillón *et al*., 2011; McMurray *et al*., 2002; Pfeiffer *et al*., 2007; Pivarnik *et al*., 1998) and living area (Chillón *et al*., 2010; Machado-Rodrigues *et al*., 2011; Tambalis *et al*., 2011).

6. Conclusion:

The influence of various anthropometric, physical and motor performance components as well as certain demographic factors, sport and physical activity participation levels has prompted researchers to develop prediction models or functions which incorporate the mentioned components in order to estimate participants' $\dot{V}O_{2max}$ values, especially when direct testing is not

a viable option. In view of these facts, the literature review was aimed at firstly naming and describing the various direct and indirect methods as well as the reliability and validity of the methods cited in the scientific literature and used to determine $\dot{V}O_{2max}$. Secondly, an attempt was made to review the findings with regard to the aerobic performances or $\dot{V}O_{2max}$ values of children and adolescents. This led to a discussion on the possible influence of various anthropometric, physical and motor performance components as well as certain demographic factors (living area, race and gender), sport and physical activity participation level on the aerobic performances or $\dot{V}O_{2max}$ values of children and adolescents. Lastly, the review concluded with a discussion of all literature-identified models for the prediction of aerobic performances or $\dot{V}O_{2max}$ values in children and adolescents.

The direct determination of $\dot{V}O_{2max}$ by using open circuit spirometry is regarded as the gold standard for determining $\dot{V}O_{2max}$ values, but due to various constraints, a number of indirect testing methods have been developed. The indirect testing methods are less expensive, do not require specialized equipment and qualified personnel and can also be used to test a large number of participants outside a laboratory setting. Direct and indirect testing is done by using various testing protocols to determine the $\dot{V}O_{2max}$ values of children, adolescents and adults. The protocols include running or walking on a treadmill, submaximal or maximal cycling on an ergometer, bench stepping as well as various field-testing protocols. Correlations of r = 0.81 – 0.99 and SEE = 0.08 – 1.9 ml/kg/min have been reported for the test-retest reliability of the direct testing protocols in adult populations. The indirect testing methods make use of regression equations or prediction models from which the participants' $\dot{V}O_{2max}$ values are predicted. Reliability coefficients for the various models of R = 0.53 – 0.96 with SEE = 0.3 – 4.85 ml/kg/min have been reported for adolescent and adult populations. Very few researchers have reported on the reliability of both direct and indirect $\dot{V}O_{2max}$-testing methods of children and adolescents.

Due to the practicality of indirect testing methods, a huge amount of research is devoted to finding

the best and most accurate way of predicting $\dot{V}O_{2max}$ values with the most attention focused on the 20-m SRT as it the most widely used test for children, adolescent and adult populations. Correlations for the relationship between the 20-m SRT-predicted and directly determined $\dot{V}O_{2max}$ values range between r = 0.68 and r = 0.96 ($p < 0.001 – 0.05$) for adults and r = 0.75 to 0.75 ($p < 0.001$) for children. Despite the rather high and significant correlation values, some researcher found that the 20-m SRT significantly under-predicted $\dot{V}O_{2max}$ values of adolescents and adults. Researchers have therefore investigated the possibility of improving the prediction ability of the 20-m SRT by also including other $\dot{V}O_{2max}$ -contributing factors in the original prediction model.

The aerobic performances of children and adolescents vary to a large degree, mostly as a result of growth and maturation as is evident from either decreasing or increasing $\dot{V}O_{2max}$ values from childhood into late adolescence. The highest $\dot{V}O_{2max}$ results were reported for 12 to 14-year-old cross-country runners (61.7 ± 4.4 ml/kg/min), 9 to 19-year-old competitive distance runners (51.8 ± 6.4 - 67.8 ± 5.6 ml/kg/min), 13 to 15-year-old adolescent soccer players (65.3 ± 5.0 – 70.7 ± 4.3 ml/kg/min) and 14 to 18-year-old internationally ranked tennis players (58.9 ± 5.3 – 63.8 ± 5.7 ml/kg/min). The next best $\dot{V}O_{2max}$ values observed were for moderate to vigorously active 9-year-old children that achieved values of between 36.7 ± 5.3 and 42.3 ± 6.9 ml/kg/min and for 15-year-old adolescents that achieved values of between 40.2 ± 5.9 and 51.0 ± 6.7 ml/kg/min. The lowest $\dot{V}O_{2max}$ results were reported for obese children and adolescents (17.4 ± 3.6 – 32.0 ± 4.1 ml/kg/min).

Gender was also identified as a factor that may influence the $\dot{V}O_{2max}$ values of participants, with children and adolescent boys (41.3 ± 7.9 – 56.0 ± 5.0 ml/kg/min) that generally achieve much higher $\dot{V}O_{2max}$ values (22.11 ± 4.14 - 52.4 ± 8.2 ml/kg/min) than girls of the same age group.

Most researchers also agree that a participant's anthropometric profile is probably one of the aspects that influence aerobic performance most. In this regard body fat percentage, BMI, fat-

free and muscle mass, body stature and weight are some of the primary identified anthropometric components that influence not only the aerobic performance of children and adolescents, but also that of adult populations. Although research has mostly focused on the influence of anthropometric-related variables on participants' $\dot{V}O_{2max}$ values, physical and motor performance components have also been identified as contributors to participants' $\dot{V}O_{2max}$ values. In this regard researchers identified the following physical and motor performance components as $\dot{V}O_{2max}$ -influencing factors for adolescents and adults: 40, 50 and 300 m sprinting time, VJ height, CMJ height, VJ power, plyometric leap distance, knee flexor/extensor strength and lower body flexibility. However, the majority of the literature focused on adult populations when the last-mentioned theme was investigated.

From literature it is also clear that demographic and other factors also influence participants' aerobic performance and include, but are not limited to, participants' race, living area and sport participation or physical activity level. The majority of research suggests that rural-living non-Caucasian children and adolescents tend to outperform their Caucasian, urban-living peers with regard to aerobic performance. However, some researchers' findings were dissimilar, since it was reported that safety concerns, as well as availability of facilities in rural environments have led to children and adolescents not participating in sport or physical activities. Participants' race and living area also affect their sport participation and physical activity level. In this regard the majority of researchers reported that children and adolescents that did not participate in sport or were physical active displayed significantly lower $\dot{V}O_{2max}$ values than their sport participating and physically active peers.

Several researchers set out to develop new $\dot{V}O_{2max}$ prediction models for use in children and adolescents in view of the inaccuracy of the most frequently used and older prediction models. The new models also included variables such as the participants' PACER test results, the 20-m SRT-obtained maximal speed, body and fat-free mass, BMI, gender, race, sport participation and physical activity level. These newly developed $\dot{V}O_{2max}$ prediction models were shown to be more accurate than the older models and accentuated the fact that the above-mentioned variables need

to be included in models aimed at predicting the $\dot{V}O_{2max}$ of children and adolescents. The importance of developing specific $\dot{V}O_{2max}$ prediction models for each of the populations targeted for testing was also highlighted when researchers showed that previous $\dot{V}O_{2max}$ prediction models were inaccurate for use in certain populations of children and adolescents. However, the review of literature also showed that the current available $\dot{V}O_{2max}$ prediction models are all different with regard to the predictors included and the participants from which the models were developed. These differences between models may prevent researchers and sport practitioners alike from applying the models on their populations and from obtaining accurate indirect, predicted $\dot{V}O_{2max}$ values.

Therefore, to conclude, the literature presently contains a rather large amount of data concerning the influence of various factors on the aerobic performance or $\dot{V}O_{2max}$ values of especially adults, but insufficient data with regard to the influence of different factors on the $\dot{V}O_{2max}$ of children and adolescents. Also, up until now, only a few researchers have attempted to develop $\dot{V}O_{2max}$ prediction models specific to children and adolescents. However, the validity of these models for use on other populations of children and adolescents over and above the population for which it was originally developed is unclear. The use of simple and affordable anthropometric measurements, physical and motor performance tests as well as easily obtainable information for the development of accurate and valid $\dot{V}O_{2max}$ prediction models will enable less qualified and less fortunate practitioners to determine the $\dot{V}O_{2max}$ values of children and adolescents in especially rural areas. Hence there is an urgent need for scientists to do high-quality studies and to develop $\dot{V}O_{2max}$ prediction models for specific use among children and adolescents of different races and genders while also considering various anthropometric, physical and motor performance components.

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CHAPTER 3

3 THE USE OF ANTHROPOMETRIC MEASUREMENTS AND THE INFLUENCE OF DEMOGRAPHIC FACTORS ON THE PREDICTION OF VO_{2MAX} IN A COHORT OF ADOLESCENTS: THE PAHL STUDY

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Disclaimer

6. References

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The use of anthropometric measurements and the influence of demographic factors on the prediction of $\dot{V}O_{2max}$ in a cohort of adolescents: The PAHL study

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$\dot{V}O_{2max}$ prediction models have only focussed on children and adolescents' from other parts of the world than South Africa and have not included demographic factors such as the gender, race, and living area as well as sport participation level of the adolescents as possible predictors. Therefore the purpose of this study was to determine whether a valid $\dot{V}O_{2max}$ prediction function can be developed from several anthropometric measurements and demographic factors such as gender, race and living area as well as sport participation level of a cohort of adolescents living in the Tlokwe Local Municipality of North West Province, South Africa. A total of 214 adolescent boys (n = 88) and girls (n = 126) (15.82 ± 0.68 years) were purposefully selected from pre-requested class lists from six secondary schools. Data was collected by means of various questionnaires, anthropometric measurements as well as the 20-m Shuttle Run Test (SRT). The forward stepwise regression analysis showed that muscle mass percentage, sport participation level, stature, hip circumference and ectomorphy acted as significant predictors ($p \leq 0.05$) of the indirect, 20-m SRT $\dot{V}O_{2max}$ values of a cohort of adolescents. Furthermore, it was found that 70% of the variance in the indirect, 20-m SRT $\dot{V}O_{2max}$ values could be explained by making use of this model. A cross-validation further revealed that the model is a valid for predicting the 20-m SRT-derived indirect $\dot{V}O_{2max}$ values of this cohort of adolescents. The model developed through this study is aimed at South African adolescents from different racial backgrounds, living areas and gender groups and may allow practitioners in the field of Human Movement Science to more accurately screen the indirect $\dot{V}O_{2max}$ values of this population.

Keywords: Youth, exercise, body composition, aerobic, fitness, regression equation

1. Introduction

Research suggests that body composition or the anthropometry of a person is positively related to the following cardiorespiratory and cardiovascular responses: ventilation rate, oxygen consumption ($\dot{V}O_2$), heart rate and the ventilatory equivalents for $\dot{V}O_2$ and carbon dioxide ($\dot{V}CO_2$) during peak exercise (Bolonchuk, Siders, Lykken, & Lukasi, 2009). Chaouachi, Chaouachi, Chamari, Chtara, Feki, Amri, and Trudeau (2005) also emphasized the influence of anthropometry on gains in aerobic capacity, particularly with regard to $\dot{V}O_{2max}$, relative $\dot{V}O_{2max}$ and relative $\dot{V}O_2$ at the ventilatory threshold level, when athletes are subjected to an aerobic training program of more or less 12 weeks.

Additionally, researchers agree that a taller and leaner body build is more ideal for the attainment of aerobic or endurance performances (Ackland, & De Ridder, 2009). In contrast, excess body fat and adiposity are detrimental to aerobic or endurance performances (Ara, Moreno, Leiva, Gutin, & Casajús, 2007; Ortega, Ruiz, Hurtig-Wenlöf, Vicente-Rodriguez, Castillo, & Sjöström, 2010). Conversely, Ekelund, Poortvliet, Nilsson, Yngve, Holmbertg, and Sjöström (2001) reported a significant negative correlation between the $\dot{V}O_{2max}$ values and fat percentage of adolescent boys and girls (14-15 years) (r = -0.43 to -0.48; $p \leq$ 0.001-0.004). These researchers and others also concluded that fat percentage accounted for 10-31% of the variation in $\dot{V}O_{2max}$ between adolescents (Ekelund et al., 2001; Mota, Guerra, Leandro, Pinto, Ribeiro & Duarte, 2002; Rowlands, Eston, & Ingledew, 1999). Low levels of adiposity benefit weight-bearing activities due to a decrease in energy demand caused by the lower mass of metabolic inactive body tissue that needs to be displaced (Ara et al., 2007; Huotari, Nupponen, Laakso, & Kujala, 2010; Nevill, Tsiotra, Tsimeas, & Koutedakis, 2009). Muscle mass is another anthropometric-related variable that may influence the $\dot{V}O_{2max}$ values of adolescents due to the strong significant correlation (r = 0.87, $p \leq$ 0.001) that exists between the muscle mass and $\dot{V}O_{2max}$ values of pre-pubertal children (Goran, Fields, Hunter, Herd, & Weinsier, 2000).

$\dot{V}O_{2max}$ can either be measured in the laboratory or through field tests (Buono et al., 1991). The

20-m Multistage Shuttle Run Test (20-m SRT) is the most widely used test among sport scientists, coaches and teachers for the prediction of $\dot{V}O_{2max}$ values (Aziz, Chia, & Teh, 2005; Cooper, Baker, Tong, Roberts, & Hanford, 2005). Although this field test is practical, valid and reliable to predict the $\dot{V}O_{2max}$ values of groups of adults and athletes (Aziz et al., 2005; Cooper et al., 2005), research with regard to children and adolescents (8 to 17-year-old) suggests that significant and non-significant correlations of between r = 0.77 to 0.87 ($p \leq 0.001$) and r = 0.72 ($p > 0.05$), respectively exist between the direct measured $\dot{V}O_{2peak}$ and the estimated, predicted $\dot{V}O_{2max}$ values of the 20-m SRT (Liu, Plowman, & Looney, 1992; Matsuzaka, Takahashi, Yamazoe, Kumakura, Ikeda, Wilk, & Bar-Or, 2004). According to Mahar, Welk, Rowe, Crotts, and McIver (2006), the accuracy of the original Léger and Lambert (1982) equation for the prediction of 12 to 14-year-old healthy adolescents' 20-m SRT $\dot{V}O_{2max}$ values can be improved by adding body mass index (BMI) and body mass values to the regression equation. Similarly, the inclusion of body mass and demographic factors such as gender and age will also improve the accuracy of the previously mentioned prediction model for 9 to 15-year-old children and adolescents (Arngrímsson, Sveinsson, & Jóhannson, 2008).

The possible influence of other demographic factors, such as race, sport participation level and area of living on the aerobic capacity of adolescents has also been investigated by various researchers (Pfeiffer, Dowda, Dishman, Sirard, & Pate, 2007; Pivarnik, Taylor, & Cummings, 1998). With respect to race, most researchers agree that African American children and adolescents (5-16 years) in general obtain significant lower aerobic performance scores and greater sum of skinfold values than their Caucasian counterparts (McMurray, Harrell, Bradley, Deng, & Bangdiwala, 2002; Pivarnik et al., 1998). The interaction of race and living areas led Felton, Dowda, Ward, Dishman, Trost, Saunders, and Pate (2002) to conclude that non-Caucasian 12 to14-year-old girls living in rural settings were physically more active than those living in urban areas, whereas among Caucasian girls, those in urban areas were physically more active than their peers in rural areas (Felton et al., 2002). These results together, with other research suggest that rural living promotes physical activity and is associated with higher aerobic capacities among adolescents (Felton et al., 2002; Machado-Rodrigues, Coelho-e-Silva, Mota, Cumming, Riddoch, & Malina, 2011). This relationship seems to diminish in participants that live in areas where safety is of concern (Felton et al., 2002) or, as South African studies have shown, where adequate facilities

and equipment are not available (McHunu & Le Roux, 2010; Vandendriessche, Vandorpe, Vaeyens, Malina, Lefevre, Lenoir, & Phillippaerts, 2012).

Significantly higher aerobic capacity values were observed for sport-participating children and adolescents (11-15 years) (basketball and handball players) than those that only participated in physical education classes (Vamvakoudis, Vrabas, Galazoulas, Stefanidis, Metaxas, & Mandroukas, 2007; Vicente-Rodriguez, Dorado, Perez-Gomez, Gonzales-Henriquez, & Calbet, 2004).

The above-mentioned results suggest that anthropometric characteristics as well as demographic factors such as gender, race and living area as well as sport participation level should be considered when predicting adolescents' aerobic performance or $\dot{V}O_{2max}$ values. The development of a $\dot{V}O_{2max}$ prediction function of this nature will possibly allow practitioners in the field of Human Movement Science to use an inexpensive, practical and accurate indirect method for determining the $\dot{V}O_{2max}$ values of adolescents. This will especially be of value in cases where adolescents live in rural areas and are part of large epidemiological field studies where $\dot{V}O_{2max}$ values are screened. Also, to date no attempt has been made to develop such an anthropometric-related model for the prediction of South African adolescents' $\dot{V}O_{2max}$ values. Hence the purpose of this study was to determine whether a valid $\dot{V}O_{2max}$ prediction function can be developed from several anthropometric measurements and demographic factors such as gender, race and living area as well as sport participation level of a cohort of adolescents in the Tlokwe Local Municipality, North West Province in South Africa.

2. Methods

2.1 Research design

The participants of this research study formed part of a larger longitudinal study, The Physical Activity and Health Longitudinal Study (PAHLS), which is an observational multidisciplinary study. The study started in 2010 and will be continued until 2014 (Monyeki, Neetens, Moss, & Twisk, 2012). For purposes of the current study a cross-sectional experimental research design was implemented in which the data from the 2012 sample was used. The study was approved by the

Ethics Committee of the North-West University (NWU-0058-01-A1) and by the District Director of the Department of Basic Education in the Tlokwe Local Municipality.

2.2 Participants

A total of 214 grade 10 adolescents of high schools in the Tlokwe Local Municipality (Potchefstroom area) of North West Province in South Africa were purposefully selected in 2010 from pre-acquired class lists, from six secondary schools. Two of the selected schools were in the Potchefstroom City area, which comprised learners living in urban areas and four schools in the Ikageng Township area, which predominantly comprised learners living in rural areas. Only learners in grade 10 at the time of measurement (2012) were eligible for participation in the study. Prior to the start of the study, all participants were informed of the nature of the study, and all potential risks and benefits were explained to them. Informed consent for the investigation was requested from the school authorities, the parents and the learners of the participating schools during the weeks prior to the testing period.

2.3 Questionnaires

A questionnaire in which learners had to provide information with regard to the following was also administered during the testing period:

Information with regard to demographic or general aspects: The school of attendance; The grade in which the learner was at the time of testing; The name of the learner; The address of the learner; The ethnic group within which the learner falls.

Information with regard to sport and training habits: An indication of the learner's participation in sport

Information with regard to maturation: For girls only: Menarche age; For boys only: Age at which the voice broke

2.4 Maturity age

Maturity age was estimated by using the anthropometric measures of body stature, sitting height and body mass together with the variables of gender, date of birth and date of measurement in order to calculate peak height velocity (PHV) age. Maturity age was calculated by subtracting age at PHV from chronological age at the time of measurement (Thompson, Baxter-Jones, Mirwald, & Bailey, 2002). In cases where the age at PHV was the same as the chronological age, maturity age

was categorised as being 0 (Thompson et al., 2002). In cases where chronological age was higher than the age at PHV, maturity age was regarded as positive whereas negative results were an indication that the age at PHV was higher than chronological age (Thompson et al., 2002). Information with regard to the menarche age of the girls and the age at which the boys' voice broke, was also used to verify the maturation age of each of the genders. Although not the direct aim of this study, the maturity age of the adolescents was considered in order to verify certain trends with regard to their anthropometric and aerobic profile. Cultural beliefs and practices prevented the researchers of this study from using the Tanner stages (Faulkner, 1996) for determining the maturation age of each of the adolescents.

2.5 Anthropometric measurements

Anthropometric measurements were taken according to the protocols of The International Society for the Advancement of Kinanthropometry (ISAK) (Stewart, Marfell-Jones, Olds, & De Ridder, 2011) and included the following: body mass to the nearest 0.1 kg with a portable electronic scale (Beurer Ps07 Electronic Scale, Ulm, Germany) and stature to the nearest 0.1 cm with a Harpenden portable stadiometer (Holtain Limited, U.K.); skinfolds of the biceps-, triceps-, subscapular-, supraspinal-, abdominal-, frontal thigh- and medial calf skinfolds to the nearest 0.2 mm with a Harpenden skinfold calliper with a constant pressure of $10g/mm^2$ (Holtain Limited, U.K.); breadths of the humerus, wrist, femur and ankle to the nearest 0.1 cm with a Holtain Bicondylar calliper (Holtain Limited U.K.); girths of the relaxed and flexed arm, waist, gluteal and mid-thigh to the nearest 0.1 cm with a Lufkin metal tape (Cooper Industries, U.S.A.) and length measurements of the upper and lower arm as well as those of the hand and foot to the nearest 0.1 cm with a Rosscraft segmometer (Rosscraft Innovations Incorporated, Canada). All anthropometric measurements were taken twice by Level 2 ISAK certified anthropometrists at the right side of the body. The technical error of measurement (TEM) was calculated by applying the formula of Pederson and Gore (1996) and values of 1.27% (1.24 mm) were revealed for all skinfold measurements, 2.08% (0.56 cm) for all breadth measurements, 0.11% (0.38 cm) for all girth measurements and 1.23% (0.79 cm) for all length measurements.

Arm, mid-thigh and calf girth were corrected for the different skinfolds at these sites by applying the following formula: Corrected girth = Girth – (π x skin fold thickness). According to Martin, Spenst, Drinkwater, and Clarys (1990), corrected girths provide better indicators of musculoskeletal size at each site.

The different anthropometric measurements were used to calculate percentage body fat according to the equations of Lohman, Caballero, Himes, Davis, Stewart, Houtkaper, Going, Hunsberger, Weber, Reid, and Stephenson (2000) as well as Slaughter, Lohman, Boileau, Harswill, Stillman, Van Loan, and Bemben (1998). Muscle mass was calculated by applying the formula of Poortmans, Boisseau, Moraine, Moreno-Reyes, and Goldman (2005) and somatotype by applying the formulas of Carter and Heath (1990). BMI was calculated as body mass/stature² (kg/m²).

2.6 20-m Shuttle Run Test (20-m SRT)

The 20-m Shuttle Run Test (20-m SRT) was conducted to determine the indirect aerobic performance of the participants. On their arrival, the test procedure was clearly explained to each participant and a Fix Polar Heart Rate Transmitter Belt (Polar Electro, Kempele, Finland) was strapped to the chest of each participant before commencement of the test. The participants' heart rates were measured with the use of a Polar Team² Pro Electro system (Kempele, Finland) and were recorded on a laptop computer with the Polar Team² Pro software program. This test was conducted according to the procedures described by the Australian Sports Commission (1998). The participants were verbally encouraged to perform maximally during each assessment and had to run the test barefoot. Before the start of the 20-m SRT the participants were firstly subjected to a thorough warm-up of more or less 15 minutes that consisted of aerobic running exercises for more or less 8 minutes after which a specific warm-up period of shorter, high intensity movements and dynamic stretches followed.

2.7 Data analysis

The software package Statistica 11 for Windows (StatSoft, 2013) was used for the analyses of all data. The descriptive statistics of each test variable for all the adolescents were firstly calculated and this was followed by independent *t*-tests to reveal significant differences between the variables for each group of participants. Secondly, a cluster analysis of the different variables used to detect clusters of measures that appear to tap similar abilities was determined. This was followed by the dichotomisation of gender, sport participation level, areas of living (rural or urban) and race into different categories by making use of numerical values of 0 and 1. The cluster analysis' reduced variables as well as the different dichotomised variables were then entered into the forward stepwise multiple regression analysis to determine their contribution to the prediction of the adolescents' indirect $\dot{V}O_{2max}$ values. The level of significance was set at $p \leq 0.05$. In order to

validate the stepwise multiple regression analyses-derived prediction functions, a cross-validation was performed by separately performing stepwise multiple regression analyses on a random selection of 25% and 75% of the original sample, respectively. The squares of each of the regression analysis' correlation coefficients were then inserted into a formula to determine Cohen's effect size value. The effect size values were then interpreted as follow: a value of 0.1 as small, 0.3 as medium and a value of 0.5 as large (Cohen, 1988). Small to medium effect size values would be an indication that the stepwise multiple regression analysis-identified prediction function is a valid function for the prediction of adolescents' $\dot{V}O_{2max}$ values.

3. Results

The descriptive statistics of the chronological and maturity age, aerobic performance as well as the various anthropometric-related variables of the various groups of adolescents are presented in Tables 1 to 6. The results in Table 1 show that no statistical differences existed with regard to chronological and maturity age-related variables between the different groups of adolescents. However, significant differences ($p \leq 0.05$) were observed for the indirect $\dot{V}O_{2max}$ values between gender groups (boys higher values than girls), racial groups (Caucasian group higher values than non-Caucasian) as well as non-sport participants and sport participants (sport participants higher values than non-sport participants).

Furthermore, results in Table 2 indicate that sport participants displayed significantly lower values in all of the fat-related variables (13 out of a possible 13) than the non-sport participants. Similarly, adolescents living in rural areas showed significantly lower values in their fat-related variables (9 out of a possible 13) than those living in urban areas. Only 10 of the fat-related variables displayed significantly lower values for the boys than for the girls. In contrast, for the sport participants as well as for the boys, significantly higher muscle-related variables (2 out of a possible 3) were observed than for the non-sport participants and for the girls. With regard to the breadth- and girth measurements (Tables 4 and 5) significantly lower values were seen for the non-Caucasian than for the Caucasian group, as well as for those living in rural areas, than for the urban-living group in the majority of measurements (11 out of a possible 14). All the length-related measurements (Table 6) displayed significantly lower values for the girls, non-Caucasians and adolescents living in rural areas than for the adolescents in each of the other groups. However, all

the length measurements, except one, obtain significantly lower values for the non-sport participants than for the sport participants.

Table 1.

Descriptive statistics (mean ± SD), statistical significance of the differences in the chronological, maturity age and aerobic performance-related variables of the various groups of adolescents.

Variables	Total group (*n* = 214)	Gender groups		Racial groups		Sport participation level		Area of living	
		Boys (*n* = 88)	Girls (*n* = 126)	Caucasian (*n* = 59)	Non-Caucasian (*n* = 155)	Sport participants (*n* = 160)	Non-sport participants (*n* = 54)	Urban (*n* = 64)	Rural (*n* = 150)
Age (yr)	15.82 ± 0.68	15.84 ± 0.63	15.81 ± 0.71	15.70 ± 0.58	15.87 ± 0.71	15.86 ± 0.70	15.71 ± 0.59	15.69 ± 0.58	15.87 ± 0.71
PHV (yr)	14.22 ± 0.69	14.19 ± 0.72	14.23 ± 0.67	14.21 ± 0.59	14.22 ± 0.72	14.28 ± 0.67	14.02 ± 0.72	14.17 ± 0.57	14.24 ± 0.74
Maturity age (yr)	1.78 ± 0.42	1.77 ± 0.43	1.79 ± 0.41	1.78 ± 0.43	1.79 ± 0.41	1.80 ± 0.41	1.72 ± 0.45	1.78 ± 0.43	1.78 ± 0.41
$\dot{V}O_{2max}$ ($ml/kg/min^{-1}$)	34.54 ± 8.23	42.01 ± 5.62	29.38 ± 5.28*	37.37 ± 6.94	33.47 ± 8.44*	37.20 ± 7.27	26.66 ± 5.36*	35.92 ± 7.28	33.96 ± 8.55

years (yr), Peak Height Velocity (PHV)

* $p \leq 0.05$

Table 2

Descriptive statistics (mean ± SD), statistical significance of the differences for the body mass, stature and body composition-related variables of the various groups of adolescents.

Variables	Total group	Gender groups		Racial groups		Sport participation level		Area of living	
	(*n* = 214)	Boys (*n* = 88)	Girls (*n* = 126)	Caucasian (*n* = 59)	Non-Caucasian (*n* = 155)	Sport participants (*n* = 160)	Non-sport participants (*n* = 54)	Urban (*n* = 64)	Rural (*n* = 150)
Stature (cm)	163.70 ± 8.70	169.08 ± 8.87	159.85 ± 6.12*	170.52 ± 9.60	161.10 ± 6.72*	164.93 ± 8.94	160.04 ± 9.77*	169.41 ± 9.91	161.26 ±6.82*
Body mass (kg)	57.18 ± 14.16	59.34 ± 15.00	55.36 ± 12.89*	66.83 ± 17.04	53.51 ± 10.90*	55.50 ± 12.39	62.18 ± 17.65*	66.77 ± 16.40	53.09 ± 10.80*
BMI (kg/m^{-2})	21.23 ± 4.42	20.56 ± 4.06	21.61 ± 4.55	22.83 ± 4.89	20.62 ± 4.07*	20.23 ± 3.10	24.19 ± 6.12*	23.13 ± 4.68	20.42 4.05*
Fat mass (%)	20.12 ± 9.50	12.67 ± 7.03	25.18 ± 7.36*	20.58 ± 9.27	19.95 ± 9.60	17.12 ± 7.46	29.06 ± 9.31*	22.29 ± 8.86	19.20 ± 9.63*
Fat mass (kg)	12.16 ± 8.38	8.34 ±7.53	14.65 ± 7.82*	14.56 ± 9.84	11.25 ± 7.58*	9.79 ± 5.75	19.18 ± 10.76*	15.44 ± 9.35	10.76 ± 7.54*
Muscle mass (%)	34.01 ± 5.63	39.76 ± 3.13	30.05 ± 2.91*	34.99 ± 5.15	33.64 ± 5.77	35.44 ± 5.36	29.80 ± 4.13*	33.70 5.22±	34.15 ± 5.81
Muscle mass (kg)	19.34 ± 5.25	23.29 ± 4.51	16.51 ± 3.56*	23.19 ± 5.84	17.88 ± 4.17*	19.70 ± 5.38	18.27 ± 4.72	22.51 ± 6.18	17.99 ± 4.13*
Endomorphy	3.67 ± 1.86	2.42 ± 1.41	4.51 ± 1.63	3.69 ± 1.91	3.66 ± 1.84	3.07 ± 1.38	5.45 ± 1.94*	4.02 ± 1.87	3.52 ± 1.83
Mesomorphy	3.82 ± 1.76	4.01 ± 1.41	3.65 ± 1.93	4.58 ± 2.04	3.52 ± 1.55*	3.64 ± 1.66	4.33 ± 1.95*	4.52 ± 1.99	3.51 ± 1.56*
Ectomorphy	2.99 ± 1.58	3.54 ± 1.43	2.62 ± 1.56*	2.71 ± 1.44	3.09 ± 1.61	3.34 ± 1.35	1.93 ± 1.73*	2.49 ± 1.38	3.20 ± 1.61*

Body Mass Index (BMI)

* $p \leq 0.05$

Table 3

Descriptive statistics (mean ± SD), statistical significance of the differences for the skinfold-related variables of the various groups of adolescents.

Variables	Total group	Gender groups		Racial groups		Sport participation level		Area of living	
	(*n* = 214)	Boys (*n* = 88)	Girls (*n* = 126)	Caucasian (*n* = 59)	Non-Caucasian (*n* = 155)	Sport participants (*n* = 160)	Non-sport participants (*n* = 54)	Urban (*n* = 64)	Rural (*n* = 150)
Biceps SF (cm)	7.35 ± 4.37	4.29 ± 2.09	9.44 ± 4.30*	7.26 ± 4.23	7.39 ± 4.35	5.97 ± 3.00	11.46 ± 5.16*	8.32 ± 4.88	6.94 ± 4.07*
Triceps SF (cm)	13.41 ± 6.60	8.73 ± 4.93	16.58 ± 5.63*	13.90 ± 6.96	13.22 ± 6.48	11.39 ± 5.06	19.41 ± 7.04*	15.08 ± 6.66	12.70 ± 6.47*
Subscapular SF (mm)	11.74 ± 7.47	8.64 ± 5.01	13.79 ± 8.13*	11.67 ± 6.89	11.76 ± 7.70	9.62 ± 5.37	17.99 ± 9.18*	12.46 ± 6.90	11.43 ± 7.70
Supraspinal SF (mm)	10.92 ± 7.30	7.87 ± 6.40	12.94 ± 7.13*	12.45 ± 8.27	10.34 ± 6.83	8.74 ± 4.71	17.39 ± 9.50*	13.37 ± 8.05	9.88 ± 6.71*
Abdominal SF (mm)	17.01 ± 9.24	11.93 ± 7.57	20.39 ± 8.63*	18.84 ± 9.71	16.32 ± 8.99	14.27 ± 7.07	25.14 ± 10.16*	19.93 ± 9.18	15.77 ± 9.01*
Front thigh SF (mm)	22.04 ± 11.72	13.37 ± 7.51	27.95 ± 10.35*	21.03 ± 11.10	22.42 ± 11.96	18.33 ± 8.69	33.03 ± 12.67*	23.46 ± 11.27	21.43 ± 11.89
Medial calf SF (mm)	15.10 ± 7.66	9.90 ± 5.12	18.59 ± 7.04*	14.45 ± 7.31	15.35 ± 7.80	12.83 ± 5.68	21.82 ± 8.79*	15.93 ± 7.56	14.74 ± 7.70
Sum of 7 SF (mm)	97.35 ± 49.76	64.74 ± 36.67	119.31 ± 45.04*	99.61 ± 54.47	96.49 ± 49.24	80.85 ± 34.02	146.24 ± 56.78*	108.56 ± 50.55	92.58 ± 48.82*

Skinfold (SF)

* $p \leq 0.05$

Table 4

Descriptive statistics (mean ± SD), statistical significance of the differences for the breadth-related variables of the various groups of adolescents.

Variables	Total group	Gender groups		Racial groups		Sport participation level		Area of living	
	(*n* = 214)	Boys (*n* = 88)	Girls (*n* = 126)	Caucasian (*n* = 59)	Non-Caucasian (*n* = 155)	Sport participants (*n* = 160)	Non-sport participants (*n* = 54)	Urban (*n* = 64)	Rural (*n* = 150)
Humerus breadth (mm)	6.20 ± 0.60	6.69 ± 0.47	5.85 ± 0.38*	6.65 ± 0.60	6.03 ± 0.51*	6.29 ± 0.61	5.93 ± 0.45*	6.54 ± 0.65	6.06 ± 0.51*
Wrist breadth (mm)	5.16 ± 2.00	5.58 ± 3.05	4.87 ± 0.50*	5.74 ± 3.70	4.94 ± 0.50*	5.04 ± 0.41	5.52 ± 3.94	5.65 ± 3.56	4.95 ± 0.50*
Femur breadth (mm)	8.96 ± 0.80	9.31 ± 0.70	8.69 ± 0.73*	9.51 ± 0.85	8.75 ± 0.67*	8.94 ± 0.74	8.99 ± 0.96	9.45 ± 0.86	8.75 ± 0.67*
Ankle breadth (mm)	6.81 ± 3.49	7.06 ± 0.47	6.62 ± 4.53	7.06 ± 0.60	6.71 ± 4.08	6.67 ± 0.63	7.22 ± 6.89	6.97 ± 0.66	6.71 ± 4.15

* $p \leq 0.05$

Table 5

Descriptive statistics (mean ± SD), the statistical significance of the differences for the girth-related variables of the various groups of adolescents.

Variables	Total group	Gender groups		Racial groups		Sport participation level		Area of living	
	(*n* = 214)	Boys (*n* = 88)	Girls (*n* = 126)	Caucasian (*n* = 59)	Non-Caucasian (*n* = 155)	Sport participants (*n* = 160)	Non-sport participants (*n* = 54)	Urban (*n* = 64)	Rural (*n* = 150)
Head girth (cm)	55.11 ± 3.62	55.50 ± 3.12	54.82 ± 3.93	55.37 ± 1.72	55.01 ± 4.13	55.28 ± 2.53	54.59 ± 5.79	55.67 ± 1.84	54.87 ± 4.14
Relaxed arm girth (cm)	25.38 ± 4.00	25.48 ± 4.19	25.22 ± 3.77	28.00 ± 4.40	24.38 ± 3.34*	24.68 ± 3.48	27.43 ± 4.72*	28.08 ± 4.19	24.22 ± 3.31*
Flexed arm girth (cm)	27.79 ± 6.62	28.04 ± 4.25	27.54 ± 7.84	30.66 ± 7.80	26.70 ± 5.77*	27.25 ± 6.37	29.37 ± 7.13*	30.60 ± 7.47	26.59 ± 5.85*
Waist (cm)	68.60 ± 9.38	69.62 ± 8.86	67.43 ± 9.34	73.36 ± 10.91	66.59 ± 8.00*	67.09 ± 7.51	72.52 ± 12.71*	73.26 ± 10.80	66.41 ± 7.89*
Hip (cm)	90.27 ± 11.37	86.92 ± 9.64	92.42 ± 11.82*	94.86 ± 10.49	88.51 ± 11.23*	87.89 ± 8.85	97.47 ± 14.73*	95.69 ± 9.61	87.94 ± 11.30*
WHPR	0.77 ± 0.13	0.80 ± 0.04	0.74 ± 0.16*	0.77 ± 0.06	0.76 ± 0.14	0.77 ± 0.11	0.75 ± 0.17	0.76 ± 0.06	0.77 ± 0.15
WHTR	0.42 ± 0.05	0.41 ± 0.05	0.42 ± 0.06	0.43 ± 0.06	0.43 ± 0.05*	0.41 ± 0.04	0.45 ± 0.07	0.43 ± 0.06	0.41 ± 0.05*
Mid-thigh girth (cm)	48.59 ± 6.60	47.85 ± 5.71	49.00 ± 7.07	50.82 ± 6.36	47.74 ± 6.51*	47.26 ± 5.13	52.51 ± 8.67*	51.27 ± 6.23	47.44 ± 6.43*
Max calf girth (cm)	33.09 ± 3.85	33.39 ± 3.75	32.80 ± 3.84	35.58 ± 3.70	32.14 ± 3.48*	32.74 ± 3.37	34.12 ± 4.92*	35.55 ± 3.68	32.04 ± 3.44*
Fore arm girth (cm)	23.80 ± 2.58	24.87 ± 2.69	23.00 ± 2.14*	25.55 ± 2.94	23.13 ± 2.08*	23.68 ± 2.49	24.15 ± 2.84	25.45 ± 2.88	23.09 ± 2.09*

Waist to hip ratio (WHPR), Waist to height ratio (WHTR)

* $p \leq 0.05$

Table 6

Descriptive statistics (mean ± SD), the statistical significance of the differences for the length-related variables of the various groups of adolescents.

Variables	Total group	Gender groups		Racial groups		Sport participation level		Area of living	
	(*n* = 214)	Boys (*n* = 88)	Girls (*n* = 126)	Caucasian (*n* = 59)	Non-Caucasian (*n* = 155)	Sport participants (*n* = 160)	Non-sport participants (*n* = 54)	Urban (*n* = 64)	Rural (*n* = 150)
Sitting height (cm)	119.83 ± 14.51	121.60 ± 15.81	118.50 ± 13.46	119.83 ± 14.51	117.87 ± 14.49*	121.06 ± 12.18	116.20 ± 19.54	124.70 ± 12.79	117.79 ±14.73*
Acromial-radial length(cm)	31.10 ± 2.30	32.38 ± 1.94	30.18 ± 2.05*	32.32 ± 2.39	30.64 ± 2.09*	31.31 ± 2.34	30.50 ± 2.08*	32.36 ± 2.30	30.61 ± 2.12*
Radial-stylion length (cm)	24.61 ± 1.60	25.40 ± 1.35	24.05 ± 1.52*	25.07 ± 1.58	24.44 ± 1.58*	24.72 ± 1.53	24.30 ± 1.79	24.95 ± 1.66	24.47 ± 1.56*
Midstylion-dactylion length (cm)	19.62 ± 1.50	20.91 ± 1.10	18.70 ± 0.93*	20.26 ± 1.63	19.37 ± 1.38*	19.87 ± 1.50	18.88 ± 1.23*	20.10 ± 1.63	19.41 ± 1.40*
Foot length (cm)	25.16 ± 1.81	26.62 ± 1.38	18.70 ± 0.94*	26.17 ± 1.93	24.77 ± 1.61*	25.41 ± 1.87	24.43 ± 1.41*	26.00 ± 1.92	24.80 ± 1.64*

* $p \leq 0.05$

The cluster analysis reduced the number of anthropometric variables from 37 to 10 variables. The 10 variables remaining were: muscle mass percentage, ectomorphy, head and mid-thigh girth (cm), body mass (kg), waist and hip circumference (cm), sitting height (cm), sum of 7 skinfolds (mm) and stature (cm). These anthropometric variables, together with the dichotomised values of gender (male = 1, female = 0), living area (urban = 0, rural = 1), sport participation level (yes = 1, no = 0) and race (Caucasian = 0, non-Caucasian = 1), were entered into the forward stepwise regression analysis. The results of this analysis are presented in Table 7.

Table 7

Results of the forward stepwise regression analysis based on the adolescents' demographic and anthropometric data

Variables	Beta in	Partial R	Semi-partial R	R-square change	*p*-Value
Muscle mass percentage (%)	0.63	0.61	0.42	0.59	0.000*****
Sport participation level	0.20	0.29	0.17	0.06	0.000*****
Stature (cm)	0.23	0.28	0.16	0.01	0.003*****
Hip circumference (cm)	-0.16	-0.09	-0.05	0.01	0.006*****
Ectomorphy	-0.28	-0.22	-0.13	0.02	0.001*****
Mid-thigh girth (cm)	-0.20	-0.10	-0.06	0.00	0.091
Area of living	-0.06	-0.08	-0.05	0.00	0.231

Correlation (R)

***** $p \leq 0.05$

Results of the forward stepwise regression analysis indicate that the following variables served as significant predictors of adolescents' indirect $\dot{V}O_{2max}$ values: muscle mass percentage, sport participation level, stature, hip circumference and ectomorphy. Both hip circumference and ectomorphy displayed significant negative relationships with $\dot{V}O_{2max}$ whereas the rest of the variables displayed significant positive relationships with the dependant variable. The R-square change was calculated to determine how much each independent variable contributed to the prediction of $\dot{V}O_{2max}$. The results of this analysis are presented graphically in Figure 1. From these

results muscle mass percentage emerged as the strongest predictor (59%) of adolescents' $\dot{V}O_{2max}$ values, followed by sport participation level (6%), ectomorphy (2%), stature (1%) and hip circumference (1%). The overall stepwise regression analysis correlation coefficient of $R^2 = 0.70$ suggests that the prediction function of identified variables accounted for 70% of the variance in adolescents' $\dot{V}O_{2max}$ values. Variables other than the variables in this study contributed 30% to the variance in the $\dot{V}O_{2max}$ values among the adolescents.

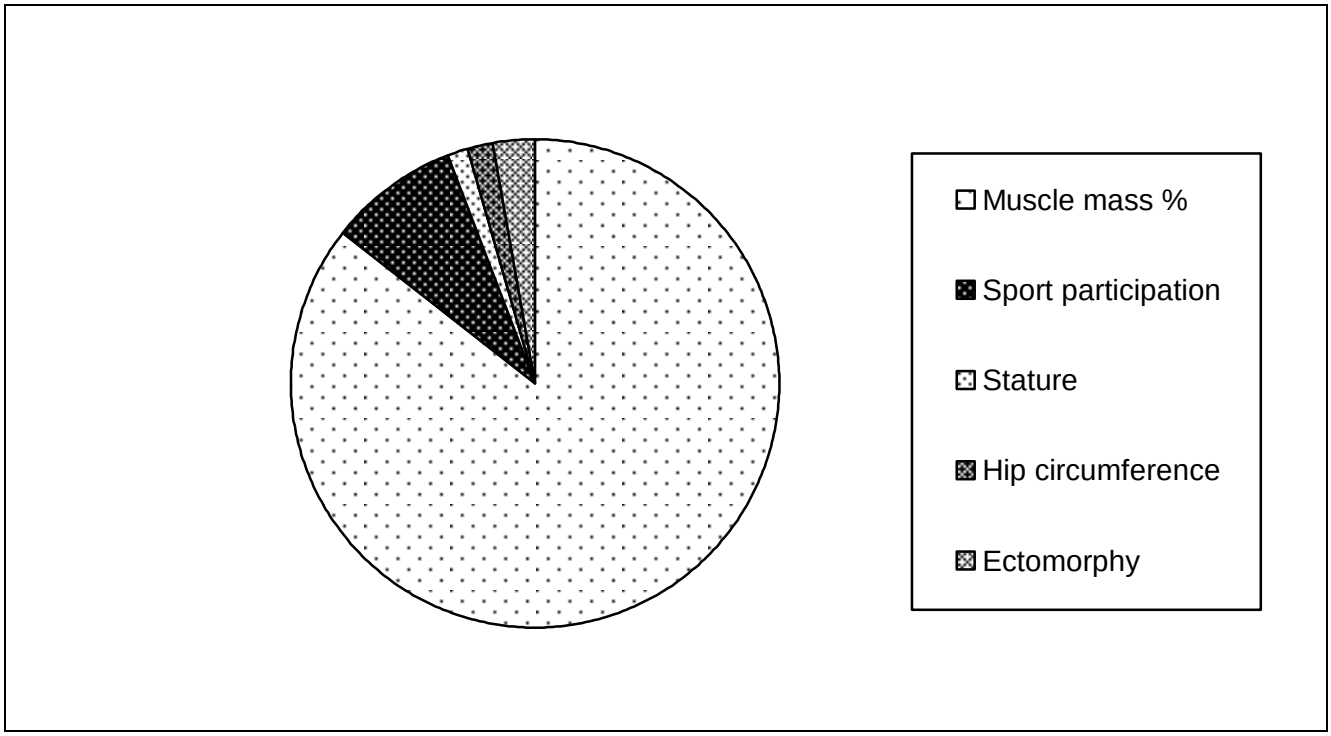

Fig 1. The percentage contribution of each of the independent variables from the forward stepwise regression analysis to the prediction of $\dot{V}O_{2max}$

In an attempt to validate the stepwise multiple regression analysis-derived prediction functions the R^2 of the 75% sample group ($R^2 = 0.71$) and the R^2 of the 25% sample group ($R^2 = 0.67$) were inserted into Cohan's effect size formula, which delivered a value of 0.1. What this indicates, is that

the stepwise multiple regression analysis-derived function is valid to predict the indirect $\dot{V}O_{2max}$ values of adolescents.

4. Discussion

The purpose of this study was to determine whether a valid $\dot{V}O_{2max}$ prediction function can be developed from several anthropometric measurements and demographic factors such as gender, race and living area as well as sport participation level of a cohort of adolescents living in the Tlokwe Local Municipality of North West Province, South Africa. To the authors' knowledge, this is the first study to attempt to identify various anthropometric measurements and demographic factors to predict the indirect, 20-m SRT $\dot{V}O_{2max}$ values of a South African population. Up until now $\dot{V}O_{2max}$ prediction models have focussed on children and adolescents from Europe (Denmark, Portugal, Estonia and Norway), Iceland, Nepal, America, Japan, Spain and China (Adegboye, Anderssen, Froberg, Sardinha, Heitmann, Steene-Johannesen, Kolle, & Andersen, 2011; Arngrímsson et al., 2008; Chatterjee, Banerjee, Das, & Debnath, 2009; Goran et al., 2000; Mahar et al., 2006; Matsuzaka et al., 2004; Pfeiffer et al., 2007; Ruiz, Ramirez-Lachuga, Ortega, Castro-Piñero, Benitez, Arauzo-Azofra, Sanchez, Sjöström, Castillo, Gutierrez, & Zabala, 2008; Tong, Fu, & Chow, 2001) and did not consider demographic factors such as the gender, race and living area or sport participation level of the participants.

The forward stepwise multiple regression analysis only identified the following five anthropometric measurements and demographic factors as well as sport participation level to be significant predictors of the indirect 20-m SRT $\dot{V}O_{2max}$ values: muscle mass percentage, sport participation level, stature, hip circumference and ectomorphy. Muscle mass percentage emerged as the strongest predictor with more or less 59% of the variance in $\dot{V}O_{2max}$ values that could be explained by this anthropometric variable. In view of research that reported a strong and significant correlation (r = 0.87; $p \leq 0.0001$) between muscle mass and the direct $\dot{V}O_{2max}$ values of 129 prepubertal children (8-11 years) from America (Caucasian as well as African American)

(Goran et al., 2000) as well as a high negative correlation (r = -0.8; $p \leq 0.001$) between fat-free mass and the indirect $\dot{V}O_{2max}$ values of 15 to18-year-old Brazilian adolescents, this result is not unexpected. Muscle mass has also been shown to influence the trainability of the $\dot{V}O_{2max}$ response with the greatest improvements seen in the $\dot{V}O_{2max}$ values of individuals with meso-ectomorph (12%) and mesomorph somatotypes (15.3%) after more or less 12 weeks of training (Chaouachi et al., 2005). The use of a larger muscle mass during execution of the 20-m SRT may enable participants to increase the mass of mitochondria sharing in the production of ATP through oxidative phosphorylation (Bassett & Howley, 2000). Furthermore, Coyle, Coggan, Hopper, and Walters (1988) stated that individuals with especially a larger amount of musculature would be better able to distribute work and reduce muscular work, which would benefit aerobic capacity. The possibility also exists that a greater muscle mass will allow a participant to achieve greater oxygenation that will lead to an increase in the $\dot{V}O_{2max}$ response (Eliakim, Barstow, Brasel, Ajie, Lee, Renslo, Berman, & Cooper, 1996). All of these findings may provide an explanation for the identification of muscle mass as the strongest predictor of $\dot{V}O_{2max}$ values among the adolescents.

Together, the other anthropometric-related variables (excluding muscle mass percentage) identified as significant predictors only contributed 4% to the variance in adolescents' $\dot{V}O_{2max}$ values. The significant negative correlation between ectomorphy and the adolescents' indirect $\dot{V}O_{2max}$ values is surprising in view of research findings that a tall, linear ectomorphic body build is ideally suited for aerobic performance (Chaouachi et al., 2005). The negative relationship between ectomorphy and the indirect $\dot{V}O_{2max}$ values may be explained by the following factors: Ectomorphy is dependent on the body height-weight ratio of each adolescent as the ratio of body stature and the cube root of body mass are used in the ectomorphy calculation (Stewart et al., 2011). According to the results in Table 1, the children in this study obtained an average PHV age of 14.22 years, while their average chronological age at the time of testing was 15.82 years. In view of the data of Malina, Bouchard, and Bar-Or (2004), which suggests that the duration of the growth spurt is anything between two and three years, the results of our study suggest that most of the adolescents were still in their growth spurt with regard to body stature and weight at the time of

testing. The growth spurt will first occur in stature and then in weight, which would cause an increase in the height-to-weight ratio and ectomorphy value during this time period (Malina et al., 2004). Research also indicates that especially boys may experience a period of clumsiness in motor coordination due to the disproportional growth in body stature (leg and sitting height length) and weight (muscle mass *inter alia*) (Malina et al., 2004; Philippaerts, Vaeyens, Janssens, Van Rentergheim, Matthys, Craen, Bourgois, Vrijens, Beunen, & Malina, 2006; Yagüe & De la Fuente, 1998). In this regard a decline in shuttle run performance 8 months after the occurrence of PHV has also been reported for Spanish boys and girls (observed from 9-16 years) indicating opposite trajectories in endurance run performance and stature (Yagüe & De la Fuente, 1998). Similarly, Philippaerts et al. (2006) found a decline in maximal endurance run values 6-12 months post-PHV in Flemish youth soccer players (10.4-13.7 years), emphasising the disruption that occurs in motor coordination at this time period.

However, despite the present findings with regard to ectomorphy, stature contributed positively with 1% to the variance in $\dot{V}O_{2max}$ values. Generally, individuals with a taller stature will display a lower mechanical cost during running than shorter individuals that will use more steps per distance due to a shorter stride frequency, resulting in a greater mechanical cost (Rowland, 1996; Unnithan & Eston, 1990). However, research by Ruiz et al. (2008) indicates that body stature will positively influence 20-m SRT up until a certain body stature height where after it will negatively impact test performance due to the multiple changes in direction that take place during the execution of the test (Flouris et al., 2006; Ruiz et al., 2008).

Hip circumference was the last anthropometric-related measurement that was identified as a significant predictor of $\dot{V}O_{2max}$ and showed a negative relationship with $\dot{V}O_{2max}$. A previous study by Freedman, Serdula, Srinivasan, and Berenson (1999) suggests that hip circumference is strongly correlated with skinfold thickness (R = 0.80-0.90, $p \leq 0.001$), which serves as an indicator of adipose tissue in the body. To test this contention, the correlation coefficients (R) of the relationships between the adolescents' hip circumference values as well as sum of seven skinfolds (mm), fat percentage (%) and fat mass (kg) were calculated and revealed significant R-values of 0.77, 0.72 and 0.85 ($p \leq 0.05$) respectively for the last-mentioned relationships. In this regard, various researchers have confirmed the negative influence of excess fat mass on children and adolescents' aerobic performance (Ekelund et al., 2001; Huotari et al., 2010; Nevill et al., 2009; Ortega et al., 2010). As been mentioned earlier, low levels of adiposity benefit weight-bearing

activities due to a decrease in energy demand caused by the lower mass of metabolic inactive body tissue that needs to be displaced.

The only other variable that served as a significant predictor of indirect $\dot{V}O_{2max}$ values was sport participation level, which contributed 6% to the variance in $\dot{V}O_{2max}$. Various researchers have consistently proven that participation in organised physical activity leads to enhanced aerobic performance among a wide range of children and adolescents (middle-school girls, grade 8 African American and Caucasian children, 13 to 14-year-old Greek boys and 7 to 16-year-old Spanish children) (Koutedakis & Bouziotas, 2003; Pfeiffer et al., 2007; Sirard et al., 2008). Additionally, sport participation leads to improved aerobic performance as a result of a decrease in body fat percentages as well as improvements in cardiorespiratory health and fitness (Ara et al., 2007; Chillón et al., 2011).

Although mid-thigh girth and area of living were also identified as predictors of adolescents' indirect 20-m SRT $\dot{V}O_{2max}$ values, none of these predictors delivered significant results and the contribution of these variables to the prediction of $\dot{V}O_{2max}$ was negligibly small (< 1% in total).

In order to validate the stepwise multiple regression analysis-derived prediction function, a cross-validation was performed which yielded an effect size value of 0.1, indicating that this model is extremely accurate in predicting the 20-m SRT-derived indirect $\dot{V}O_{2max}$ values of this cohort of adolescents.

Despite the fact that 70% (stepwise regression analysis $R^2 = 0.70$) of the variance in the indirect, 20-m SRT $\dot{V}O_{2max}$ values could be explained by the anthropometric measurements, demographic factors and sport participation level identified in our study, other variables not considered for this study contributed 30% to the variance in the $\dot{V}O_{2max}$ values among the adolescents. Although the scope of this study was narrowed down to only include anthropometric and demographic variables such as gender, race and living area as well as sport participation level of participants in the multiple regression function, research suggests that physical and motor performance variables also contribute to aerobic performance. In this regard variables such as sprint speed, flexibility, leg explosive power, balance, muscle strength and agility have also been identified as possible

predictors of 20-m SRT-derived $\dot{V}O_{2max}$ values among adolescents (Chatterjee et al., 2009; Koutedakis, & Bouziotas, 2003; Trehearn & Buresh, 2009). Therefore, the inclusion of physical and motor performance variables may possibly increase the strength of the 20-m SRT-derived $\dot{V}O_{2max}$ prediction function. Additionally, the present results were based on a rather small cohort of 15-year-old adolescents from the Tlokwe Local Municipality, which means that the group of learners cannot be considered representative of the adolescent population, either of the Tlokwe local municipality area or of South Africa in general. However, these study results serve as a foundation for further studies in this regard.

5. Conclusion

In conclusion, our study succeeded in developing a valid anthropometric and demographic based $\dot{V}O_{2max}$ prediction model for use in adolescents of the North West Province in South Africa. The development of a $\dot{V}O_{2max}$ prediction function of this nature will allow practitioners in the field of Human Movement Science to use an inexpensive, practical and accurate indirect method for determining the $\dot{V}O_{2max}$ values of adolescents. This will especially be of value in cases where adolescents live in rural areas and are part of large epidemiological field studies where $\dot{V}O_{2max}$ values are screened. Also, to date no attempt has been made to develop such an anthropometric-related model for the prediction of South African adolescents' $\dot{V}O_{2max}$ values. However, due to finding that only 30% of the variance in $\dot{V}O_{2max}$ values could be explained by making use of this model, research findings warrants the inclusion of physical and motor performance variables as predictor variables in prediction models of this nature. Furthermore, a cross-sectional experimental research design was used in this study. However, to test the reliability and validity of the $\dot{V}O_{2max}$ prediction model that was developed, it would be advisable to rather use a longitudinal research design by which the predictive value of the model can be tested over time. Despite these recommendations, the model developed through this study paves the way for other researchers to

also compile and implement population-specific 20-m SRT $\dot{V}O_{2max}$ prediction models that can be used to screen the $\dot{V}O_{2max}$ values of different populations of adolescents.

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Disclaimer

Any opinion, findings and conclusions or recommendations expressed in this material are those of the authors; therefore the NRF and MRC do not accept any liability in this regard.

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CHAPTER 4

4 DEVELOPING A VO_{2MAX} PREDICTION FUNCTION FROM THE PHYSICAL, MOTOR PERFORMANCE AND DEMOGRAPHIC COMPONENTS OF A GROUP OF ADOLESCENTS: THE PAHL STUDY

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Acknowledgements

Disclaimer

References

Title:

Developing a $\dot{V}O_{2max}$ prediction function from the physical, motor performance and demographic components of a group of adolescents: The PAHL study

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Running head:

Factors influencing the prediction of $\dot{V}O_{2max}$ in adolescents.

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Tables – 3

Figures - 1

Developing a $\dot{V}O_{2max}$ prediction function from the physical, motor performance and demographic components of a group of adolescents: The PAHL study

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The study examined the possibility of developing a valid $\dot{V}O_{2max}$ prediction function from the physical and motor performance components as well as demographic variables such as gender, race and living area as well as sport participation levels of a cohort of adolescents. Data was obtained from 214 adolescent boys and girls (15.82 ± 0.68 years) by making use of various physical and motor performance tests, questionnaires as well as the 20-m shuttle run test (20-m SRT) for the indirect $\dot{V}O_{2max}$ assessment. The results from the forward stepwise regression analyses indicated that 10-m speed, sit-ups, sport participation level, handgrip strength, vertical jump test (VJT), VJT Tendo peak power, maximal heart rate, living area (rural living), right passive external shoulder rotation test (RPESRT), horizontal jump test (HJT) and the right modified Thomas iliopsoas test (RMTIT) served as significant predictors of the adolescents' indirect $\dot{V}O_{2max}$ values (R^2 = 0.71, $p \leq 0.05$). Cross validation of the regression-derived prediction model confirmed the validity of the model to predict indirect aerobic performance in this group of adolescent participants. In conclusion, from this study a valid and significant physical and motor performance-related $\dot{V}O_{2max}$ prediction model was developed. This model may enable practitioners in the field of Human Movement Science to accurately predict the $\dot{V}O_{2max}$ values of South African adolescents.

Keywords: $\dot{V}O_{2max}$, indirect, adolescents, physical, motor performance, demographic

The cost of specialized, sophisticated equipment, the unavailability of well-trained personnel, the amount of time needed to conduct tests and the inability to test a large number of participants when directly measuring $\dot{V}O_{2max}$ by indirect calorimetry and computerized instrumentation in the laboratory (12,13,17), have led researchers to develop less expensive indirect testing methods (3,11). The most well-known indirect tests include the 20-m shuttle run test (20-m SRT), the 12-minute Cooper Test and the 1-mile walk/run tests, amongst others (7,11,32). The manner in which these tests are used to predict a participant's $\dot{V}O_{2max}$ is by compiling regression equations, normogrammes and other mathematical models from the data obtained from direct $\dot{V}O_{2max}$ tests (3,65). Although several researchers have developed regression equations based on anthropometric measurements (31,47), physical and motor performance variables have also been identified as contributors to aerobic performance. Findings revealed that 40 metre sprint speed (14,59) is significantly correlated with the $\dot{V}O_{2max}$ results of adults (63,81) as well as with that of children and adolescents (14,59). Similarly, other researchers have highlighted the value of maximal running speed and agility as predictors of 20-m SRT aerobic performance in 22 healthy adult males (22.1 ± 2.4 years) (33). Koutedakis and Bouziotas (42) also identified 50-yard dash times, mile run time, sit-and-reach distance, flamingo balance time, standing broad jump distance, hand grip strength and sit-up repetitions as possible predictors of 20-m SRT-derived $\dot{V}O_{2max}$ values among 84 schoolboys (13.6 ± 0.3 years). Flexibility also seems to benefit the running economy of participants, with the most economic distance runners that display the highest $\dot{V}O_{2max}$ values and the best lower leg flexibility values (27,58,75).

Results from the 20-m SRT are currently interpreted by making use of the equation of Léger and Lambert (43) which, although being the most widely used prediction function of indirect aerobic performance, does not yield accurate results for different populations of participants (10,55). This is mainly due to the fact that the prediction model of Léger and Lambert was developed by using data obtained from European adults between ages 18 and 37 years. In order to address the problem of inaccuracy, researchers have developed prediction models for use in specific participants (46,47,65).

Another shortcoming of the currently available $\dot{V}O_{2max}$ prediction models is that other factors

that may also influence the predicted $\dot{V}O_{2max}$ values are not considered. In this regard, demographic factors such as the gender, race and living areas (rural or urban) as well as sport participation levels of the testing population may influence the outcome of the regression equations and need to be considered in order to improve the accuracy of the models (48,80). In this regard 5 of the available prediction models include gender as a possible factor (2,5,46,47,65) whereas only the model of Pfeifer et al. (61) accounted for race as well as sport participation and physical activity level (moderate as well as vigorous). Researchers agree that gender differences in predicted $\dot{V}O_{2max}$ values are predominantly related to differences in body composition between boys and girls (39,65). Ruiz et al. (65) indicated significant differences ($p < 0.001$) in the height and weight measurements of 193 adolescent boys and girls (16.1 ± 1.2 years) which resulted in significantly higher $\dot{V}O_{2max}$ values ($p < 0.001$) for the boys in both the 20-m SRT-derived (47.0 ± 5.0 *vs.* 63.2 ± 2.9) and directly measured $\dot{V}O_{2max}$ values (53.9 ± 6.2 *vs.* 37.1 ± 5.0).

A study by Rowlands et al. (64) reported that 8 to 10-year-old children that displayed greater physical activity levels achieved higher aerobic fitness levels that less physically active children. Furthermore, the study by Pfeiffer et al. (61) showed that sport participation or physical activity levels directly influences children's $\dot{V}O_{2max}$ levels with sport participating school girls from grades 8, 9 and 12 that displayed significantly better $\dot{V}O_{2max}$ values than their non-sport participating peers. Non-sport participating middle-school girls (13.6 ± 0.6 years), Greek boys (13.6 ± 0.3 years) and Spanish children and adolescents (7-17 years) have all shown lower $\dot{V}O_{2max}$ and aerobic performance values than those that took part in physical activity or organised sports (4,15,42,61).

To date, most studies showed that African American or black children and adolescents generally display lower $\dot{V}O_{2max}$ values than Caucasian children and adolescents (25,49,54,62,69,76), which may possibly be related to their higher physical activity levels (41). Another reason for the differences in aerobic capacity or $\dot{V}O_{2max}$ between children and adolescents from different racial groups is the differences in the areas of living.

Children that live and grow up in rural areas do not necessarily have the facilities to their disposal as do urban children (53,77). This constraint, combined with safety concerns, may prevent

children in rural areas from participating in physical activities and sport (25). However, some researchers found that children living in rural areas experienced greater freedom to partake in physical activities and subsequently achieve higher $\dot{V}O_{2max}$ values than children living in urban areas (15,45,70).

It is in the light of this background on the possible contribution of physical and motor performance measurements to the prediction of $\dot{V}O_{2max}$ as well as the possible influence of demographic variables such as gender, race and living area (rural or urban) and sport participation level on the prediction, that the following study aim was compiled: To develop a valid $\dot{V}O_{2max}$ prediction function from the physical and motor performance components as well as demographic variables such as gender, race and living area and sport participation level of a cohort of adolescents. To the authors' knowledge this is the first study of its kind to consider all of the last-mentioned factors in setting up a $\dot{V}O_{2max}$ prediction function for South African adolescents. We hypothesized that physical and motor performance components as well as demographic variables such as gender, race and areas of living and sport participation level can be used to develop a valid $\dot{V}O_{2max}$ prediction function for South African adolescents.

Methods

Research design

This research study is part of a larger longitudinal study, The Physical Activity and Health Longitudinal Study (PAHLS), which is an observational multidisciplinary study. The study started in 2010 and will be continued until 2014. For purposes of the current study a selected group, cross-sectional experimental research design was used. Furthermore, only data from the 2012 sample was analysed. The study was approved by the Ethics Committee of the North-West University (NWU-0058-01-A1) and the Director of the Department of Basic Education in the Potchefstroom District. Prior to the main part of the study being undertaken, a pilot study was performed during which one school's children were subjected to the physical and motor performance tests to determine the reliability of the tests in this population.

Participants

A total of 214 adolescents (88 = boys and 126 = girls) in grade 10 of high schools in the Tlokwe Local Municipality (Potchefstroom area) of North West Province in South Africa were purposefully selected from pre-acquired class lists, from six secondary schools. Two of the selected schools were in the Potchefstroom City area, which comprised learners living in urban areas and four schools from the Ikageng Township area, which predominantly comprised learners living in rural areas. Due to the fact that the learners were not randomly selected according to the population density of the two geographical areas, the learners cannot be considered representative of the adolescents' population; nor of the Tlokwe Local Municipality (Potchefstroom area) of South Africa. Only learners in grade 10 at the time of measurement (2012) were eligible to participate in the study. Prior to participating in the study, all participants were informed about the nature of the study, and all potential risks and benefits were explained to them. Informed consent for the investigation was requested from the school authorities, the parents and learners of the participating schools during the weeks prior to the testing period.

Measurements

Demographic and general information questionnaire. A questionnaire in which participants had to provide information with regard to the following was also administered during the testing period:

Information with regard to demographics of general aspects: The school of attendance; the grade in which the participant was at the time of testing; the name of the participant; the address of the participant; the ethnicity of the participant.

Information with regard to sport and training habits. An indication of the participant's participation in sport;

Information with regard to maturation. For girls only: Menarche age; for boys only: age at which the voice broke.

Information with regard to physical activity. The days, during the last 7 days on which the participant did very hard physical activities, such as heavy lifting, digging, aerobics, or high-intensity cycling; The hours spent on high intensity physical activities during the above-mentioned days; The days during the last 7 days on which the participant did moderate physical activities, such as carrying light loads, cycling at a moderate pace, or playing recreational tennis; The hours spent on moderate intensity physical activities during the above-mentioned days.

Anthropometric measurements. Body mass (to the nearest 0.1 kg) stature as well as sitting height (to the nearest 0.1 cm) was measured according to the protocols of The International Society for the Advancement of Kinanthropometry (ISAK) (72) by Level 2 ISAK-certified anthropometrists.

Maturity. Maturity age was estimated by using the anthropometric measures of body stature, sitting height and body mass together with the variables of gender, date of birth and date of measurement in order to calculate peak height velocity (PHV) age. Maturity age was calculated by subtracting age at PHV from chronological age at the time of measurement (73). In cases where the age at PHV was the same as the chronological age, maturity age was categorised to be 0 (73). In cases where chronological age was higher than the age at PHV, maturity age was regarded as positive whereas negative results were an indication that the age at PHV was higher than chronological age (73). Information with regard to the menarche age of the girls and the age at which the voice broke of the boys, were also used to verify the maturation age of each of the genders. Cultural beliefs and practices prevented the researchers of this study from using the Tanner stages (24) to determine the maturation age of each of the adolescents. Although not the direct aim of this study, the maturity age of the adolescents was considered in order to verify certain trends with regard to their anthropometric and aerobic profile.

Physical and motor performance measurements. The Passive-straight-leg-raise test (PSLRT) was executed according to the method of Maud and Kerr (49). Each measurement was done twice. If a difference of more than 5° was observed between the first and the second measurement, a third measurement was taken.

The Active-straight-leg-raise test (ASLRT) was executed in exactly the same manner as the PSLRT. The only difference being that the participants had to cross their arms on their chest and they had to lift the test leg by themselves without any assistance from the tester while the knee was kept in total extension (35).

The Modified-Thomas-Iliopsoas test (MTIT) was executed according to the method of Harvey and Mansfield (35) as well as Maud and Kerr (49) and the Modified-Thomas-Quadriceps test (MTQT) was executed according to the method of Harvey and Mansfield (35). Each measurement was done twice. In the case of a difference of more than 5° observed between the first and second measurement, a third measurement was taken.

The Passive Shoulder External Rotation Test (PSERT) and Passive Shoulder Internal Rotation Test (PSIRT) were executed according to the method of Harvey and Mansfield (35) as well as Maud and Kerr (49). Each measurement was taken twice. If a difference of more than 5° was observed between the two measurements, a third measurement was taken.

All the flexibility measurements were only taken on the right side of the body.

Before the start of the under-mentioned tests participants were firstly subjected to a thorough warm-up of more or less 15 minutes consisting of aerobic running exercises for more or less 8 minutes after which a specific warm-up period of shorter high-intensity movements and dynamic stretches followed.

The Seated Medicine Ball Put Test (MBPT) is regarded as an objective (r = 0.99) (38), valid (r = 0.77 – 0.90) (29,38) and reliable test (r = 0.77 – 0.99) (29) to assess the muscular power of the arms and shoulder girdle (8). The arc of the ball was controlled by a ring that was positioned 2 metres in front of the participant at a height that controlled the angle of release to be approximately 45º. Participants were given two practice trials, followed by three maximal efforts with a rest period of 30 seconds between each effort. The best distance was recorded to the nearest centimetre. The average test-retest reliability coefficient for the two measurements during the pilot study was calculated to be 0.94.

Vertical Jump Test (VJT) is seen as an objective (r = 0.90) and valid test (r = 0.93) for determining the explosive leg power of participants (67). The VJT was executed according to the method of Harman et al. (34). The better of two trials were recorded to the nearest 0.1 cm (the distance between adjacent vanes of the Vertec device (Power Systems, Knoxville, Tennessee) with a 10-seconds rest period between each trial. Power output during the VJT was measured for each jump with a Tendo™ Power Output Unit (Tendo Sports Machines, Trensin, Slovak Republic). The Tendo™ unit consists of a transducer that was attached to the waist of each participant and measured linear displacement and time. Subsequently, jump velocity was calculated and power was determined. Both peak and mean power output was recorded for each jump and used for the subsequent analyses. According to Hoffman et al. (37), the test-retest reliability of the Tendo unit is $r \geq 0.90$. The average test-retest reliability coefficient for the pilot study's measurements was calculated to be 0.91 for the VJT measurement of the adolescents.

The Horizontal jump test (HJT) is regarded as a reliable (r = 0.89-0.9) and valid test to determine the peak anaerobic power output of participants (50). Participants were allowed a 10-seconds rest period between each trial and the better of the two trials to the nearest 0.1 cm was recorded.

Calculation of the average test-retest reliability coefficient for the pilot study's measurements revealed an average value of 0.99.

The forty-metre acceleration and speed test is seen as an objective, reliable and valid test for determining the speed of participants (36). It is also recommended that a standing start be used during execution of the 40-metre test (22). Intermediate beam electronic timing gates (Brower Timing Systems, Utah, USA) which automatically recorded interval times, were set at 0, 5, 10 and 40-metre intervals on a section of a grass field. Split times (at 5 minutes and 10 minutes) and the final time (40 minutes) for 2 trials, with a 2-minute rest period between each, was recorded to the nearest 0.01 seconds. The best time for each 5, 10 and 40 minutes was used in the final analysis. The average test-retest reliability coefficient for the pilot study's measurements was calculated to be 0.93, 0.96 and 0.92 for the 5, 10 and 40 minute speed values respectively.

The purpose of the 5-0-5 Agility Test (ATT) was to measure the ability to rapidly change body direction and position in the horizontal plane (22). The 5-0-5 agility test is seen as a reliable (r = 0.91) test for determining the agility of participants (78). The participants were required to perform 2 trials with each leg and a 2-minute rest period was given between each trial. The time of each trial was recorded to the nearest 0.01 seconds and the fastest time for each foot was used for the final analysis. Calculation of the average test-retest reliability coefficient for the 2 trials of the agility test data showed an average value of 0.89 for the pilot study.

The Abdominal stage test (AST) is a graded test for assessment of abdominal strength and was conducted according to the method of Ellis et al. (22) and was performed over seven stages of which the starting position was a supine lying position on the floor with 90º bent knees, feet without shoes comfortably open, in contact with the floor and not held.

Abdominal endurance was conducted by means of the 1-minute sit-ups test according to the method of the European Test of Physical Fitness Protocol (23). Throughout the test the participant's feet were held down at the ankles by a helper. The number of correct sit-ups performed in 1 minute was recorded.

Handgrip strength was measured as described by Russel and Owies (66). The participants performed a minimum of two trials and the better of the two trials was used for data analyses. Calculation of the average test-retest reliability coefficient for the 2 trials of the agility test data showed an average value of 0.98 for the pilot study.

For the execution of the 20-metre Shuttle Run Test (20-m SRT), a Fix Polar Heart Rate Transmitter Belt (Polar Electro, Kempele, Finland) was strapped to the chest of each participant

before commencement of the test. The participants' heart rates were measured with the use of a Polar Team² Pro Electro system (Kempele, Finland) and were recorded on a laptop computer with the Polar Team² Pro software program. This test was conducted according to the procedures described by the Australian Sports Commission (6). The test was terminated the moment the participant voluntarily dropped out or could not make it to either end marks of the 20-metre distance within the given beep signal during 2 successive shuttles. Both lines were therefore monitored by two testers at either end. The results noted were the last number called and the shuttle reached before dropping out. The participants were verbally encouraged to perform maximally during each assessment and subjects had to run the test barefoot.

Data analysis. The Statistical Data Processing package for Windows Statistica 11 (71) was used to do all analyses of the data. The variables of gender, sport participation level, areas of living (rural or urban) and race were firstly dichotomised into different categories by making use of numerical values of 0 and 1. Secondly, the descriptive statistics for each of the variables in all groups were determined and this was followed by independent *t*-tests to reveal significant differences between the variables for each group of participants. A cluster analysis of the physical and motor performance variables was done to detect clusters of measures that appear to tap similar abilities. The cluster analysis' reduced variables as well as the different dichotomised variables were then entered into the forward stepwise multiple regression analysis to determine each of the variables' contribution to the 20-m SRT-derived $\dot{V}O_{2max}$ values of the adolescents. The level of significance was set at $p \leq 0.05$. In order to validate the stepwise multiple regression analyses-derived prediction function, a cross-validation was performed by separately performing stepwise multiple regression analyses on a random selection of 25% and 75% of the original sample, respectively. The squares of each of the regression analysis' correlation coefficients were then inserted into a formula to determine Cohen's effect size value. The effect size values were then interpreted as follows: a value of 0.1 as small, 0.3 as medium and a value of 0.5 as large (16). Small to medium effect size values would be an indication that the stepwise multiple regression analysis-identified prediction function is a valid function for the prediction of adolescents' $\dot{V}O_{2max}$ values.

Results

The descriptive statistics of the anthropometric, chronological and maturity age as well as physical and motor performance-related variables of the various groups of adolescents are presented in Tables 1 and 2.

Table 1 Descriptive statistics (mean ± *SD*) and statistical significance of the differences for the age, stature, body mass, maturity and flexibility-related variables of the adolescent participants.

Variables	Total group (*n* = 214)	Gender		Racial groups		Sport participation levels		Area of living	
		Boys (*n* = 88)	Girls (*n* = 126)	Caucasian (*n* = 59)	Non-Caucasian (*n* = 155)	Sport participants (*n* = 160)	Non-sport participants (*n* = 54)	Urban (*n* = 64)	Rural (*n* = 150)
Age (years)	15.82 ± 0.68	15.84 ± 0.63	15.81 ± 0.71	15.70 ± 0.58	15.87 ± 0.71	15.86 ± 0.70	15.71 ± 0.59	15.69 ± 0.58	15.87 ± 0.71
PHV (years)	14.22 ± 0.69	14.19 ± 0.72	14.23 ± 0.67	14.21 ± 0.59	14.22 ± 0.72	14.28 ± 0.67	14.02 ± 0.72	14.17 ± 0.57	14.24 ± 0.74
Maturity age (years)	1.78 ± 0.42	1.77 ± 0.43	1.79 ± 0.41	1.78 ± 0.43	1.79 ± 0.41	1.80 ± 0.41	1.72 ± 0.45	1.78 ± 0.43	1.78 ± 0.41
Stature (cm)	163.70 ± 8.70	169.08 ± 8.87	159.85 ± 6.12*	170.52 ± 9.60	161.10 ± 6.72*	164.93 ± 8.94	160.04 ± 9.77*	169.41 ± 9.91	161.26 ±6.82*
Body mass (kg)	57.18 ± 14.16	59.34 ± 15.00	55.36 ± 12.89*	66.83 ± 17.04	53.51 ± 10.90*	55.50 ± 12.39	62.18 ± 17.65*	66.77 ± 16.40	53.09 ± 10.80*
RPSERT (º)	98.46 ± 13.20	94.98 ± 17.35	100.85 ± 8.69*	95.95 ± 20.76	99.42 ± 8.67	98.34 ± 14.20	98.83 ± 9.75	97.28 ± 20.36	98.97 ± 8.53
RPSIRT (º)	42.52 ± 16.24	43.23 ± 17.89	42.16 ± 15.06	37.42 ± 17.18	44.47 ± 15.49*	42.59 ± 16.54	42.33 ± 15.44	36.16 ± 15.99	45.24 ± 15.62*
RPSLRT (º)	99.38 ± 16.51	96.72 ± 18.09	101.44 ± 14.94*	93.29 ± 17.19	101.70 ± 15.69*	99.94 ± 15.88	97.72 ± 18.30	94.58 ± 16.77	101.43 ± 16.02*
RASLRT (º)	80.42 ± 21.26	75.23 ± 22.08	84.15 ± 19.98*	74.32 ± 24.83	82.74 ± 19.32*	80.34 ± 19.72	80.67 ± 25.50	78.19 ± 25.89	81.37 ± 18.96
RMTIT (º)	4.89 ± 11.86	7.61 ± 14.38	2.99 ± 9.41*	9.95 ± 16.18	2.96 ± 9.08*	6.39 ± 11.89	0.44 ± 10.69*	8.09 ± 17.04	3.52 ± 8.49*
RMTQT (º)	66.10 ± 11.49	63.53 ± 11.21	67.84 ± 11.42*	61.33 ± 10.06	67.79 ± 11.51*	64.31 ± 11.94	71.26 ± 11.56*	62.50 ± 11.20	67.53 ± 11.32*

PHV = Peak height velocity, RPSERT = Right passive shoulder external rotation test, RPSIRT = Right shoulder passive internal rotation test, RPSLRT = Right passive straight leg raise test, RASLRT = Right active straight leg raise test, RMTIT = Right Modified Thomas iliopsoas test, RMTQT = Right Modified Thomas quadriceps test

(*$p \leq 0.05$ between groups)

Table 2 Descriptive statistics (mean ± *SD*) and statistical significance of the differences in the physical and motor performance-related variables of the adolescent participants.

Variables	Total group (*n* = 214)	Gender		Racial groups		Sport participation levels		Area of living	
		Boys (*n* = 88)	Girls (*n* = 126)	Caucasian (*n* = 59)	Non-Caucasian (*n* = 155)	Sport participants (*n* = 160)	Non-sport participants (*n* = 54)	Urban (*n* = 64)	Rural (*n* = 150)
VJT (cm)	32.61 ± 12.44	41.82 ± 9.10	26.14 ± 10.20*	39.10 ± 10.38	30.14 ± 12.29*	35.36 ± 11.47	24.44 ± 11.66*	37.55 ± 11.10	30.50 ± 12.41*
VJT Tendo peak power (W)	1347.21 ± 373.90	1535.49 ± 408.81	1207.49 ± 258.65*	1646.12 ± 433.59	1233.43 ± 274.39*	1364.64 ± 372.27	1295.56 ± 377.41	1620.05 ± 428.32	1230.80 ± 276.88*
VJT Tendo peak speed ($m \cdot s^{-1}$)	2.41 ± 0.31	2.63 ± 0.22	2.25 ± 0.26*	2.52 ± 0.28	2.37 ± 0.30*	2.49 ± 0.27	2.16 ± 0.28*	2.48 ± 0.30	2.38 ± 0.31*
HJT (cm)	164.70 ± 36.22	184.58 ± 34.33	150.85 ± 30.90*	174.83 ± 36.30	160.84 ± 35.55*	172.41 ± 33.48	141.83 ± 34.60*	173.28 ± 41.24	161.03 ± 33.34*
MBPT (cm)	4.61 ± 2.84	5.04 ± 0.92	4.31 ± 3.59	5.80 ± 5.01	4.16 ± 0.95*	4.83 ± 3.20	3.97 ± 1.00	5.63 ± 4.86	4.18 ± 0.94*
Handgrip strength (kg)	30.83 ± 8.40	37.44 ± 8.02	26.18 ± 4.75*	36.59 ± 9.74	28.64 ± 6.66*	31.89 ± 8.85	27.70 ± 5.91*	35.41 ± 10.10	28.88 ± 6.69*
AST (level)	2.29 ± 1.87	2.91 ± 1.89	1.87 ± 1.75*	3.56 ± 1.74	1.81 ± 1.69*	2.53 ± 1.88	1.61 ± 1.68*	3.36 ± 1.88	1.84 ± 1.68*
Sit-ups (reps)	26.98 ± 10.37	33.20 ± 7.60	22.52 ± 9.78*	34.39 ± 8.42	24.12 ± 9.63*	28.93 ± 10.00	20.96 ± 9.19*	33.45 ± 8.82	24.18 ± 9.75*
5m speed (s)	1.27 ± 0.16	1.16 ± 0.10	1.35 ± 0.14*	1.22 ± 0.12	1.29 ± 0.17*	1.23 ± 0.14	1.40 ± 0.13*	1.25 ± 0.14	1.28 ± 0.16
10m speed (s)	2.16 ± 0.24	1.96 ± 0.13	2.29 ± 0.20*	2.07 ± 0.16	2.19 ± 0.25*	2.08 ± 0.19	2.38 ± 0.20*	2.11 ± 0.18	2.18 ± 0.25*
40m speed (s)	7.15 ± 3.38	6.67 ± 5.18	7.49 ± 0.82	6.39 ± 0.66	7.44 ± 3.91*	6.90 ± 3.84	7.89 ± 0.91	6.51 ± 0.73	7.43 ± 3.98

VJT = Vertical Jump Test, HJT = Horizontal Jump Test, MBPT = Medicine ball put test, AST = Abdominal Strength Test

(*$p \leq 0.05$ between groups)

Table 2 (cont) Descriptive statistics (mean ± *SD*) and statistical significance of the differences in the physical and motor performance-related variables of the adolescent participants.

Variable	Total group (*n* = 214)	Gender		Racial groups		Sport participation level		Area of living	
		Boys (*n* = 88)	Girls (*n* = 126)	Caucasian (*n* = 59)	Non-Caucasian (*n* = 155)	Sport participants (*n* = 160)	Non-sport participants (*n* = 54)	Urban (*n* = 64)	Rural (*n* = 150)
505 ATT left (s)	3.00 ± 0.25	2.83 ± 0.18	3.11 ± 0.23*	2.89 ± 0.24	3.04 ± 0.25*	2.94 ± 0.22	3.17 ± 0.27*	2.93 ± 0.25	3.02 ± 0.25*
505 ATT right (s)	3.01 ± 0.26	2.82 ± 0.18	3.14 ± 0.23*	2.89 ± 0.24	3.05 ± 0.25*	2.93 ± 0.22	3.24 ± 0.24*	2.94 ± 0.25	3.04 ± 0.26*
20-m SRT (LL)	5.91 ± 2.46	8.14 ± 1.70	4.37 ± 1.58*	6.76 ± 2.14	5.59 ± 2.50*	6.71 ± 2.16	3.56 ± 1.64*	6.36 ± 2.22	5.72 ± 2.54
20-m SRT (LS)	5.05 ± 2.70	5.13 ± 2.85	4.97 ± 2.59	5.00 ± 2.92	5.07 ± 2.62	5.14 ± 2.77	4.78 ± 2.45	4.75 ± 2.83	5.17 ± 2.64
$\dot{V}O_{2max}$ (ml·kg·min^{-2})	34.54 ± 8.23	42.01 ± 5.62	29.38 ± 5.28*	37.37 ± 6.94	33.47 ± 8.44*	37.20 ± 7.27	26.66 ± 5.36*	35.92 ± 7.28	33.96 ± 8.55
HR_{max} (bpm)	199.06 ± 10.83	200.60 ± 8.58	197.84 ± 12.06	197.88 ± 8.67	199.52 ± 11.55	200.46 ± 8.75	194.93 ± 14.79*	198.23 ± 8.73	199.42 ± 11.63

ATT = Agility T-test, 20-m SRT = 20 m Shuttle Run Test, LL = Last level, LS = Last shuttle, $\dot{V}O_{2max}$ = Maximal oxygen uptake, HRmax = Heart rate maximum

(*$p \leq 0.05$ between groups)

The results from Table 1 show no statistical differences with regard to the chronological and maturity age between the different groups of adolescents. Stature and body mass were significantly different between the groups. With regard to the flexibility-related measurements (Table 1), the most statistically significant ($p \leq 0.05$) differences (5 out of a possible 6 measurements), were found between gender and racial groups. The descriptive statistics from Table 2 indicate that all the indicators for lower body explosive power (VJT, VJT Tendo peak power, VJT Tendo peak speed, HJT) showed significant ($p \leq 0.05$) differences among the groups. The same results were also found for the muscle strength and strength endurance measurements (handgrip strength, AST and sit-up test). The only speed-related variable that obtained significant differences between all the groups was 10-metre speed time. However, all the 505 ATT times displayed significant differences between groups. The last shuttle (LS) achieved by the participants showed no significant difference between any of the groups with the last level (LL) reached as well as $\dot{V}O_{2max}$ values indicating significant differences for the gender, racial as well as sport participation groups. No differences were found for maximal heart rate.

The cluster analysis reduced the amount of physical and motor performance variables from 23 to 14 variables. The 14 remaining variables were: VJT height and Tendo peak power, handgrip strength, sit-up repetitions, sit-and-reach distance, horizontal jump distance, 10-metre speed time, HR_{max} as well as all the flexibility measurements in degree (RPSIRT RMTIT, RPSERT, RPSLRT, RASLRT, RMTQT). These 14 variables (Table 3), together with the dichotomised values of gender (male = 1, female = 0), living area (urban = 0, rural = 1), sport participation (yes = 1, no = 0) and race (Caucasian = 0, non-Caucasian = 1) were entered into the forward stepwise regression analysis.

Table 3 Results of the forward stepwise regression analysis based on the adolescents' demographic, physical and motor performance data

Variables	Beta in	Partial R	Semi-partial R	R-square change	*p*-Value
10 m Speed (s)	-0.272	-0.310	-0.176	0.535	0.000*
Sit-ups (reps)	0.299	0.397	0.234	0.056	0.000*
Sport participation level	0.174	0.253	0.141	0.026	0.000*
Handgrip strength (kg)	0.336	0.329	0.188	0.019	0.001*
VJT Tendo peak power (W)	-0.193	-0.202	-0.112	0.025	0.000*
HR_{max} (bpm)	0.130	0.225	0.125	0.017	0.001*
Living area	0.099	0.146	0.080	0.010	0.011*
RPSERT (º)	-0.010	-0.170	-0.093	0.006	0.050*
HJT (cm)	0.119	0.180	0.098	0.008	0.021*
RMTIT (º)	0.085	0.148	0.081	0.007	0.037*

VJT = Vertical jump test, HRmax = Heart rate maximum, RPSERT = Right shoulder external rotation test, HJT = Horizontal jump test, RMTIT = Right Modified Thomas iliopsoas test, R = Correlation

(*$p \leq 0.05$)

The forward stepwise regression analysis' results indicate that the following 10 variables contributed significantly ($p \leq 0.05$) to the 20-m SRT-derived indirect $\dot{V}O_{2max}$ values of the adolescents: 10-metre speed, sit-ups, sport participation level, handgrip strength, VJT Tendo peak power, HR_{max}, living area, RPSERT, HJT and RMTIT. VJT Tendo peak power, 10-metre speed and RSER showed significant negative correlations with the $\dot{V}O_{2max}$ values whereas all the other variables showed significant positive correlations with the dependent variable. From the results in Figure 1 it is clear that 10-metre speed was the biggest contributor (53.5%) to the $\dot{V}O_{2max}$ values. The rest of the variables contributed 17.4% to the overall variance in $\dot{V}O_{2max}$ values. The overall stepwise regression analysis correlation coefficient ($R^2 = 0.71$) indicates that the above-mentioned variables were responsible for 71% of the variance in the $\dot{V}O_{2max}$ values of the adolescents. Variables other than the variables in this study were responsible for 29% of the variation in the results.

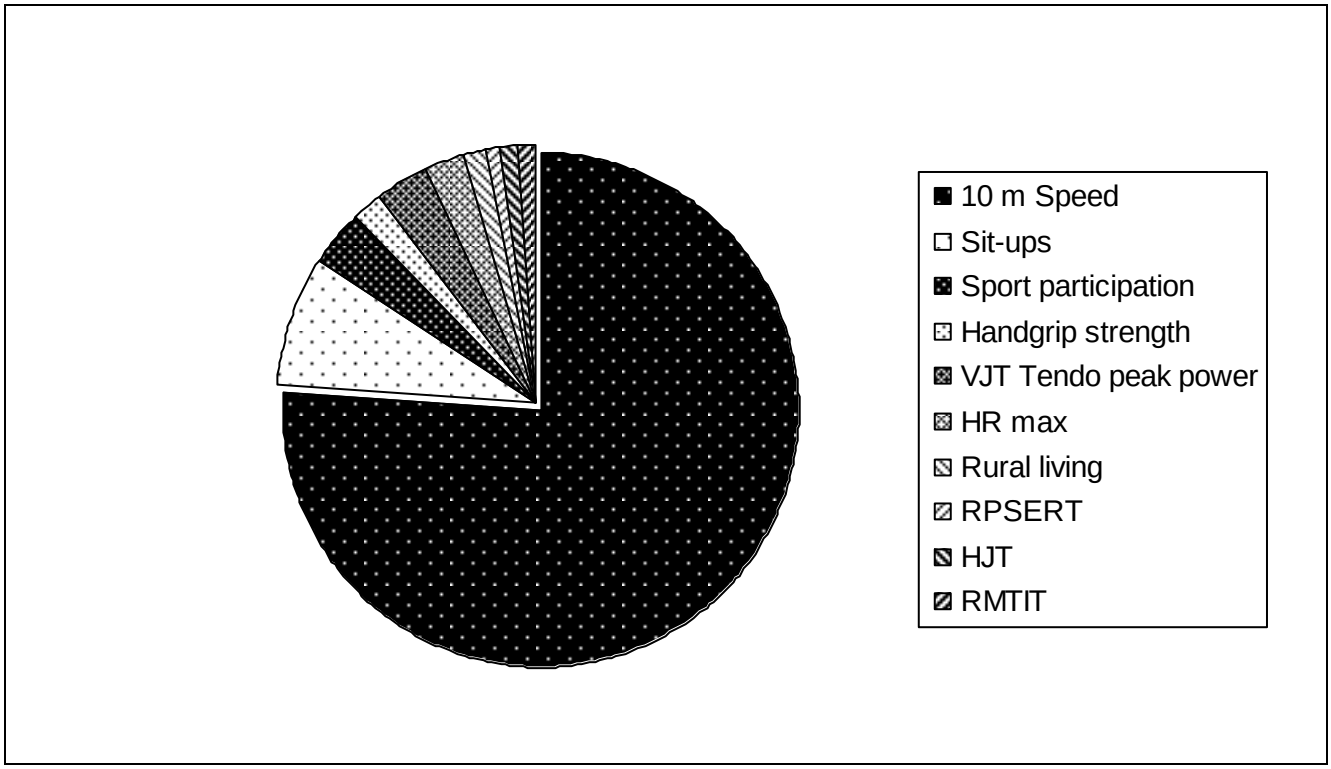

Figure 1 The percentage contribution of each of the independent variables from the forward stepwise regression analysis to the total prediction of the indirect $\dot{V}O_{2max}$.

In order to validate the stepwise multiple regression analysis-derived prediction function the multiple regression analysis results of 75% of the sample group (R^2 = 0.726), together with the results of the 25% sample group (R^2 = 0.615), were entered into Cohen's effect size formula. The effect size result was 0.3, indicating a medium effect size (data not shown). The prediction function is therefore valid in predicting the $\dot{V}O_{2max}$ results of the adolescents.

Discussion

To the authors' knowledge, this is the first study attempting to develop a valid $\dot{V}O_{2max}$ prediction function for South African adolescents by making use of physical and motor performance components as well as demographic variables such as the gender, race and living areas as well as

sport participation level of the participants. The results revealed that a valid $\dot{V}O_{2max}$ prediction function could be compiled by making use of the 10-metre speed, sit-up repetitions, sport participation level, handgrip strength, VJT Tendo peak power, HR_{max}, living area, RPSERT, HJT and RMTIT. All of the last-mentioned variables served as significant predictors of the indirect, 20-m SRT-derived $\dot{V}O_{2max}$ prediction function. However, only 10-metre speed served as a major contributor (53.5%) to the indirect $\dot{V}O_{2max}$ values of the adolescents. This result is similar to those of Chatterjee et al. (14) (maximal running speed: $r = 0.95$, $p \leq 0.01$) and Tong et al. (74) (40 m sprint speed; $r = 0.542$, $p \leq 0.001$) who also found maximal running speed to be a significant $\dot{V}O_{2max}$ predictor for 10 to 16-year-old children and adolescents. Various researchers have referred to the importance of the anaerobic energy system in the execution of the 20-m SRT due to a high number of accelerations and decelerations that take place when running between the 20-metre shuttles (7,56). It is expected that the main energy contribution for the execution of the 10-metre speed test will come from the Adenosine Triphosphate-Creatine Phosphate (ATP-CP) energy stores due to the short duration of this test (51). In this regard McCully et al. (52) showed that PCr resynthesis rate is positively correlated with the activity of citrate synthase, a mitochondrial enzyme that plays a vital role during aerobic metabolism and shows a strong relationship with $\dot{V}O_{2max}$ (79). This last-mentioned finding may serve as a physiological explanation for the identification of 10-metre speed as the major contributor to the indirect $\dot{V}O_{2max}$. Another two anaerobic-related variables also contributed significantly to the indirect $\dot{V}O_{2max}$ values, namely VJT Tendo peak power (2.5%) and HJT (0.8%). These findings may be explained by Foster and Lucia (27), who suggested that plyometric-related training and an increase in explosive leg power will benefit running economy which may positively influence aerobic performance and $\dot{V}O_{2max}$.

Additionally, individual variability in the different test results may have “pulled” skew the multiple regression results and might explain the negative relationship observed. For example, the individual VJT Tendo peak power varied between 696 W (minimum) and 2 870 W (maximum) with a standard deviation of 373 W. The high individual variability in different VJT Tendo peak power results may also suggest that the adolescents in this study showed no clear pattern with regard to the last-

mentioned variable.

The sit-up test results also contributed significantly with 5.6% to the prediction of indirect $\dot{V}O_{2max}$. An inability to stabilize the lumbar pelvic region during running may lead to poor running technique due to inefficient force application, which may provide a reason for the identification of abdominal strength endurance as a predictor of $\dot{V}O_{2max}$ (68).

With regard to the identification of the adolescents' iliopsoas flexibility as a small but significant predictor (0.7%) of indirect $\dot{V}O_{2max}$, research suggests that limited hip extension flexibility as assessed by the Thomas iliopsoas test may cause an increase in pelvic tilt and lumbar lordosis during running (28). According to Hubiche and Pradet (as quoted by Copaver et al. (18)), a deviation in the lumbosacral hinge (such as lordosis) may possibly limit the transmission of ground reaction forces because it is between the force restitution point (pelvis) and the centre of gravity. It can therefore be contended that poor iliopsoas flexibility may give rise to a forward pelvic tilt which may limit ground reaction forces during the running action and ultimately cause a higher stride frequency and lower running economy.

Another unexpected outcome of this study is that RPSERT was also identified as a significant predictor (0.6% contribution) of indirect $\dot{V}O_{2max}$. What is even more interesting is that a negative relationship was observed between the two last-mentioned variables. In view of the fact that no other researchers have reported on the possible influence of shoulder flexibility on the running and $\dot{V}O_{2max}$ performances of participants, the researchers in this study can only speculate on the reason for this result. One possible reason may be that the elbow positioning during the execution of the shoulder external rotation test was totally different from the position maintained during the running action. During the test the participants were in a supine position with the shoulder in 90° abduction and the elbow in 90° flexion compared to the running action during which the shoulder is in an adducted position and the elbow flexed 90° fairly close to the body. According to Gillham (30), a stable midline on the arm back swing during the running action is more dependent on good shoulder extension and internal rotation flexibility than any other shoulder flexibility-related actions.
A strength-related component, namely handgrip strength, also emerged as a significant predictor of $\dot{V}O_{2max}$ (1.9%). Research suggests that handgrip strength is significantly correlated (r = 0.60;

$p \leq 0.001$) with the muscle mass of participants (40). To test this contention the correlation coefficient (R) of the relationship between the adolescents' muscle mass (as obtained from another part of the study) as well as grip strength was calculated and revealed a significant R-value of 0.82. In this regard, a greater muscle mass has been shown to lead to improved ATP production for energy expenditure (9), thereby improving aerobic performance. In addition, Goran et al. (31) also reported a strong and significant correlation ($r = 0.87$, $p \leq 0.001$) between the muscle mass values and aerobic performance of boys and girls.

The fact that HR_{max} was also highlighted as a significant predictor of $\dot{V}O_{2max}$ (1.7%) was not unexpected due to the maximum effort required by participants to elicit a $\dot{V}O_{2max}$ response during execution of the 20-m SRT. Only one study also included HR_{max} as a possible predictor of adolescents' $\dot{V}O_{2max}$ values and reported that a maximal cycle ergometer test elicited an average HR_{max} of 199 bpm which is very near to the running-related HR_{max} found in this study (197 bpm) (5). According to research, an HR_{max} of more than 90%-95% of the age-predicted HR_{max} (19,60) or an HR greater than 185 bpm (26) is an indication that a true $\dot{V}O_{2max}$ was achieved. These criteria would suggest that the adolescents in this study did reach their $\dot{V}O_{2max}$.

The need for the inclusion of demographic variables in the $\dot{V}O_{2max}$ prediction models for adolescents was highlighted by the identification of both sport participation (2.6%) and living area (rural)(1%) as significant predictors of $\dot{V}O_{2max}$. As mentioned before, only one group of researchers has thus far included sport participation as a possible contributor to $\dot{V}O_{2max}$ performances among adolescent girls and reported significantly better aerobic performances for sport participants compared than those of non-sport participants (61). Furthermore, Edgett et al. (20) indicated that training adaptations normally experienced with participation in endurance type activities can also be derived from participation in recreational sport by showing that 4 weeks of sport participation among women led to significant ($p \leq 0.05$) increases in $\dot{V}O_{2max}$ ($p \leq 0.05$) and decreases in respiratory exchange ratio (RER) values. Both the male and female groups, also experienced significant ($p \leq 0.05$) decreases in the $\dot{V}O_2$ kinetics (transition from 0 W to 80 W,

measuring baseline L·min; amplitude l/min and end exercise L·min) which are normally associated with improved fitness levels as well as exercise performance (20).

Despite the acknowledgement by other researchers that participants' living conditions influence aerobic performance, this is the first study to investigate the possible influence of living area on the prediction of $\dot{V}O_{2max}$. The results of the present study showed a significant correlation ($p \leq 0.05$) for rural living conditions with the predicted aerobic performance of the participants. Similar conclusions were also drawn by Chillón et al. (15) who reported higher cardiorespiratory fitness levels ($p \leq 0.001$) in Spanish adolescents living in rural areas than did their peers living in urban settings. Machado-Rodrigues et al. (45) also observed that Portuguese rural living adolescents were 76% more likely to be classified as aerobically fit than urban-living adolescents. Felton et al. (25) reported that even after controlling for race, Caucasian and non-Caucasian girls living in rural areas had higher inclinations of being physically fit than their urban living counterparts. Our results concur with all of the last-mentioned results, despite the fact that McHunu and LeRoux (53) indicated that townships and rural communities in South Africa have inadequate facilities for sport participation and physical activity. Researchers point out that the fact that adolescents living in rural areas have to walk to school as other transport is not always available (57) may serve as a possible reason for the higher cardiorespiratory fitness levels among these adolescents (15).

Cross-validation analyses for the proposed regression-derived prediction model from the current study showed validity and accuracy to predict indirect $\dot{V}O_{2max}$ values in the adolescent participants. None the less, although 71% ($R^2 = 0.71$) of the variation in the indirect $\dot{V}O_{2max}$ performance of the adolescents can be predicted by means of certain physical and motor performance components as well as sport participation level and living area, variables other than these last-mentioned variables might account for the rest of the variation in $\dot{V}O_{2max}$ performance (29%). These variables might include certain anthropometric variables such as fat percentage (21), muscle mass (31) as well as stature and body weight (1) which have all been identified as possible predictors of aerobic performance. It will therefore be important to include these variables in a prediction function to improve the accuracy as well as validity of such a model. However, due to the fact that this prediction model is the first of its kind for a South African population, the need for further validation studies to improve the prediction accuracy of $\dot{V}O_{2max}$ prediction functions,

specific to the South African adolescent population cannot be over-accentuated.

Conclusions

To the authors' knowledge this is the first study to investigate the possibility of predicting indirect aerobic performance in South African adolescents by making use of physical and motor performance test results as well as demographic information, such as the gender, race and living area as well as sport participation level of the participants. The results indicated that variables of 10-metre speed, sit-up repetitions, sport participation level, handgrip strength, VJT Tendo peak power, HR_{max}, living area, RPSERT, HJT and RMTIT served as significant and valid contributors to predict 71% of the variation in South African adolescents' 20-m SRT-derived $\dot{V}O_{2max}$ values. Although the indirect 20-m SRT is a well-known and frequently used test for the prediction of children's $\dot{V}O_{2max}$ values, the prediction model of Léger and Lambert used European adults and did not consider variables related to the characteristics of the participants to compile the model. The model is therefore inaccurate and non-specific for use in adolescent populations from other countries. However, the model developed from this study will enable researchers and human movement-related practitioners to accurately predict the 20-m SRT $\dot{V}O_{2max}$ values of South African adolescents. The use of simple and affordable physical and motor performance tests as well as easily obtainable information for the development of this model will further enable less qualified and less fortunate practitioners to accurately determine the $\dot{V}O_{2max}$ values of adolescents in especially rural areas. However, further studies with larger numbers of South African adolescents are warranted in order to refine and improve the proposed model for use over a wider range of South African children.

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CHAPTER 5

5 THE VALIDITY OF THE 20-M SRT TO DETERMINE VO_2 AND VO_{2MAX} OF A COHORT OF ADOLESCENT BOYS: THE PAHL STUDY

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Abstract

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Acknowledgements

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The Validity of the 20-m Shuttle Run Test to Determine the $\dot{V}O_2$ and $\dot{V}O_{2max}$ of a Cohort of Adolescent Boys: The PAHL study

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Objective: To assess the validity of the 20-m SRT to estimate the $\dot{V}O_2$ and $\dot{V}O_{2max}$ of a cohort of adolescent boys in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa.
Design: 52 Boys (age 15.83 ± 0.65 years; height 168.10 ± 8.37; body mass 59 ± 15.43) took part in a cross-sectional research design.
Methods: Anthropometric measurements were taken and were followed by the performance of a dynamic warm-up after which all the adolescent boys executed a 20-m SRT while they were fitted with a portable gas analyser apparatus (Cosmed k4b2). The rate of oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), minute ventilation ($\dot{V}_E$), respiratory exchanges ratio (RER) and heart rate were continuously measured throughout the test.
Results: The independent t-test revealed significant differences ($p \leq 0.05$) between the predicted indirect (42.06 ± 4.53 ml/kg/min) and the direct $\dot{V}O_{2peak}$ results (50.62 ± 7.11 ml/kg/min). Furthermore, significant differences ($p \leq 0.05$) were observed between the directly and indirectly predicted $\dot{V}O_2$ values at levels 1-9 compared to no significant differences at levels 10 and 11 of the 20-m SRT. The ratio of variation between the direct and indirect $\dot{V}O_2$-values as well as the standard error of the 20-m SRT showed that the extent of variation between the direct and indirect $\dot{V}O_2$ results decreased as the 20-m SRT levels increased.

Conclusions: The 20-m SRT is not a valid test for estimating the $\dot{V}O_2$ and $\dot{V}O_{2max}$ of a cohort of adolescent boys in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa. The 20-m SRT significantly under-predicted the participants' $\dot{V}O_{2max}$ values when compared to the directly measured values for the majority of levels.

Keywords: youth, exercise, aerobic, fitness, regression equation, reliability

1. Introduction

The most accurate method for determining maximal aerobic capacity or $\dot{V}O_{2max}$, which is regarded by most researchers as the best single measurement of cardiorespiratory endurance and aerobic fitness,[4,25] is by means of indirect calorimetry and specifically by open-circuit spirometry and computerized instrumentation in the laboratory.[7,8] However, due to various constraints such as the need for expensive, laboratory equipment as well as qualified personnel and the huge amount of time required for conducting direct tests, researchers have investigated alternative indirect tests which are more easily accessible and allow a larger number of participants to be tested simultaneously.[6,8] Indirect tests are especially important in situations where the aerobic fitness of school children needs to be evaluated and where research is done in rural areas or when large epidemiological field studies are conducted. [5]

Various indirect testing methods have been investigated by researchers,[5,9] but the 20-m Shuttle Run Test (20-m SRT) remains the most extensively researched and utilized indirect test for the prediction of $\dot{V}O_{2max}$ or $\dot{V}O_{2peak}$ [2,8] Although the 20-m SRT is regarded as a practical, valid and reliable indirect test for predicting the $\dot{V}O_{2max}$ values of adult subjects,[2,8] research findings with regard to 8 to 17-year-old children and adolescents are scarce and contradictory. In this regard significant correlations of between r = 0.53 and 0.76 ($p \leq 0.001$ and $p \leq 0.05$) and non-significant correlations of between r = 0.66 and 0.72 ($p > 0.05$ and $p > 0.1$) are reported for the relationship between direct $\dot{V}O_{2max}$ and the estimated, 20-m SRT-predicted $\dot{V}O_{2max}$ values of adolescents.[7,13,15,16,19,27,39] Furthermore, the correlation coefficients between the 20-m SRT and directly determined $\dot{V}O_{2max}$ values of Japanese (r = 0.75 and r = 0.76); Hispanic (r = 0.62, $p \leq 0.001$)[37] and Scottish adolescents (r = 0.60 and 0.65, $p \leq 0.05$),[22] are inconsistent and in most instances, lower than the values for adults (r = 0.92-0.96, $p \leq 0.001$).[11,19,24]

Also, despite the above-mentioned results, most researchers have determined the relationship between the direct and indirect measurements of $\dot{V}O_{2max}$ among different populations of subjects by comparing the indirectly predicted $\dot{V}O_{2max}$ values of the 20-m SRT with the direct laboratory, incremental, treadmill protocol-determined $\dot{V}O_{2max}$ values.[15,16,36] Seen from a physiological point of

view it can be expected that the 20-m SRT will display a curtailed ability to predict $\dot{V}O_{2max}$ values due to differences in the exercise modes utilised.[11] The emergence and use of portable gas analysis equipment have allowed researchers to measure $\dot{V}O_{2max}$ directly during the execution of field tests as opposed to laboratory-confined tests on, for example, a treadmill. However, only a few researchers have analysed the validity of the 20-m SRT by using the respiratory parameters collected by means of a portable gas analyser during execution of the 20-m SRT. In this regard Batista et al.,[3] Ruiz et al.[30] and Ruiz et al.[29] found that the original Léger and Lambert equation[12] of the 20-m SRT significantly underestimated $\dot{V}O_{2max}$ values in 11 to 13-year-old ($p \leq 0.05$) and 13 to 19-year-old adolescents ($p \leq 0.001$). In addition, Melo et al.[23] reported an over-prediction of $\dot{V}O_2$ in less fit and an under prediction of $\dot{V}O_2$ in more fit 8 to 10-year-old children ($p \leq 0.05$) when directly measuring $\dot{V}O_2$ during execution of the 20-m SRT. These results suggest that the energy demands of the 20-m SRT are higher than those of treadmill running and that these differences could possibly be attributed to differences in intensity, exercise mode, technique and musculature employed between the two tests.[11] During execution of the 20-m SRT frequent changes in direction are taking place and the participants are constantly accelerating and decelerating. In contrast, the movements during the direct measurement of $\dot{V}O_2$ on the treadmill are continuous, forward running at constant speeds. The muscle recruitment patterns during the execution of the 20-m SRT will therefore probably be different from those of the direct $\dot{V}O_{2max}$ treadmill progressive load incremental test.[2]

Despite the availability of research that has tested the validity of the 20-m SRT on adolescents by making use of the respiratory parameters collected during the test, the use of diverse populations of participants of both genders and of various ages might have negatively influenced the study outcomes and results. Also up until now, no study has attempted to determine the validity of the 20-m SRT in South African adolescents. Therefore, in view of this background, the purpose of this investigation was to assess the validity of the 20-m SRT to estimate the $\dot{V}O_2$ and $\dot{V}O_{2max}$ of a cohort of adolescent boys in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa. Results of this study could possibly give coaches and sport scientists a clear indication of the 20-m SRT's validity and value in evaluating the aerobic capacity of South

African adolescents.

2. Methods

This research study forms part of a larger longitudinal study, The Physical Activity and Health Longitudinal Study (PAHLS), which is an observational multidisciplinary study. The study started in 2010 and will be continued until 2014. The general goal of PAHLS is to describe the development of physical activity and the determinants of health risk factors and health behaviour, sport determinants and recreational activities in 14 to 17-year-old adolescents attending high schools in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa, over a five-year period. For purposes of the current study a selected group, cross-sectional experimental research design in which the data from the 2012 sample was used, was implemented. The study was approved by the Ethics Committee of the North-West University (NWU-0058-01-A1) as well as the North West Department of Health and the District Director of the Potchefstroom Department of Education. In view of a previous study on adolescents that made use of a similar method to evaluate the validity of the 20-m SRT,[29] we hypothesized that the study results would show that the 20-m SRT is not a valid test for estimating the $\dot{V}O_2$ and $\dot{V}O_{2max}$ of a cohort of adolescent boys in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa.

A total of 52 boys in grade 10 (aged 15.83 ± 0.65 yrs; height 168.10 ± 8.37 cm; weight 59.00 ± 15.43 kg; maturity age 1.80 ± 0.42) of high schools in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa were purposefully selected from pre-acquired class lists, from six secondary schools. Two of the selected schools were in the Potchefstroom City area, which predominantly comprised learners from a high socio-economic status and four from the Ikageng Township area, which predominantly comprised learners from a low socio-economic background. Due to the fact that the learners were not randomly selected according to the population density of the two geographical areas, the learners cannot be considered representative of the adolescents' population; nor of the Tlokwe Local Municipality (Potchefstroom area) or of South Africa. Only learners in grade 10 at the time of measurement (2012) were eligible to participate in the study. Prior to participating in the study, all participants were informed about the nature of the study, and all potential risks and benefits were explained to them. Informed consent for the investigation was requested from the school authorities, the parents and learners of the participating schools during the weeks prior to the testing period.

On arrival the participants first completed an informed consent form together with a Demographic, General Information, Sport and Training Habits, Physical Activity and Maturity Determination Questionnaire, after which the anthropometric measurements and the cardiovascular endurance test followed. Before the start of the cardiovascular endurance test the participants were subjected to a thorough warm-up of more or less 15 minutes that consisted of aerobic running exercises for more or less 8 minutes, after which a specific warm-up period of shorter, high-intensity movements and dynamic stretches followed.

Body mass was measured with a portable electronic scale (Beurer Ps07 Electronic Scale, Ulm, Germany) to the nearest 0.1 kilogramme and stature as well as sitting height was taken to the nearest 0.1 centimetre with a Harpenden portable stadiometer (Holtain Limited, U.K.) according to the protocols of The International Society for the Advancement of Kinanthropometry (ISAK).[35] Skinfold measurements were taken with a Harpenden skinfold calliper (Holtain Limited, U.K.) to determine body-fat percentage of the participants according to the equations of Lohman et al.[14] and Slaughter et al.[32] All measurements were taken twice by ISAK Level 2 certified anthropometrists.

Maturity age was estimated by using the anthropometric measures of body stature, sitting height and body mass together with the variables of gender, date of birth and date of measurement in order to calculate peak height velocity (PHV) age. Maturity age was calculated by subtracting age at PHV from chronological age at the time of measurement.[38] In cases where the age at PHV was the same as the chronological age, maturity age was categorised as 0.[38] In cases where chronological age was higher than the age at PHV, maturity age was regarded as positive, whereas negative results were an indication that the age at PHV was higher than chronological age. [38] Information with regard to the menarche age of the girls and the age at which the boys' voice broke were also used to verify the maturation age of each of the genders. Cultural beliefs and practices prevented the researchers of this study from using the Tanner stages[10] to determine the maturation age of each of the adolescents. Although not the direct aim of this study, the maturity age of the adolescents was considered in order to verify certain trends with regard to their anthropometric and aerobic profile.

The 20-m Shuttle Run Test (20-m SRT) was conducted according to the procedures described by the Australian Sports Commission. [1] On their arrival the test procedure was clearly explained to each participant. A Fix Polar Heart Rate Transmitter Belt (Polar Electro, Kempele, Finland) was strapped to the chest of each participant before commencement of the test. The learners' heart rates were measured for each 5-second period with the use of a Polar Team² Pro Electro system (Kempele, Finland) and were recorded on a laptop computer with the Polar Team² Pro software

program. The 20-m SRT was conducted barefoot on a flat, clearly marked 20-metre stretch on a grass field.

All of the participants ran the 20-m SRT while they were fitted with a portable gas analyser apparatus (Cosmed K4b2, Cosmed Ltd., Rome, Italy) which was used to sample expired air continuously and the rate of oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), minute ventilation ($\dot{V}_E$) and respiratory exchange ratio (RER). The portable gas analyser was calibrated with standard gases before commencement of the test.

The criteria for reaching the $\dot{V}O_{2max}$ value used is a heart rate of 220 bpm minus age in years, an RER-value of bigger than 1.05; and oxygen consumption that ceases to rise and reached a plateau or began to fall even though the work rate continued to increase.[17]

The descriptive statistics (averages, standard deviations, minimum and maximum values) of each test variable were firstly calculated. This was followed by the execution of independent *t*-tests between the direct and indirect values of the 20-m SRT. The level of significance was set at $p \leq 0.05$. Lastly, the average ratio of differences between the direct and indirect measurements of the 20-m SRT was calculated and plotted along with the standard error (SE) of measurements against the various 20-m SRT levels. This graph provided the researchers with answers regarding the variation in the relationship between the predicted and directly measured $\dot{V}O_2$ values. All analyses were done on the statistical data processing package for Windows Statistica.[34]

3. Results

Results pertaining to the 20-m SRT are presented in Tables 1 and 2. The results in Table 1 indicate that the minimum 20-m SRT level reached was level 3 and the maximum level, level 11. Less than 50% of the total group reached level 9 (n = 22) and only one participant reached level 11 of the 20-m SRT. Significant differences ($p \leq 0.05$) existed between the directly and indirectly predicted $\dot{V}O_2$ values at levels 1-9 of the 20-m SRT. No significant differences with regard to the last-mentioned values were observed for levels 10 and 11.

Table 2 contains the maximal values participants reached during execution of the 20-m SRT. The maximal respiratory exchange ratio (RER) reached during the 20-m SRT was 1.29 ± 0.21. The participants obtained an average maximal heart rate of 199.75 ± 13.25 bpm and an average direct

$\dot{V}O_{2max}$ value of 50.62 ± 7.11 ml/kg/min which is significantly higher than the average indirectly predicted measurement of 42.06 ± 4.53 ml/kg/min. The $\dot{V}O_{2max}$ value was achieved at an average 20-m SRT level of 8.

Table 1.

Descriptive statistics for the 20-m SRT-related variables of the adolescent boys. Values are mean ± *SD*.

Levels of the 20-m SRT	Number of participants (*n*)	Heart rate values per level (bpm)	Indirect predicted $\dot{V}O_2$-values per level (ml/kg/min)	Direct measured $\dot{V}O_2$-values per level (ml/kg/min)
Level 1	52	166.29 ± 10.71	19.55 ± 0.00	35.16 ± 4.25*
Range		140.00 - 183.00	19.55 - 19.55	21.54 - 44.71
Level 2	52	177.25 ± 10.64	22.95 ± 0.00	40.21 ± 4.22*
Range		152.00 - 195.00	22.95 - 22.95	24.02 - 47.96
Level 3	52	183.56 ± 10.12	26.08 ± 0.13	43.23 ± 5.00*
Range		159.00 - 201.00	25.15 - 26.10	25.10 - 54.15
Level 4	51	188.53 ± 10.00	29.50 ± 0.00	45.96 ± 4.70*
Range		156.00 - 208.00	29.50 - 29.50	33.00 - 55.39
Level 5	51	193.08 ± 10.20	32.90 ± 0.00	47.50 ± 5.11*
Range		148.00 - 208.00	32.90 - 32.90	33.72 - 65.00
Level 6	51	195.41 ± 10.77	36.30 ± 0.43	48.59 ± 5.74*
Range		152.00 - 214.00	33.60 ± 36.40	31.34 - 58.32
Level 7	47	198.96 ± 7.84	39.65 ± 0.64	50.04 ± 5.33*
Range		172.00 - 213.00	37.45 - 39.90	37.17 - 63.37
Level 8	39	200.51 ± 7.95	42.45 ± 1.17	50.58 ± 5.66*
Range		177.00 - 218.00	40.20 - 43.30	36.90 - 60.77

* $p \leq 0.05$

Table 1. (continued)

Descriptive statistics for the 20-m SRT-related variables of the adolescent boys. Values are mean ± *SD*.

Levels of the 20-m SRT	Number of participants (*n*)	Heart rate values per level (bpm)	Indirect predicted $\dot{V}O_2$-values per level (ml/kg/min)	Direct measured $\dot{V}O_2$-values per level (ml/kg/min)
Level 9	22	201.18 ± 15.05	45.34 ± 1.29	50.73 ± 5.41*
Range		146.00 - 222.00	43.60 - 46.80	40.64 - 61.84
Level 10	8	195.50 ± 22.22	48.19 ± 1.05	50.34 ± 6.40
Range		146.00 - 221.00	47.10 - 50.20	40.72 - 60.65
Level 11	1	204.00 ± 0.00	52.20 ± 0.00	59.98 ± 0.00

* $p \leq 0.05$

Table 2

Maximal values obtained during the 20-m SRT. Values are mean ± *SD*.

Variables	Maximal values obtained
20-m SRT last level	8.19 ± 1.39
20-m SRT last shuttle	4.71 ± 2.75
Direct $\dot{V}O_{2max}$ value (ml/kg/min)	50.62 ± 7.11
Indirect $\dot{V}O_{2max}$ value (ml/kg/min)	42.06 ± 4.53
HR_{max} (bpm)	199.75 ± 13.25
RER-value	1.29 ± 0.21

20-m SRT: 20 m shuttle run test; $\dot{V}O_{2max}$: maximal oxygen uptake; HRmax: maximal heart rate; RER: respiratory exchange ratio

In order to compare the directly and indirectly measurement techniques, the average ratios of the differences between every participant's directly and indirectly predicted $\dot{V}O_2$ values were determined. The values, expressed as the ratio of variation as well as the standard error (SE) of measurements are presented in Figure 1. From Figure 1 it is evident that ratio of variation between the direct and indirect measurement was high at the first levels of the 20-m SRT (direct:indirect = 1.8) but decreased as the test progressed (direct:indirect = 1.15 at level 11).

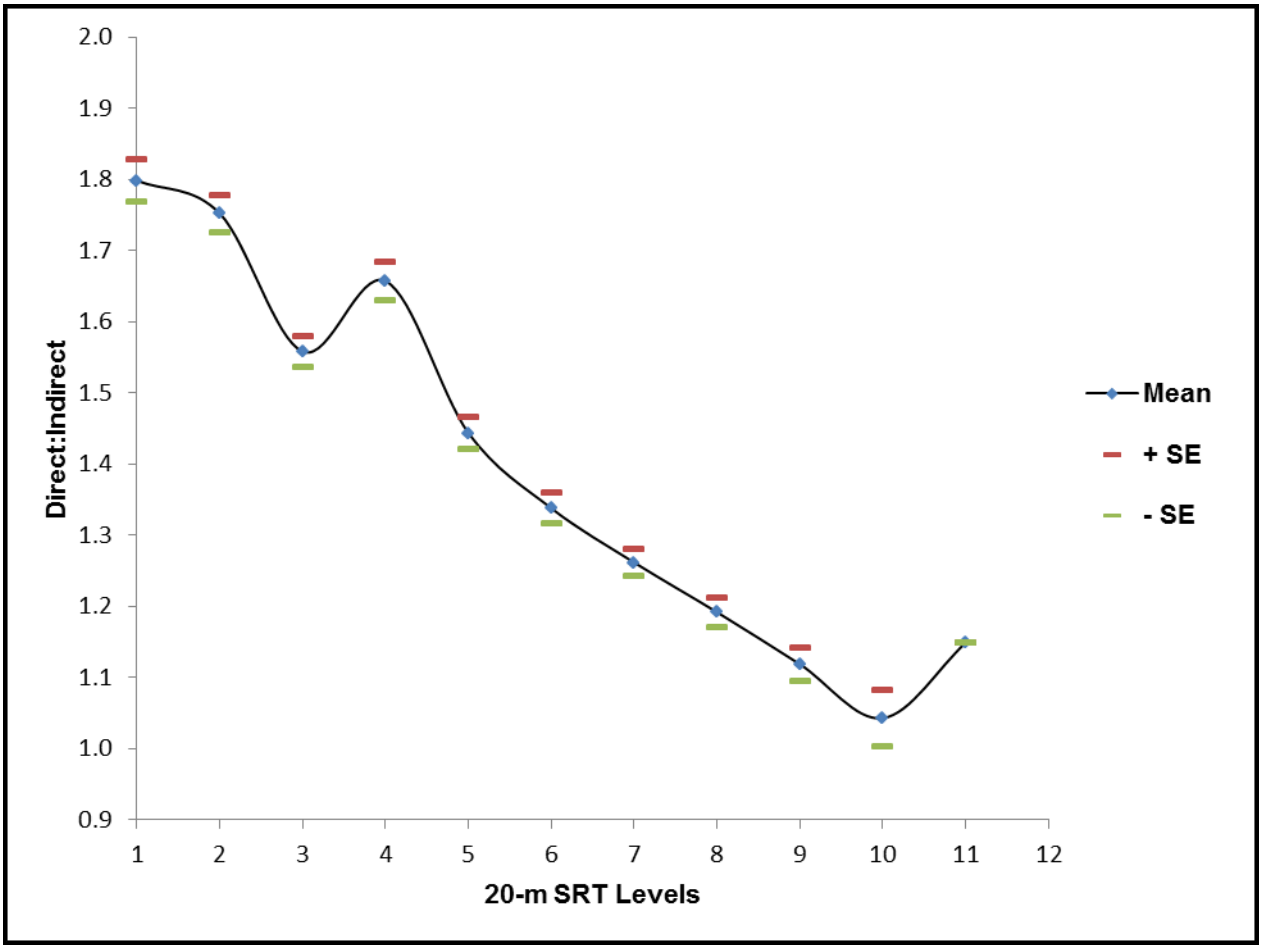

Fig 1. The ratio of variation between the direct and indirect $\dot{V}O_2$ values as well as the *SE* of the 20-m SRT plotted against the levels of the 20-m SRT.

4. Discussion

To our knowledge, this is the first South African-based study to investigate the relationship between the indirectly predicted and direct $\dot{V}O_{2max}$ values of the 20-m SRT. The study found a significant difference ($p \leq 0.05$) between the predicted indirect $\dot{V}O_{2max}$ results (42.06 ± 4.53 ml/kg/min) as obtained from the 20-m SRT booklet and the direct $\dot{V}O_{2max}$ results (50.62 ± 7.11 ml/kg/min) as obtained from the gas analysis. Furthermore significant differences ($p \leq 0.05$) were observed

between the directly and indirectly predicted $\dot{V}O_2$ values at levels 1-9 of the 20-m SRT compared to no significant differences at levels 10 and 11 of the 20-m SRT. A figure (Figure 1) in which the ratio of variation between the direct and indirect $\dot{V}O_2$-values as well as the *SE* of the 20-m SRT were plotted against the levels of the 20-m SRT, also showed that the extent of variation between the directly and indirectly predicted $\dot{V}O_2$ results decreased as the 20-m SRT levels increased. Changes in variation between the direct and indirect scores would suggest that the predicted scores are more accurate at higher levels of the 20-m SRT. However, it must be underscored that very few of the adolescents in this study completed the higher levels (level 11: 8 participants; level 11: 1 participant) of the 20-m SRT test. It is therefore possible that this phenomenon may have influenced the changes in the variation between the direct and indirect $\dot{V}O_2$ values as the 20-m SRT increased. Despite these facts, results revealed that the 20-m SRT booklet significantly under-predicted the participants' $\dot{V}O_{2peak}$ values when compared to direct measured values for the majority of 20-m SRT levels. The hypotheses that the study results would show that the 20-m SRT is not a valid test for estimating the $\dot{V}O_2$ and $\dot{V}O_{2max}$ of a cohort of adolescent boys in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa, is therefore accepted.

Although other researchers have also compared the indirectly predicted and direct $\dot{V}O_{2max}$ values of the 20-m SRT by making use of portable gas analyses,[3,23,30] none of these studies focussed on adolescents from South Africa. We were thus unable to directly compare the results of this study with those of similar studies. Despite these differences between this study and those that made use of a similar methodology, all the last-mentioned authors also reported that the original Léger and Lambert equation[12] used to compile the $\dot{V}O_{2max}$ prediction table of the 20-m SRT booklet, underestimated the direct $\dot{V}O_{2max}$ values of the adolescents. In this regard, Ruiz et al.[29] for example observed a significantly higher direct $\dot{V}O_{2max}$ measurement of 47.1 ± 8.1 ml/kg/min than a predicted $\dot{V}O_{2peak}$ value of 41.5 ± 5.2 ml/kg/min for 48 adolescents.

The under-prediction of $\dot{V}O_2$-values by the 20-m SRT booklet can be the result of various

factors: The prediction equation used in the 20-m SRT booklet was developed by Léger and Lambert in 1982.[12] The population from which the prediction equation was developed was 91 European adults between ages 18 and 37 years,[12] whereas the participants in the current study were a group of 52 adolescent boys with an average age of 15.83 ± 0.65 years. Comparatively, adolescents will expend more energy to complete each level of the 20-m SRT than adults, which will result in higher $\dot{V}O_2$-values for each 20-m SRT level.[17] The higher energy expenditure by adolescents is probably due to greater stride frequencies for every 20-m SRT level, poorer running mechanics, a lower running economy[21,26,28] and less effective breathing and ventilation[28] than those of adults.

Another factor that needs to be considered when interpreting the study results is the influence of gender on aerobic performance. Males tend to show higher $\dot{V}O_2$ responses for the same exercise intensity than females.[30,31] The original Léger and Lambert participant group consisted of 32 females and 59 males.[12] The inclusion of females in the testing group may have caused a decrease in the overall average $\dot{V}O_2$ response to the 20-m SRT compared to this study where 52 male adolescents formed the participant group.

Finally, research has also suggested that environmental factors such as climate and altitude may influence the $\dot{V}O_2$-values. In this regard Sproule et al.[33] attributed the under-prediction of $\dot{V}O_2$ values by the 20-m SRT in a group of male and female physical education students (aged 23.6 ± 3.4 years) from Singapore to climatic differences between Singapore and the United Kingdom (UK) where the original equation was developed. This statement, together with the climatic differences between South Africa and the UK, may therefore also serve as a possible reason for the under-prediction of $\dot{V}O_2$ by the 20-m SRT in this study. Altitude is another factor that will have a pronounced effect on the 20-m SRT-predicted $\dot{V}O_2$ values with a higher altitude leading to an increased level of effort due to a decrease in partial oxygen levels.[20] The participants in this study performed the 20-m SRT at an altitude of 1 351 metres above sea level, as opposed to those in Léger and Lambert's study[12] in which participants performed the test at more or less 92 metres above sea level (Leicester, UK). Therefore it can be expected that the participants in this study will experience higher $\dot{V}O_2$ values**,** which may cause an under-prediction of predicted scores by the 20-m SRT booklet.

In contrast to the last-mentioned conclusions with regard to the validity of the 20-m SRT for the prediction of adolescents' $\dot{V}O_{2max}$ values, some researchers supported the use of the 20-m SRT-predicted $\dot{V}O_{2max}$ scores in groups of children and adolescents.[7,16, 27] Several of these researchers reported small insignificant differences ($p > 0.1$) between the directly measured and predicted $\dot{V}O_2$ of the 20-m SRT (Chatterjee et al.[7]: direct: 51.68 ± 5.25ml/kg/min *versus* indirect: 51.36 ± 5.36 ml/kg/min; Mahar et al.[16]: direct: 44.4 ± 8.4 ml/kg/min *versus* indirect: 43.5 ± 6.0 ml/kg/min). However, all the researchers that found more favourable results for the 20-m SRT, made use of treadmill protocols and static gas analysers to compare the directly obtain $\dot{V}O_2$ values to the indirectly predicted values of the 20-m SRT. Also, despite the fact that their research supported the use of the 20-m SRT in adolescent populations, the majority of researchers still recommended the use of other equations to improve the accuracy of predicting adolescents' $\dot{V}O_2$ values by making use of the 20-m SRT.[7,16,19]

5. Conclusion

In conclusion, the research results of this study suggest that the 20-m SRT is not a valid test for accurately predicting $\dot{V}O_2$ and $\dot{V}O_{2max}$ of a cohort of adolescent boys in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa. However, it would seem that the relationship between the indirect and direct $\dot{V}O_2$-values of the 20-m SRT are influenced by the number of levels participants execute with the predicted scores that are more accurate at higher levels of the 20-m SRT. These results emphasise the necessity for the development of $\dot{V}O_2$ prediction models for specific populations and for specific age groups.[18,19] Practitioners and researchers, that apply $\dot{V}O_2$ prediction models on participants for which the models were not originally developed, will obtain inaccurate and invalid $\dot{V}O_2$ results. To date no such model has been develop for use among South African adolescents. The results of this study accentuate the need for such a model to enable practitioners and researchers alike to accurately determine

adolescents' $\dot{V}O_2$ and $\dot{V}O_{2peak}$ values by making use of the 20-m SRT.

Practical implications

- The original 20-m SRT is not suitable for predicting aerobic performance in South African adolescents.
- Further investigation with regard to the development of a $\dot{V}O_2$ prediction model for use among South African adolescents is needed.

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Disclaimer

Any opinion, findings and conclusions or recommendations expressed in this material are those of the authors; therefore the NRF and MRC do not accept any liability in this regard.

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CHAPTER 6

6 SUMMARY, CONCLUSIONS, LIMITATIONS & RECOMMENDATIONS

1. **Summary**

2. **Conclusions**

3. **Limitations and Recommendations**

1. Summary

The purpose of this study was firstly, to determine whether a valid $\dot{V}O_{2max}$ prediction function can be developed from several anthropometric measurements and demographic factors such as gender, race, and living area as well as sport participation level of a cohort of adolescents in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa; secondly, to determine whether a valid $\dot{V}O_{2max}$ prediction function can be developed from the physical and motor performance components as well as demographic variables such as gender, sport participation levels, race and living area of a cohort of adolescents in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa; lastly, to assess the validity of the 20-m SRT to estimate the $\dot{V}O_2$ and $\dot{V}O_{2max}$ of a cohort of adolescent boys in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa.

Chapter 1 provided a brief summary of the problem that underlies the research questions of the study and the research questions as such, the objectives and the related hypotheses of the study as well as the structure of the thesis.

Chapter 2 consisted of a literature overview titled: “Predictors and prediction models/equations of aerobic power in children and adolescents”. The purposes of this review were firstly, to name and describe the various direct and indirect methods for determining $\dot{V}O_{2max}$ cited in the scientific literature. In cases where the reliability and validity of the different methods have been investigated, findings with regard to these results were reported. The second aim was to provide a review on the findings with regard to the aerobic performances or $\dot{V}O_{2max}$ values of children and adolescents. The third aim was to discuss the possible influence of various anthropometric, physical and motor-performance components on the aerobic performances or $\dot{V}O_{2max}$ values of the last-mentioned groups of subjects. As part of this aim other literature-identified factors such as certain demographic factors (living area, race and gender), sport and physical activity participation level which may also influence the aerobic performances and $\dot{V}O_{2max}$ values of the participants, were discussed. Lastly, all literature-identified models for the prediction of aerobic performances or

$\dot{V}O_{2max}$ values in children and adolescents were mentioned and discussed.

The direct determination of $\dot{V}O_{2max}$ by making use of open circuit spirometry is regarded as the gold standard to determine $\dot{V}O_{2max}$ values but due to various constraints, a number of indirect testing methods have been developed. The indirect testing methods are less expensive, do not require specialized equipment and qualified personnel and can also be used to test a large number of participants outside a laboratory setting. Direct and indirect testing is done by making use of various testing protocols to determine the $\dot{V}O_{2max}$ values of children, adolescents and adults. The protocols include running or walking on a treadmill, submaximal or maximal cycling on an ergometer, bench stepping as well as various field testing protocols. Correlations of r = 0.81 – 0.99 and Standard Error of Estimate (SEE) = 0.08 – 1.9 ml/kg/min have been reported for the test-retest reliability of the direct testing protocols in adult populations. The indirect testing methods make use of regression equations or prediction models from which the participants' $\dot{V}O_{2max}$ values are predicted. Reliability coefficient for the various models of r = 0.53 – 0.96 with SEE = 0.3 – 4.85 ml/kg/min have been reported for adolescent and adult populations. Very few researchers have reported on the reliability of both the direct and indirect $\dot{V}O_{2max}$ testing methods for children and adolescents.

The 20-m SRT is the most widely used indirect testing method for children, adolescents and adult populations. Correlations for the relationship between the 20-m SRT-predicted and directly determined $\dot{V}O_{2max}$ values range between r = 0.68 and r = 0.96 ($p \leq 0.001 – 0.05$) for adults and r = 0.75 to 0.75 ($p \leq 0.001$) for children. Despite the rather high and significant correlation values, some researchers found that the 20-m SRT significantly under-predicted $\dot{V}O_{2max}$ values of adolescents and adults. Researchers have therefore investigated the possibility of improving the prediction ability of the 20-m SRT by also including other $\dot{V}O_{2max}$ -contributing factors in the original prediction model.

The aerobic performance reported for children and adolescents varies to a large degree, mostly due to the influence of growth and maturation from childhood into adolescents. The highest $\dot{V}O_{2max}$ results are reported for 12 to 14-year-old cross-country runners (61.7 ± 4.4 ml/kg/min), 9 to 19-year-old competitive distance runners (51.8 ± 6.4 - 67.8 ± 5.6 ml/kg/min), 13 to 15-year-old adolescent soccer players (65.3 ± 5.0 – 70.7 ± 4.3 ml/kg/min) and 14 to 18-year-old internationally ranked tennis players (58.9 ± 5.3 – 63.8 ± 5.7 ml/kg/min). The next best $\dot{V}O_{2max}$ values were observed for moderate to vigorously active 9-year-old children that achieved values of between 36.7 ± 5.3 and 42.3 ± 6.9 ml/kg/min and for 15-year-old adolescents that achieved values of between 40.2 ± 5.9 and 51.0 ± 6.7 ml/kg/min. The lowest $\dot{V}O_{2max}$ results were reported for obese children and adolescents (17.4 ± 3.6 – 32.0 ± 4.1 ml/kg/min). Together with the influence of growth and maturation, gender has also been identified in literature as a factor that might influence the $\dot{V}O_{2max}$ results of participants. In this regard children and adolescent boys (41.3 ± 7.9 – 56.0 ± 5.0 ml/kg/min) generally achieve much higher $\dot{V}O_{2max}$ values (22.11 ± 4.14 - 52.4 ± 8.2 ml/kg/min) than girls of the same age group.

Most researchers agree that a participant's anthropometric profile is probably one of the aspects that influence aerobic performance most. In this regard body fat percentage, BMI, fat-free and muscle mass, body stature and weight are some of the primary identified anthropometric components that influence not only the aerobic performance of children and adolescents, but also adult populations. Although research has primarily focused on the influence of anthropometric-related variables on participants' $\dot{V}O_{2max}$ values, physical and motor-performance components have also been identified as contributors to participants' $\dot{V}O_{2max}$ values. In this regard researchers identified the following physical and motor performance components as $\dot{V}O_{2max}$ -influencing factors for adolescents and adults: 40, 50 and 300 metre sprinting time, VJ height, CMJ height, VJ power, plyometric leap distance, knee flexor/extensor strength and lower body flexibility. However, the majority of the literature focused on adult populations when the last-mentioned theme was investigated.

Demographic factors that have shown to possibly influence aerobic performance include race, living area and sport participation or physical activity level. Overall, literature suggests that rural-living non-Caucasian participants outperform their Caucasian, urban-living peers. Literature that does not support this finding suggests that safety concerns, as well as the unavailability of facilities in rural environments, contribute to low sport or physical activity levels in these children and adolescents. The majority of researchers also reported that children and adolescents that did not participate in sport or were physically inactive displayed significantly lower $\dot{V}O_{2max}$ values than their sport-participating and physically active peers.

Newer prediction models that have been developed in order to improve the accuracy of older models have included variables such as the participants' PACER test results, the 20-m SRT-obtained maximal speed, body and fat-free mass, BMI, gender, race, sport participation and physical activity level. The new models are not only more accurate in predicting $\dot{V}O_{2max}$ but also highlight the importance of developing models which consider the above-mentioned variables and which are more specific to the population being tested.

Presently, a large amount of literature pertaining to the influence of various factors on adult populations' $\dot{V}O_{2max}$ is available but a limited number of researchers has focused on the influence of various factors on the $\dot{V}O_{2max}$ results of children and adolescents. More research is also needed with regard to accurate and simpler $\dot{V}O_{2max}$ prediction models for children and adolescents of specific populations.

Chapter 3 consisted of the first article which was compiled in accordance with the guidelines of the journal Human Movement Science and titled: "The use of anthropometric measurements and the influence of demographic factors on the prediction of $\dot{V}O_{2max}$ in a cohort of adolescents: The PAHL study". The purpose of this article was to develop a valid $\dot{V}O_{2max}$ prediction function from several anthropometric measurements and demographic factors such as gender, race and living area as well as sport participation level of a cohort of adolescents living in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa. The article succeeded in showing that

muscle mass percentage, sport participation level, stature, hip circumference and ectomorphy act as significant predictors ($p \leq 0.05$) of the indirect 20-m SRT $\dot{V}O_{2max}$ values of a cohort of adolescents in the in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa. Both hip circumference and ectomorphy displayed significant negative relationships with $\dot{V}O_{2max}$, whereas the rest of the variables displayed significant positive relationships with the dependant variable. Furthermore, it was found that 70% of the variance in the indirect, 20-m SRT $\dot{V}O_{2max}$ values could be explained by making use of the anthropometric measurement and non-anthropometric-related forward stepwise multiple regression analysis-derived model. Muscle mass percentage emerged as the strongest predictor (59%) of adolescents' $\dot{V}O_{2max}$ values, followed by sport participation level (6%), ectomorphy (2%), stature (1%) and hip circumference (1%). A cross-validation also revealed that the model is a valid model (Cohan's effect size of 0.1) for predicting the 20-m SRT-derived indirect $\dot{V}O_{2max}$ values of this cohort of adolescents.

Chapter 4 contained the second article, which was compiled in accordance with the guidelines of the Pediatric Exercise Science journal and titled: "Developing a $\dot{V}O_{2max}$ prediction function from the physical, motor-performance and demographic components of a group of adolescents: The PAHL study". The purpose of this study was to develop a $\dot{V}O_{2max}$ prediction function from the physical and motor performance components as well as demographic variables such as gender, race and living area as well as sport participation level of a cohort of adolescents living in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa. The results of this article revealed that a valid $\dot{V}O_{2max}$ prediction function (Cohen's effect size of 0.3) could be compiled by making use of the 10-metre speed, sit-up repetitions, sport participation level, handgrip strength, Vertical Jump Test (VJT), Tendo peak power, maximal heart rate (HR_{max}), living area, right shoulder external rotation flexibility (RPSERT), horizontal jump test distance (HJT) and right Modified Thomas iliopsoas flexibility (RMTIT). All of the last-mentioned variables served as significant predictors ($p \leq 0.05$) of the indirect, 20m-SRT-derived $\dot{V}O_{2max}$ prediction function. However, only 10 metre speed served as a major contributor (53.5%) to the indirect $\dot{V}O_{2max}$ values

of the adolescents. The rest of the variables contributed 17.4% to the overall variance in $\dot{V}O_{2max}$ values. Overall, last-mentioned variables were responsible for 71% of the variance in the $\dot{V}O_{2max}$ values of the adolescents.

Chapter 5 consisted of the third and final article which was compiled according to the guidelines of the Journal of Science and Medicine in Sport and titled: "The validity of the 20-m Shuttle Run Test to determine the $\dot{V}O_2$ and $\dot{V}O_{2max}$ in a cohort of adolescent boys: The PAHL study". The purpose of the article was to determine the validity of the 20-m SRT to estimate the $\dot{V}O_2$ and $\dot{V}O_{2max}$ of a cohort of adolescent boys in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa. This was the first article to explore the validity of the 20-m SRT for adolescent boys in South Africa. The results of this investigation showed a significant difference ($p \leq 0.05$) between the predicted indirect $\dot{V}O_{2max}$ results (42.06 ± 4.53 ml/kg/min) as obtained from the 20-m SRT booklet and the direct $\dot{V}O_{2max}$ results (50.62 ± 7.11 ml/kg/min) as obtained from the gas analysis. Furthermore, significant differences ($p \leq 0.05$) were observed between the directly and indirectly predicted $\dot{V}O_2$ values at levels 1 – 9 of the 20-m SRT, whereas no significant differences were observed at levels 10 and 11 of the 20-m SRT. Results also showed that the extent of variation between the direct and indirect $\dot{V}O_2$ results decreased as the 20-m SRT levels increased. The results therefore suggest that the 20-m SRT is not a valid test for the accurate prediction of $\dot{V}O_2$ and $\dot{V}O_{2max}$ of a cohort of adolescent boys in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa.

2. Conclusions

The conclusions drawn from this research are presented in accordance with the set hypotheses from Chapter 1:

Hypothesis 1: *A valid $\dot{V}O_{2max}$ prediction function can be developed by making use of the fat percentage, body mass and muscle mass as well as BMI and demographic variables such as gender, race and living area as well as sport participation level of a cohort of adolescents living in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa.*

Hypothesis 1 is partly accepted, based on the fact that a valid $\dot{V}O_{2max}$ *prediction* model was developed by making use of the muscle mass percentage, sport participation level, stature, hip circumference and ectomorphy values of the participants. These variables all contributed significantly to the indirect $\dot{V}O_{2max}$ values of the participants. A cross-validation also revealed that the model is valid for predicting the 20-m SRT-derived indirect $\dot{V}O_{2max}$ values of this cohort of adolescents.

Hypothesis 2: *A valid $\dot{V}O_{2max}$ prediction function can be developed by making use of the speed, agility, explosive power, strength and flexibility measurements as well as demographic variables such as gender, race and living area as well as sport participation level of a cohort of adolescents living in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa.*

Hypothesis 2 is partly accepted in view of the fact that a valid $\dot{V}O_{2max}$ **prediction** function was developed by making use of the 10-metre speed, sit-ups, sport participation level, handgrip strength, VJT Tendo peak power, HR_{max}, living area, RPSERT, HJT and RMTIT values of the cohort of adolescents. Cross-validation of the proposed model also revealed that it is a valid model for predicting these adolescents' $\dot{V}O_{2max}$ values.

Hypothesis 3: *The 20-m SRT is not a valid test for estimating the $\dot{V}O_2$ and $\dot{V}O_{2max}$ of a cohort of adolescent boys in the Tlokwe Local Municipality (Potchefstroom area) of North West Province, South Africa.*

Hypothesis 3 is accepted, due to the study results which indicated that a significant difference ($p \leq 0.05$) existed between the predicted indirect $\dot{V}O_{2max}$ results as obtained from the 20-m SRT booklet and the direct $\dot{V}O_{2max}$ results as obtained from the gas analysis. Furthermore, significant differences ($p \leq 0.05$) were observed between the directly and indirectly predicted $\dot{V}O_2$ values at levels 1 – 9 of the 20-m SRT compared to no significant differences at levels 10 and 11 of the 20-m SRT.

3. Limitations and Recommendations

To the researchers' knowledge, this is the first study to investigate the predictive value of anthropometric, physical and motor performance components as well as the influence of demographic factors such as gender, race, living area as well as sport participation level on the prediction of $\dot{V}O_{2max}$ performance of adolescents in South Africa. Furthermore, this is also the first study to investigate the relationship between the indirect and direct measurements of the 20-m SRT-derived values among a group of adolescents in South Africa. Also, up until now, no researchers have attempted to develop specific $\dot{V}O_{2max}$ prediction models for use on South African adolescents. The model developed through this study is aimed at South African adolescents from different racial backgrounds, living areas and gender groups and may allow practitioners in the field of Human Movement Science to more accurately screen the indirect $\dot{V}O_{2max}$ values of this population. Despite these facts, several shortcomings of this study should, however, be considered along with recommendations for future researchers that wish to focus on this field of study:

- The anthropometric measurements, physical and motor performance components as well as demographic variables included in the prediction functions of this study accounted on average for 70.5% of the variance in adolescents' $\dot{V}O_{2max}$ values. Variables other than those in this study contributed on average 29.5% to the variance in the $\dot{V}O_{2max}$ values among the adolescents. Although all available research of the last 15 years, which investigated the

aerobic power of adults, children and adolescents, were scanned and used to determine the primary anthropometric measurements, physical and motor-performance components as well as demographic variables which need to be considered for the $\dot{V}O_{2max}$ prediction models, other variables may also possibly influence the $\dot{V}O_{2max}$ results. In this regard psychological variables (Cairney *et al*., 2008; Midgley *et al*., 2007), nutrition status (Birrer & Levine, 1987; McNaughton *et al*., 2006) and genetics (McNaughton *et al*., 2006) may also possibly influence participants' $\dot{V}O_{2max}$ results. As such, it can be recommended that further studies focus on more elaborate $\dot{V}O_{2max}$ prediction models which also include the last-mentioned variables as possible $\dot{V}O_{2max}$ predictors.

- The participants in the current study were not randomly selected according to the population density of the Tlokwe local municipality area and are therefore not representative of the adolescent population in this area or of South Africa as a whole. Future studies should therefore include adolescents according to the population density of the Tlokwe Local Municipality Area or/and South Africa in order to generalize study results.
- A selected group, cross-sectional experimental research design was used in this study. However, to test the reliability and validity of the $\dot{V}O_{2max}$ prediction models developed, it would be advisable to rather use a longitudinal research design by means of which the predictive value of the models can be tested over time.

APPENDIX

APPENDIX A, B, C, D & E

APPENDIX A	**Ethical Approval.**
APPENDIX B	**Demographic, general information questionnaire and informed consent forms**
APPENDIX C	**Physical activity questionnaire, anthropometric, physical and motor performance data collection forms**
APPENDIX D	**The instructions for authors from the Journal of Human Movement Science, Pediatric Exercise Science and the Journal of Science and Medicine in Sport respectively.**

APPENDIX A ETHICAL APPROVAL

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ETHICS APPROVAL OF PROJECT

The North-West University Ethics Committee (NWU-EC) hereby approves your project as indicated below. This implies that the NWU-EC grants its permission that, provided the special conditions specified below are met and pending any other authorisation that may be necessary, the project may be initiated, using the ethics number below.

Project title: Five year Longitudinal Study of Physical Activity status and the Determinants of Health in Adolescents attending high school in Potchefstroom areas of South Africa (PAHLS-Study)

Ethics number:

N	W	U	-	0	0	5	8		-	1	0	-	A	1
Institution				Project Number						Year			Status	

Status: S = Submission, R = Re-Submission, P = Provisional Authorisation, A = Authorisation

Approval date: 2010/07/19 **Expiry date**: 2015/07/18

Special conditions of the approval (if any): None

General conditions:

While this ethics approval is subject to all declarations, undertakings and agreements incorporated and signed in the application form, please note the following:

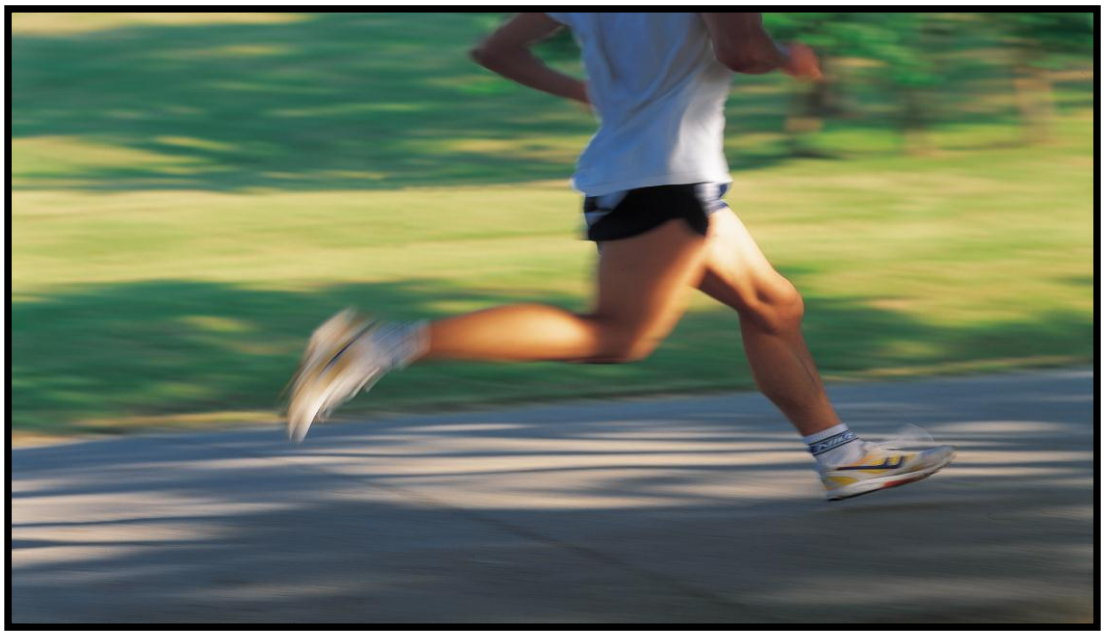
- *The project leader (principle investigator) must report in the prescribed format to the NWU-EC:*
  - *annually (or as otherwise requested) on the progress of the project,*
  - *without any delay in case of any adverse event (or any matter that interrupts sound ethical principles) during the course of the project.*
- *The approval applies strictly to the protocol as stipulated in the application form. Would any changes to the protocol be deemed necessary during the course of the project, the project leader must apply for approval of these changes at the NWU-EC. Would there be deviated from the project protocol without the necessary approval of such changes, the ethics approval is immediately and automatically forfeited.*
- *The date of approval indicates the first date that the project may be started. Would the project have to continue after the expiry date, a new application must be made to the NWU-EC and new approval received before or on the expiry date.*
- *In the interest of ethical responsibility the NWU-EC retains the right to:*
  - *request access to any information or data at any time during the course or after completion of the project;*
  - *withdraw or postpone approval if:*
    - *any unethical principles or practices of the project are revealed or suspected,*
    - *it becomes apparent that any relevant information was withheld from the NWU-EC or that information has been false or misrepresented,*
    - *the required annual report and reporting of adverse events was not done timely and accurately,*
    - *new institutional rules, national legislation or international conventions deem it necessary.*

The Ethics Committee would like to remain at your service as scientist and researcher, and wishes you well with your project. Please do not hesitate to contact the Ethics Committee for any further enquiries or requests for assistance.

Yours sincerely

Prof MMJ Lowes
(chair NWU Ethics Committee)

APPENDIX B GENERAL INFORMATION QUESTIONNAIRE AND INFORMED CONSENT FORMS



School of Biokinetics, Recreation and Sport Science
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2520
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E-mail: andries.monyeki@nwu.ac.za
25 January 2010
http://www.nwu.ac.za

The District Operational Director

Department of Education
North West Province
Potchefstroom

REQUEST TO CONDUCT RESEARCH WITHIN YOUR DISTRICT

Dear Sir,

We the researcher from the School of Biokinetics, Recreation and Sport Science are hereby making a request to conduct research in the district under your authority.

To give the background of the study, research revealed that physical activity in adolescents is drastically declining. The decline in the level of physical activity of human populations has been observed, and such decline is been associated with increased mechanization, reliance on technology and urbanization, and the high rate of crime in South Africa and elsewhere in the world. Physical inactivity is thought to be one of the main risk factors for the development of obesity, diabetes, cardiovascular disease, osteoporosis and psychological constraints or risks of behavioral health.

Cross-sectional studies in South Africa which investigate the relationship between physical activity and determinants of cardiovascular disease for children and adults are available. Findings from these study revealed inactivity was significantly related to the determinants of cardiovascular disease. Little from the abovementioned studies could investigate physical activity and determinants of cardiovascular disease on a longitudinal basis. It is therefore important to note that South Africa is a country of paradox where obesity in children co-exists with malnutrition and many other ailments of health. It is therefore, against this background that a longitudinal study investigating the development and tracking of physical activity and the determinants of cardiovascular diseases in South African adolescents is needed. Adolescence is a time when independence is established and dietary and activity patterns may be adopted that is followed for many years. Most of the physiological, psychological and social changes within people take place during this period of life. The period of adolescence can be looked upon as a time of more struggle

and turmoil than childhood. Adolescents have long been regarded as a group of people who are searching for themselves to find some form of identity and meaning in their lives. Thus, it has great influence on adult fatness and chronic disease of lifestyle as well as long-term outcome on quality of life. If youth health behaviors are tracked during adolescence, it would add support to the primary assumptions given for early interventions to prevent cardiovascular disease as well as delay in cognitive development. For this longitudinal study, tracking is defined as the stability of health behaviors over time, or the predictability of future values by early measurements. From the above given background, therefore, the aims of the study is to investigate over a five year period (2010-2014) a follow-up longitudinal development of physical activity and determinants of health risk factors of health behavior in 14 years-old adolescents attending schools in Potchefstroom area of the North West Province of South Africa.

The above matter background information refers:

1. Permission is requested to conduct research in selected schools in your district as follows:
1.1. BA Seobi Sec. School
1.2. Tlokwe High School
1.3. Resolofetse High School
1.4. Botokwa High School
1.5. Potchefstroom High School for Boys
1.6. Potchefstroom High School for Girls
1.7. Hoer Volkskool Potchefstroom
1.8. Potchefstroom Gimnasium School

2. The targeted groups are boys and girls aged 14 years, in essence the grade 8 learners (NB: the proportion will be as follow: in mixed schools, 35 girls and 35 boys; in blacks schools 30 boys and 30 girls will be required).

3. The targeted term is the first term of 2010 (to be continued during the same term in the subsequent years up until 2014)

4. Items to be assessed or measured are:
4.1. Demographic information of the selected participants
4.2. Anthropomtric measurements (i.e. body height; weight; skinfolds thickness (triceps, subscapular and calf skinfolds), and waist and hip circumferences)
4.3. Maturation (Tanner questionnaire)
4.4. Blood pressure measurement (mercury sphygmomanometer)
4.5. Physical activity questionnaire
4.6. ActiHeart (heart rate recorder with an integrated omnidirectional accelerometer. It is clipped onto two ECG electrodes worn on the chest.)
4.7. Health-related physical fitness (i.e. 20m shuttle run, standing broad jump, sit-and-reach, bent arm hang, sit-ups)
4.8. Social and self-efficacy questionnaire
4.9. Resting metabolic rate (determined by means of a mobile gas analyser)
4.10. Blood sampling (i.e. The participants will be requested to fast overnight (10 hours). A fasting sample of 10 ml blood will be taken from each participant in order to obtain ample blood for the various analyses of the study.)
4.11. Nutritional intake questionnaire.
4.12. Leisure and recreation constraint questionnaires

5. The schedule of the project will be as follow (Specific dates for selected schools will be finalised per arrangement with the principals concerned):

Month and week	Duration
April 2010, week 12 – 16	3 hours per child in a selected school
April 2010, week 19 – 23	3 hours per child in a selected school

Due to the fact that participants will be asked to fast 10 hours without eating breakfast in the morning, therefore sandwiches provision will be made available upon completion of the measurements. The outcomes of this project will benefit the children and the schools with the information regarding the physical activity status and the determinants of health for future.

Hoping for a positive response.

Yours sincerely,

Thank you,

Prof. M. Andries. Monyeki
(Principal Investigator, NWU-Potchefstroom)

Dr Hanlie Moss
Leader of Niche Area for Physical Activity, Sports and Recreation, NWU-Potchefstroom

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25 January 2010
http://www.nwu.ac.za

INFORMATION LETTER TO THE PARENTS AND CONSENT FORMS: *PAHLS STUDY*

Dear Parent or Guardian,

Your child is been invited to participate in a study entitled – Five year Longitudinal Study of Physical Activity status and the Determinants of Health in Adolescents attending high school in Potchefstroom areas of South Africa (*PAHLS-Study, 2010–2014*).

My name is Professor Makama Andries Monyeki (from Potchefstroom Campus of the North-West University) principal investigator in the project together with the research team would like to ask your permission to allow your child (or a child under your care) to participate in our study. To give the background of the study, research revealed that physical activity in adolescents is drastically declining. The decline in the level of physical activity of human populations has been observed, and such decline is been associated with increased mechanization, reliance on technology and urbanization, and the high rate of crime in South Africa. Physical inactivity is thought to be one of the main risk factors for the development of obesity, diabetes, cardiovascular disease, osteoporosis and psychological constraints or risks of behavioral health. Therefore, the purpose of this study is to gather information about physical activity (i.e. by questionnaire & ActiHeart rate monitor) and health determinants (i.e. through measurements of anthropometry, maturation, blood pressure measurement, health-related physical fitness, social and self-efficacy questionnaire, resting metabolic rate, oxygen consumption (by the use of a portable gas analyser apparatus), blood sampling, leisure and recreation constraint questionnaires, nutritional intake questionnaire as questionnaire on risk factors of life) over a period of five years (2010–2014).

Participation in this study is not part of the child's regular classroom work; it is an optional activity in which the learner can choose to participate. The study will assess and test the following variables: anthropometric measurements, maturation, blood pressure measurement, health-related physical fitness, social and self-efficacy questionnaire, resting metabolic rate, oxygen consumption, blood sampling, leisure and recreation constraint questionnaires, nutritional intake questionnaire as questionnaire on risk factors of life. Blood samples will be collected by a registered professional nurse who will oblige to health profession practices at all times.

The data of the study will be used for research purpose only. The measurements will not be shared

with your child classmates or teacher. All information collected in this study will be kept confidential. Your child's participation is important because the information that shall be gathered on him/her will help him/her with knowledge for personal development and life skills.

Your child participation in the project is very important, but it is entirely your choice. If your child choose to refuse to participate in any part of the study or withdraw from the study at any time, for any reason, this will not cause anyone to be upset or angry, and this will not results in any type of penalty.

There are no costs required from your child (or a child under your care) to participate in the study. Further, no payment will be granted to your child (or a child under your care) for participating in the study.

If you have any question regarding this study, please feel free to call me at (018) 2991790 / e-mail:andries.monyeki@nwu.ac.za or the PHASrec Niche Area Leader Dr Hanlie Moss at (018) 2991821 / e-mail:hanlie.moss@nwu.ac.za. If you have any questions regarding your rights or your child's rights as participants in this study you can call Ms Hannekie Botha at (018) 299 4850 from Potchefstroom Campus of the North-West University Research Ethics Office.

Thank you, in advance, for considering your child participation in this study. Should you choose that your child participate, please read and sign the attached consent form. Keep one consent form for your records and return the other copy. All received consent form will be kept locked during the entire period of the study. In addition, your child is requested to bring along his/her birth clinic card. The card will be given back to the child immediately after collecting information on birth date and birth weight. A child who shall have returned a completed and signed consent form will participate in the study.
Sincerely,
Prof. Makama Andries Monyeki
Principal Investigator – PAHLS Study

CONSENT FORM
(Parent/Guardian Copy)

FIVE YEAR LONGITUDINAL STUDY OF PHYSICAL ACTIVITY STATUS AND THE DETERMINANTS OF HEALTH IN ADOLESCENTS ATTENDING HIGH SCHOOL IN POTCHEFSTROOM AREAS OF SOUTH AFRICA (*PAHLS-STUDY, 2010–2014*).

I, ..., father/mother/guardian of .....
agree to permit my child to provide the information on physical activity (i.e. by questionnaire & ActiHeart rate monitor) and health determinants (i.e. through measurements of anthropometry, maturation, blood pressure measurement, health-related physical fitness, social and self-efficacy questionnaire, resting metabolic rate, oxygen consumption (by the use of a portable gas analyser apparatus), blood sampling, leisure and recreation constraint questionnaires, nutritional intake questionnaire as questionnaire on risk factors of life), by the researchers at my child school. I understand that the results of this study of Five year longitudinal study of physical activity status and the determinants of health in adolescents attending high school in Potchefstroom areas of South Africa (*PAHLS-STUDY NWP*) will be used for research purpose and nothing else. I am aware that if I have any question or concerns about the study I can contact the researcher at (018) 299 1790 or the PHASRec Niche Area Leader at (018) 299 1821. Any questions or concerns regarding my child rights as a participant in this study can be addressed to Ms Hannekie Botha at

(018) 299 4850 from Potchefstroom Campus of the North-West University Research Ethics Office. I understand that there will be no discomfort or foreseeable risks for my child to participate in the study. I understand that all information my child provide will remain strictly confidential. I have read and understand the information provided above and in the information letter. I have been provided with the opportunity to ask questions and my questions have been answered satisfactorily. I consent to have my child participate in the study described above, understanding that he/she may refuse to participate in any part of the study and can withdraw from the study at any time. I have kept one copy of this consent for my records and will return the second copy with the clinic birth card. I am aware that by giving consent my child can participate in the study. The return consent form will be kept locked during the entire period of the study.

Child's Age:.....
Grade:.....
Teacher:.....
School Name:.....

Name of Child:.....
Name of Parent/Guardian:.....

.....	.....
(Signature of Child)	(Signature of Parent/Guardian)
.....	.....
(Date)	(Date)

CONSENT FORM (*PAHLS*)
(Return this copy with the demographic questionnaire)

FIVE YEAR LONGITUDINAL STUDY OF PHYSICAL ACTIVITY STATUS AND THE DETERMINANTS OF HEALTH IN ADOLESCENTS ATTENDING HIGH SCHOOL IN POTCHEFSTROOM AREAS OF SOUTH AFRICA (*PAHLS-STUDY, 2010–2014*).

I, ..., father/mother/guardian of .....
agree to permit my child to provide the information on physical activity (i.e. by questionnaire & ActiHeart rate monitor) and health determinants (i.e. through measurements of anthropometry, maturation, blood pressure measurement, health-related physical fitness, social and self-efficacy questionnaire, resting metabolic rate, oxygen consumption (by the use of a portable gas analyser apparatus), blood sampling, leisure and recreation constraint questionnaires, nutritional intake questionnaire as questionnaire on risk factors of life), by the researchers at my child school. I understand that the results of this study of Five year longitudinal study of physical activity status and the determinants of health in adolescents attending high school in Potchefstroom areas of South Africa (*PAHLS-STUDY NWP*) will be used for research purpose and nothing else. I am aware that if I have any question or concerns about the study I can contact the researcher at (018) 299 1790 /e-mail:andries.monyeki@nwu.ac.za or the PHASRec Niche Area Leader at (018) 299 1821 /e-mail:hanlie.moss@nwu.ac.za. Any questions or concerns regarding my child rights as a participant in this study can be addressed to Ms Hannekie Botha at (018) 299 4850 from Potchefstroom Campus of the North-West University Research Ethics Office. I understand that there will be no discomfort or foreseeable risks for my child to participate in the study. I understand that all information my child provide will remain strictly confidential. I have read and understand the information provided above and in the information letter. I have been provided with the opportunity to ask questions and my questions have been answered satisfactorily. I consent to have my child participate in the study described above, understanding that he/she may refuse to participate in any part of the study and can withdraw from the study at any time. I have kept one copy of this consent for my records and will return the second copy with the clinic birth card. I am aware that by giving consent my child can participate in the study. The return consent form will be kept locked during the entire period of the study.

Child's Age:.....
Grade:.....
Teacher:.....
School Name:.....

Name of Child:.....
Name of Parent/Guardian:.....

.....	.....
(Signature of Child)	(Signature of Parent/Guardian)
.....	.....
(Date)	(Date)

APPENDIX C

PHYSICAL ACTIVITY QUESTIONNAIRE, AND ANTHROPOMETRIC, PHYSICAL AND MOTOR PERFORMANCE DATA COLLECTION FORMS

PHYSICAL ACTIVITY QUESTIONNAIRE (PAHLS-IPAQ)

A: GENERAL INFORMATION ABOUT YOU

School:	
Grade:	
School number:	
Name of the participant:	
Subject number:	
Address:	

Date of Survey			**Grade**	**Sex (mark with a X)**		**Date of birth**			**Age**
dd	**mm**	**yy**		**F**	**M**	**dd**	**mm**	**yy**	

In the next few questions cross out the answers that are applicable to you!!

Ethnic group

White	**Coloured**	**Black**	**Indian**

Do you participate in sport or have you been participating in sport during the last two years?

☐ **YES** ☐ **NO**

If your answer is YES, answer the next questions, and IF your answer is NO go to the next page.

INFORMATION REGARDING SPORT AND TRAINING HABITS

1. **<u>Type of sport</u> that you are participating in or did participate in during the last two years – <u>main sport</u>.**

Soccer	**Rugby**	**Netball**	**Hockey**	**Volleyball**	**Athletics Javelin/ Shot pot/ Discus**	**Athletics Long jump/High jump**
Athletics 100m/ 200m	**Athletics 400m**	**Athletics 800m**	**Athletics 1500m**	**Athletics Cross country**	**Tennis**	**Squash**
Badminton	**Cricket**	**Golf**	**Wrestling**	**Boxing**	**Karate**	**Swimming**
Cycling	**Triathlon**	**Biathlon**	**Duathlon**	**Ballet**	**Artistic gymnastics**	**Rhythmic gymnastics**

Other: _____

2. Type of sport that you are participating in or did participate in during the last two years – secondary sport.

Soccer	Rugby	Netball	Hockey	Volleyball	Athletics Javelin/ Shot pot/ Discus	Athletics Long jump/High jump
Athletics 100m/ 200m	Athletics 400m	Athletics 800m	Athletics 1500m	Athletics Cross country	Tennis	Squash
Badminton	Cricket	Golf	Wrestling	Boxing	Karate	Swimming
Cycling	Triathlon	Biathlon	Duathlon	Ballet	Artistic gymnastics	Rhythmic gymnastics

Other: _____

3. Years you've been participating in your main sport.

<1 year	1-2 years	3-4 years	5-6 years	7-8 years	8-9 years	>9 years

4. Years you've been participating in your secondary sport.

<1 year	1-2 years	3-4 years	5-6 years	7-8 years	8-9 years	>9 years

5. Frequency of training - how many days per week do/did you normally train for your main sport?

1 day	2 days	3 days	4 days	5 days	6 days	7 days

6. Frequency of training - how many days per week do/did you normally train for your secondary sport?

1 day	2 days	3 days	4 days	5 days	6 days	7 days

7. Frequency of training - how many days per week do/did you normally do weight training?

1 day	2 days	3 days	4 days	5 days	6 days	7 days

8. Frequency of training - how many days per week do/did you normally do training on the field/track/court or in the pool/ring?

1 day	2 days	3 days	4 days	5 days	6 days	7 days

9. How many hours per day do/did you normally train?

1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 or more

10. On what level do/did you compete in your main sport?

Recreational	School	Provincial	National

11. On what level do/did you compete in your secondary sport?

Recreational	School	Provincial	National

12.What is the best performance/s that you achieved in your main sport:

Year	Sport	Distance/Height/Time/ Team/Achievement

INFORMATION REGARDING MATURITY

1. <u>For girls only</u>: At what age did you experience menarche?

9 years	10 years	11 years	12 years	13 years	14 years	Not yet

2. <u>For boys only</u>: At what age did your voice break?

11 years	12 years	13 years	14 years	Not yet

SECTION B: PHYSICAL ACTIVITY QUESTIONNAIRE

IT IS IMPORTANT TO ANSWER ALL QUESTIONS, AND BE HONEST WITH YOUR ANSWERS

1. **During the last 7 days, on how many days did you do very hard physical activities like heavy lifting, digging, aerobics, or fast bicycling?**

_____ **days per week**

☐ **No very hard physical activities** → ***Skip to question 3***

2. **How much time did you usually spend doing very hard physical activities on one of those days?**

_____ **hours per day**
_____ **minutes per day**

☐ **Don't know/Not sure**

3. **During the last 7 days, on how many days did you do moderate physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.**

_____ **days per week**

☐ **No moderate physical activities** → ***Skip to question 5***

4. How much time did you usually spend doing moderate physical activities on one of those days?

_____ **hours per day**
_____ **minutes per day**

☐ **Don't know/Not sure**

TURN TO THE NEXT PAGE

5. During the last 7 days, on how many days did you walk for at least 10 minutes at a time?

_____ **days per week**

☐ **No walking** → ***Skip to question 7***

6. How much time did you usually spend walking on one of those days?

_____ **hours per day**
_____ **minutes per day**

☐ **Don't know/Not sure**

7. During the last 7 days, how much time did you spend sitting on a week day? (watching TV, Videogames/Internet, Listening to music, reading)

_____ **hours per day**
_____ **minutes per day**

☐ **Don't know/Not sure**

Anthropometry

NAME OF LEARNER: _____ **SUBJECT NO.** _____

TEST COMPONENT	1ST READING		
BOX HEIGHT (CM)			
TEST COMPONENT	**1ST READING**	**2ND READING**	**MEAN**
BODY MASS (KG)			
BODY STATURE (CM)			
SITTING HEIGHT (CM)			
ARMSPAN (CM)			
TEST COMPONENT	**1ST READING**	**2ND READING**	**MEAN**
L: BICEPS SKINFOLD (MM)			
R: BICEPS SKINFOLD (MM)			
L: TRICEPS SKINFOLD (MM)			
R: TRICEPS SKINFOLD (MM)			
L: SUBSCAPULAR SKINFOLD (MM)			
R: SUBSCAPULAR SKINFOLD (MM)			
L: SUPRASPINALE SKINFOLD (MM)			
R: SUPRASPINALE SKINFOLD (MM)			
ABDOMINAL SKINFOLD (MM)			
L: FRONT THIGH SKINFOLD (MM)			
R: FRONT THIGH SKINFOLD (MM)			
L: MEDIAL CALF SKINFOLD (MM)			
R: MEDIAL CALF SKINFOLD (MM)			
TEST COMPONENT	**1ST READING**	**2ND READING**	**MEAN**
L: HUMERUS BREADTH (CM)			
R: HUMERUS BREADTH (CM)			
L: WRIST BREADTH (CM)			
R: WRIST BREADTH (CM)			
L: FEMUR BREADTH (CM)			
R: FEMUR BREADTH (CM)			
L: ANKLE BREADTH (CM)			
R: ANKLE BREADTH (CM)			

TEST COMPONENT	1ST READING	2ND READING	MEAN
HEAD GIRTH (CM)			
L: RELAXED ARM GIRTH (CM)			
R: RELAXED ARM GIRTH (CM)			
L: FLEXED ARM GIRTH (CM)			
R: FLEXED ARM GIRTH (CM)			

TEST COMPONENT	1ST READING	2ND READING	MEAN
WAIST (MINIMUM) GIRTH (CM)			
GLUTEAL (HIP) GIRTH (CM)			
L: MID THIGH GIRTH (CM)			
R: MID THIGH GIRTH (CM)			
L: MAXIMUM CALF GIRTH (CM)			
R: MAXIMUM CALF GIRTH (CM)			
L: FOREARM GIRTH (CM)			
R: FOREARM GIRTH (CM)			
TEST COMPONENT	**1ST READING**	**2ND READING**	**MEAN**
L: ACROMIALE-RADIALE LENGTH (CM)			
R: ACROMIALE-RADIALE LENGTH (CM)			
L: RADIALE-STYLION RADIALE LENGTH (CM)			
R: RADIALE-STYLION RADIALE LENGTH (CM)			
L: MIDSTYLION-DACTYLION (CM)			
R: MIDSTYLION-DACTYLION (CM)			
L: FOOT LENGTH (CM)			
R: FOOT LENGTH (CM)			

Flexibility tests

NAME:_____ SUBJECT NO._____

SIT-AND-REACH TEST – STARTING POINT (CM)			
TEST COMPONENT	**1ST**	**2ND**	**BEST**
SIT-AND-REACH TEST (CM) – END POINT (CM)			
L: SHOULDER EXTERNAL ROTATION TEST (°)			
R: SHOULDER EXTERNAL ROTATION TEST (°)			
L: SHOULDER INTERNAL ROTATION TEST (°)			
R: SHOULDER INTERNAL ROTATION TEST (°)			
L: LEG LENGTH (CM)			
R: LEG LENGTH (CM)			
L: FUNCTIONAL LEG LENGTH (CM)			
R: FUNCTIONAL LEG LENGTH (CM)			
L: PASSIVE KNEE EXTENSION TEST (°)			
R: PASSIVE KNEE EXTENSION TEST (°)			
L: ACTIVE KNEE EXTENSION TEST (°)			
R: ACTIVE KNEE EXTENSION TEST (°)			
L: ANKLE DORSIFLEXION (°)			
R: ANKLE DORSIFLEXION (°)			
L: ANKLE PLANTAR FLEXION (°)			
R: ANKLE PLANTAR FLEXION (°)			
L: MODIFIED THOMAS ILIOPSOAS TEST (°)			
R: MODIFIED THOMAS ILIOPSOAS TEST (°)			
L: MODIFIED THOMAS QUADS TEST (°)			
R: MODIFIED THOMAS QUADS TEST (°)			

RAW DATA FOR PAHLS (Fitness tests)

NAME OF LEARNER: _____ SUBJECT NO. _____

TEST COMPONENT	1ST TIME							
POLE HEIGHT (CM)								
VERTICAL JUMP REACHING HEIGHT (CM)	A							
FINAL VERTICAL JUMP HEIGHT A-B (CM)								
TEST COMPONENT	**1ST READING**		**2ND READING**		**HIGHEST**			
VERTICAL JUMP HEIGHT (CM)					B			
TENDO PEAK POWER (W)								
TENDO SPEED (M/SEC)								
TEST COMPONENT	**1ST READING**		**2ND READING**		**HIGHEST**			
HORIZONTAL JUMP DISTANCE (CM)								
TEST COMPONENT	**1ST READING**		**2ND READING**		**HIGHEST**			
BASKETBAL THROW DISTANCE (M)								
TEST COMPONENT	**1ST READING**		**2ND READING**		**HIGHEST**			
L: HAND GRIP STRENGTH (KG)								
R: HAND GRIP STRENGTH (KG)								
TEST COMPONENT	**1ST READING**							
ABDOMINAL STRENGTH TEST (LEVEL)	0	1	2	3	4	5	6	7
TEST COMPONENT	**1ST TIME**							
BENT ARM HANG (SEC)								
TEST COMPONENT	**1ST TIME**							
SIT UPS (REPS)								
TEST COMPONENT	**1ST READING**		**2ND READING**		**LOWEST**			
5M SPEED (SEC)								
10M SPEED (SEC)								
40M SPEED (SEC)								
TEST COMPONENT	**1ST READING**		**2ND READING**		**LOWEST**			
L: AGILITY 505-TEST (SEC)								
R: AGILITY 505-TEST (SEC)								

TEST COMPONENT	1ST READING
GENDER	M / F
BIRTH DATE	year / month / day

20M SHUTTLE RUN															
LEVEL	**SHUTTLE NUMBER AND HEART RATES**														
1	1	2	3	4	5	6	7								
2	1	2	3	4	5	6	7	8							
3	1	2	3	4	5	6	7	8							
4	1	2	3	4	5	6	7	8	9						
5	1	2	3	4	5	6	7	8	9						
6	1	2	3	4	5	6	7	8	9	10					
7	1	2	3	4	5	6	7	8	9	10					
8	1	2	3	4	5	6	7	8	9	10	11				
9	1	2	3	4	5	6	7	8	9	10	11				
10	1	2	3	4	5	6	7	8	9	10	11				
11	1	2	3	4	5	6	7	8	9	10	11	12			
12	1	2	3	4	5	6	7	8	9	10	11	12			
13	1	2	3	4	5	6	7	8	9	10	11	12	13		
14	1	2	3	4	5	6	7	8	9	10	11	12	13		
15	1	2	3	4	5	6	7	8	9	10	11	12	13		
16	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
17	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
18	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
19	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
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VO_{2MAX} (ML/KG/MIN) - DIRECT	
VE_{MAX} (L/MIN) - DIRECT	
R_{MAX} - DIRECT	
HR_{MAX} (BEATS/MIN) - DIRECT	

APPENDIX D INSTRUCTIONS FOR AUTHORS

Journal of Human Movement Science

Introduction
A Journal Devoted to Pure and Applied Research on Human Movement.

Types of contribution
Human Movement Science contains: (a) reports of empirical work on human movement; (b) theoretical (overview) articles on human movement, including its modelling; (c) letters to the editor containing a critical commentary on a published paper. In addition to regular issues, special issues addressing a single theme will be published. Special issues may also contain articles based on papers presented at conferences and workshops or consist of a `target articles' followed by peer commentaries.

Use of wordprocessing software

It is important that the file be saved in the native format of the wordprocessor used. The text should be in single-column format. Keep the layout of the text as simple as possible. Most formatting codes will be removed and replaced on processing the article. In particular, do not use the wordprocessor's options to justify text or to hyphenate words. However, do use bold face, italics, subscripts, superscripts etc. When preparing tables, if you are using a table grid, use only one grid for each individual table and not a grid for each row. If no grid is used, use tabs, not spaces, to align columns. The electronic text should be prepared in a way very similar to that of conventional manuscripts (see also the Guide to Publishing with Elsevier: http://www.elsevier.com/guidepublication). Note that source files of figures, tables and text graphics will be required whether or not you embed your figures in the text. See also the section on Electronic artwork.
To avoid unnecessary errors you are strongly advised to use the 'spell-check' and 'grammar-check' functions of your wordprocessor.

Article structure

Subdivision - numbered sections
Divide your article into clearly defined and numbered sections. Subsections should be numbered 1.1 (then 1.1.1, 1.1.2, ...), 1.2, etc. (the abstract is not included in section numbering). Use this numbering also for internal cross-referencing: do not just refer to 'the text'. Any subsection may be

given a brief heading. Each heading should appear on its own separate line.

Introduction
State the objectives of the work and provide an adequate background, avoiding a detailed literature survey or a summary of the results.

Results
Results should be clear and concise.

Discussion
This should explore the significance of the results of the work, not repeat them. A combined Results and Discussion section is often appropriate. Avoid extensive citations and discussion of published literature.

Conclusions
The main conclusions of the study may be presented in a short Conclusions section, which may stand alone or form a subsection of a Discussion or Results and Discussion section.

Appendices
If there is more than one appendix, they should be identified as A, B, etc. Formulae and equations in appendices should be given separate numbering: Eq. (A.1), Eq. (A.2), etc.; in a subsequent appendix, Eq. (B.1) and so on. Similarly for tables and figures: Table A.1; Fig. A.1, etc.

Essential title page information

• *Title.* Concise and informative. Titles are often used in information-retrieval systems. Avoid abbreviations and formulae where possible.
• *Author names and affiliations.* Where the family name may be ambiguous (e.g., a double name), please indicate this clearly. Present the authors' affiliation addresses (where the actual work was done) below the names. Indicate all affiliations with a lower-case superscript letter immediately after the author's name and in front of the appropriate address. Provide the full postal address of each affiliation, including the country name and, if available, the e-mail address of each author.
• *Corresponding author.* Clearly indicate who will handle correspondence at all stages of refereeing and publication, also post-publication. Ensure that telephone and fax numbers (with country and area code) are provided in addition to the e-mail address and the complete postal address. Contact details must be kept up to date by the corresponding author.
• *Present/permanent address.* If an author has moved since the work described in the article was done, or was visiting at the time, a 'Present address' (or 'Permanent address') may be indicated as a footnote to that author's name. The address at which the author actually did the work must be retained as the main, affiliation address. Superscript Arabic numerals are used for such footnotes.

Abstract

A concise and factual abstract is required. The abstract should state briefly the purpose of the research, the principal results and major conclusions. An abstract is often presented separately from the article, so it must be able to stand alone. For this reason, References should be avoided, but if essential, then cite the author(s) and year(s). Also, non-standard or uncommon abbreviations should be avoided, but if essential they must be defined at their first mention in the abstract itself.

Graphical abstract

A Graphical abstract is optional and should summarize the contents of the article in a concise, pictorial form designed to capture the attention of a wide readership online. Authors must provide images that clearly represent the work described in the article. Graphical abstracts should be submitted as a separate file in the online submission system. Image size: Please provide an image with a minimum of 531 × 1328 pixels (h × w) or proportionally more. The image should be readable at a size of 5 × 13 cm using a regular screen resolution of 96 dpi. Preferred file types: TIFF, EPS, PDF or MS Office files. See http://www.elsevier.com/graphicalabstracts for examples.
Authors can make use of Elsevier's Illustration and Enhancement service to ensure the best presentation of their images also in accordance with all technical requirements: Illustration Service.

Highlights

Highlights are mandatory for this journal. They consist of a short collection of bullet points that convey the core findings of the article and should be submitted in a separate file in the online submission system. Please use 'Highlights' in the file name and include 3 to 5 bullet points (maximum 85 characters, including spaces, per bullet point). See http://www.elsevier.com/highlights for examples.

Keywords

Immediately after the abstract, provide a maximum of 6 keywords, using American spelling and avoiding general and plural terms and multiple concepts (avoid, for example, 'and', 'of'). Be sparing with abbreviations: only abbreviations firmly established in the field may be eligible. These keywords will be used for indexing purposes.

Acknowledgements

Collate acknowledgements in a separate section at the end of the article before the references and do not, therefore, include them on the title page, as a footnote to the title or otherwise. List here those individuals who provided help during the research (e.g., providing language help, writing assistance or proof reading the article, etc.).

Math formulae

Present simple formulae in the line of normal text where possible and use the solidus (/) instead of a horizontal line for small fractional terms, e.g., X/Y. In principle, variables are to be presented in italics. Powers of e are often more conveniently denoted by exp. Number consecutively any equations that have to be displayed separately from the text (if referred to explicitly in the text).

Footnotes

Footnotes should be used sparingly. Number them consecutively throughout the article, using superscript Arabic numbers. Many wordprocessors build footnotes into the text, and this feature may be used. Should this not be the case, indicate the position of footnotes in the text and present the footnotes themselves separately at the end of the article. Do not include footnotes in the Reference list.
Table footnotes
Indicate each footnote in a table with a superscript lowercase letter.

Artwork

Electronic artwork
General points
• Make sure you use uniform lettering and sizing of your original artwork.
• Save text in illustrations as 'graphics' or enclose the font.
• Only use the following fonts in your illustrations: Arial, Courier, Times, Symbol.
• Number the illustrations according to their sequence in the text.
• Use a logical naming convention for your artwork files.
• Provide captions to illustrations separately.
• Produce images near to the desired size of the printed version.
• Submit each figure as a separate file.

A detailed guide on electronic artwork is available on our website:
http://www.elsevier.com/artworkinstructions
You are urged to visit this site; some excerpts from the detailed information are given here.
Formats
Regardless of the application used, when your electronic artwork is finalised, please 'save as' or convert the images to one of the following formats (note the resolution requirements for line drawings, halftones, and line/halftone combinations given below):
EPS: Vector drawings. Embed the font or save the text as 'graphics'.
TIFF: Color or grayscale photographs (halftones): always use a minimum of 300 dpi.
TIFF: Bitmapped line drawings: use a minimum of 1000 dpi.
TIFF: Combinations bitmapped line/half-tone (color or grayscale): a minimum of 500 dpi is required.
If your electronic artwork is created in a Microsoft Office application (Word, PowerPoint, Excel) then please supply 'as is'.
Please do not:
• Supply files that are optimised for screen use (e.g., GIF, BMP, PICT, WPG); the resolution is too low;
• Supply files that are too low in resolution;
• Submit graphics that are disproportionately large for the content.

Color artwork
Please make sure that artwork files are in an acceptable format (TIFF, EPS or MS Office files) and with the correct resolution. If, together with your accepted article, you submit usable color figures then Elsevier will ensure, at no additional charge, that these figures will appear in color on the Web (e.g., ScienceDirect and other sites) regardless of whether or not these illustrations are reproduced in color in the printed version. For color reproduction in print, you will receive information regarding the costs from Elsevier after receipt of your accepted article. Please indicate your preference for color: in print or on the Web only. For further information on the preparation of electronic artwork, please see http://www.elsevier.com/artworkinstructions.
Please note: Because of technical complications which can arise by converting color figures to 'gray scale' (for the printed version should you not opt for color in print) please submit in addition usable black and white versions of all the color illustrations.

Figure captions
Ensure that each illustration has a caption. Supply captions separately, not attached to the figure. A caption should comprise a brief title (not on the figure itself) and a description of the illustration. Keep text in the illustrations themselves to a minimum but explain all symbols and abbreviations used.

Text graphics
Text graphics may be embedded in the text at the appropriate position. If you are working with LaTeX and have such features embedded in the text, these can be left. Further, high-resolution graphics files must be provided separately whether or not the graphics are embedded. See further under Electronic artwork.

Tables

Number tables consecutively in accordance with their appearance in the text. Place footnotes to tables below the table body and indicate them with superscript lowercase letters. Avoid vertical rules. Be sparing in the use of tables and ensure that the data presented in tables do not duplicate results described elsewhere in the article.

References

Citation in text
Please ensure that every reference cited in the text is also present in the reference list (and vice versa). Any references cited in the abstract must be given in full. Unpublished results and personal communications are not recommended in the reference list, but may be mentioned in the text. If these references are included in the reference list they should follow the standard reference style of the journal and should include a substitution of the publication date with either 'Unpublished results' or 'Personal communication'. Citation of a reference as 'in press' implies that the item has been accepted for publication.

Web references
As a minimum, the full URL should be given and the date when the reference was last accessed. Any further information, if known (DOI, author names, dates, reference to a source publication, etc.), should also be given. Web references can be listed separately (e.g., after the reference list) under a different heading if desired, or can be included in the reference list.

Reference style
Text: Citations in the text should follow the referencing style used by the American Psychological Association. You are referred to the Publication Manual of the American Psychological Association, Sixth Edition, ISBN 978-1-4338-0561-5, copies of which may be ordered from http://books.apa.org/books.cfm?id=4200067 or APA Order Dept., P.O.B. 2710, Hyattsville, MD 20784, USA or APA, 3 Henrietta Street, London, WC3E 8LU, UK.
List: references should be arranged first alphabetically and then further sorted chronologically if necessary. More than one reference from the same author(s) in the same year must be identified by the letters 'a', 'b', 'c', etc., placed after the year of publication.
Examples:
Reference to a journal publication:
Van der Geer, J., Hanraads, J. A. J., & Lupton, R. A. (2010). The art of writing a scientific article. *Journal of Scientific Communications, 163*, 51–59.
Reference to a book:
Strunk, W., Jr., & White, E. B. (2000). *The elements of style.* (4th ed.). New York: Longman, (Chapter 4).
Reference to a chapter in an edited book:
Mettam, G. R., & Adams, L. B. (2009). How to prepare an electronic version of your article. In B. S. Jones, & R. Z. Smith (Eds.), *Introduction to the electronic age* (pp. 281–304). New York: E-Publishing Inc.

Pediatric Exercise Science

Submission Guidelines for PES

Pediatric Exercise Science welcomes submissions of original research, topical reviews, commentaries, and letters-to-the editor which address issues surrounding the science of exercise in subjects less than 18 years old. In general, *Pediatric Exercise Science* does not publish material related to physical education curricula or pedagogy, sports medicine (including athletic injuries), or motor development.

The instructions below (revised September 2011) are intended to help authors prepare high-quality and readable manuscripts. Authors are encouraged to refer to a recent issue of the journal to ascertain the preferred layout, format, style, and appearance.

The manuscript should be double-spaced, including the abstract, references, and any block quotations. Manuscripts are subject to editing to eliminate sexist and biased language.

Manuscripts must be submitted electronically via *Manuscript Central* (http://mc.manuscriptcentral.com/hk_pes). Authors of manuscripts accepted for publication will be required to transfer copyright to Human Kinetics, Inc. *Manuscript Central* manages the electronic transfer of manuscripts throughout the article review process while providing step-by-step instructions and a user-friendly design. Please access the site and follow the directions for authors

submitting manuscripts. Any problems that may be encountered can be resolved easily by selecting "Get Help Now" in the upper-right corner of any *Manuscript Central* screen. Please note that a blind review process is used to evaluate manuscripts. As such, any clues to the author's identity should be eliminated from the manuscript. The first page of the manuscript **must not** include author names or affiliations, but it should include the title of the paper and a preferred running head.

It is expected that the length of the body of the manuscript, including title page, abstract, text, and references, will be 15 to 20 double-spaced pages. Number the pages in the upper right corner beginning with the title page. Authors credited should be limited to fewer than seven except in certain cases at the discretion of the journal editor. Limit the abstract 200 words. A statement regarding institutional review board approval as well as obtaining informed consent/assent from parents/child subjects should be included in the Methods section. Figures and tables should be limited to a combined total of 5 and should not duplicate material in the text. Captions for the figures should be included at the end of the file with the full text.

The corresponding author is required to nominate two potential reviewers for the manuscript with suitable expertise in the area addressed by the manuscript. The journal is under no obligation to use any of the nominated reviewers.

Writing style should be concise and direct. Avoid using unnecessary jargon and abbreviations, but use an acronym or abbreviation if it is more commonly recognized than the spelled-out version of a term. **Formats of numbers and units *should follow the AMA Manual of Style,* 10th edition.** Measurements of length, height, mass, and volume should be reported in metric units (meter, kilogram). Only standard physiological abbreviations should be used. Avoid abbreviations in the title. The full wording should precede the first use of an abbreviation.

The reference style for Pediatric Exercise Science should follow the Vancouver style guidelines set by the **International Committee of Medical Journal Editors** (**http://www.icmje.org/about.html**) ,as they appear in the committee's **Uniform Requirements for Manuscripts Submitted to Biomedical Journals** publication (http://www.icmje.org/urm_main.html). In the reference list, the citations should be listed in alphabetical order (rather than in the order of citation). In the text, references are identified by **Arabic numerals** in **parentheses** (1). Assure that that all entries in the reference list are cited in the text and that all those in the text are included in the reference list. References should be limited to previously published works or those which are in press (accepted for publication). Usually the number of references should not exceed 50. An abstract properly identified may be cited only when it is the sole source. The reference list should be double-spaced. When the number of authors of a reference exceed seven, use the first three, followed by "et al.".

The reference style should be:

Journal article:

Soldin OP, **Mattison DR**. Sex differences in pharmacokinetics and pharmacodynamics. **Clin Pharmacokinet.** 2009;48(3):143-57.

Book:

Heyward VH, Stolarczyk LM. Applied Body Composition Assessment. Champaign, IL: Human Kinetics, 1996.

Chapter in Edited Book:

Young LR, Altose MD. Respiratory responses to ventilatory loading. In: Hornbein TF, editor. Regulation of Breathing. New York: Dekker, 1981, pp. 905-964.

Authors are encouraged to consult the following website for more detailed examples: **http://www.nlm.nih.gov/bsd/uniform_requirements.html**

Uniform Requirements for Manuscripts Submitted to Biomedical Journals:

Manuscript Preparation and Submission: Preparing a Manuscript for Submission to a Biomedical Journal

Editors and reviewers spend many hours reading manuscripts, and therefore appreciate receiving manuscripts that are easy to read and edit. Much of the information in a journal's Instructions to Authors is designed to accomplish that goal in ways that meet each journal's particular editorial needs. The following information provides guidance in preparing manuscripts for any journal.

General Principles

The text of observational and experimental articles is usually (but not necessarily) divided into the following sections: Introduction, Methods, Results, and Discussion. This so-called "IMRAD" structure is not an arbitrary publication format but rather a direct reflection of the process of scientific discovery. Long articles may need subheadings within some sections (especially Results and Discussion) to clarify their content. Other types of articles, such as case reports, reviews, and editorials, probably need to be formatted differently.

Electronic formats have created opportunities for adding details or whole sections, layering information, cross-linking or extracting portions of articles, and the like only in the electronic version. Authors need to work closely with editors in developing or using such new publication formats and should submit supplementary electronic material for peer review.

Double-spacing all portions of the manuscript— including the title page, abstract, text, acknowledgments, references, individual tables, and legends—and generous margins make it possible for editors and reviewers to edit the text line by line and add comments and queries

directly on the paper copy. If manuscripts are submitted electronically, the files should be double-spaced to facilitate printing for reviewing and editing.

Authors should number all of the pages of the manuscript consecutively, beginning with the title page, to facilitate the editorial process.
Reporting Guidelines for Specific Study Designs
Research reports frequently omit important information. Reporting guidelines have been developed for a number of study designs that some journals may ask authors to follow. Authors should consult the Information for Authors of the journal they have chosen.
The general requirements listed in the next section relate to reporting essential elements for all study designs. Authors are encouraged also to consult reporting guidelines relevant to their specific research design. A good source of reporting guidelines is the EQUATOR Network (http://www.equator-network.org/home/).

Title Page

The title page should have the following information:
1. Article title. Concise titles are easier to read than long, convoluted ones. Titles that are too short may, however, lack important information, such as study design (which is particularly important in identifying randomized, controlled trials). Authors should include all information in the title that will make electronic retrieval of the article both sensitive and specific.
2. Authors' names and institutional affiliations. Some journals publish each author's highest academic degree(s), while others do not.
3. The name of the department(s) and institution(s) to which the work should be attributed.
4. Disclaimers, if any.
5. Contact information for corresponding authors. The name, mailing address, telephone and fax numbers, and e-mail address of the author responsible for correspondence about the manuscript (the "corresponding author;" this author may or may not be the "guarantor" for the integrity of the study). The corresponding author should indicate clearly whether his or her e-mail address can be published.
6. The name and address of the author to whom requests for reprints should be addressed or a statement that reprints are not available from the authors.
7. Source(s) of support in the form of grants, equipment, drugs, or all of these.
8. A running head. Some journals request a short running head or footline, usually no more than 40 characters (including letters and spaces) at the foot of the title page. Running heads are published in most journals, but are also sometimes used within the editorial office for filing and locating manuscripts.
9. Word counts. A word count for the text only (excluding abstract, acknowledgments, figure legends, and references) allows editors and reviewers to assess whether the information contained in the paper warrants the amount of space devoted to it, and whether the submitted manuscript fits within the journal's word limits. A separate word count for the Abstract is useful for the same reason.
10. The number of figures and tables. It is difficult for editorial staff and reviewers to determine whether the figures and tables that should have accompanied a manuscript were actually included unless the numbers of figures and tables are noted on the title page.

Conflict of Interest Notification Page

To prevent potential conflicts of interest from being overlooked or misplaced, this information needs to be part of the manuscript. The ICMJE has developed a uniform disclosure form for use by ICMJE

member journals. Other journals are welcome to adopt this form. Individual journals may differ in where they include this information, and some journals do not send information on conflicts of interest to reviewers. (See *Section II. D. Conflicts of Interest*.)

Abstract

Structured abstracts are preferred for original research and systematic reviews. The abstract should provide the context or background for the study and should state the study's purpose, basic procedures (selection of study subjects or laboratory animals, observational and analytical methods), main findings (giving specific effect sizes and their statistical significance, if possible), principal conclusions, and funding sources. It should emphasize new and important aspects of the study or observations. Articles on clinical trials should contain abstracts that include the items that the CONSORT group has identified as essential (http://www.consort-statement.org/? =1190).

Because abstracts are the only substantive portion of the article indexed in many electronic databases, and the only portion many readers read, authors need to be careful that they accurately reflect the content of the article. Unfortunately, the information contained in many abstracts differs from that in the text (7). The format required for structured abstracts differs from journal to journal, and some journals use more than one format; authors need to prepare their abstracts in the format specified by the journal they have chosen.

The ICMJE recommends that journals publish the trial registration number at the end of the abstract. The ICMJE also recommends that, whenever a registration number is available, authors list that number the first time they use a trial acronym to refer to either the trial they are reporting or to other trials that they mention in the manuscript.

Introduction

Provide a context or background for the study (that is, the nature of the problem and its significance). State the specific purpose or research objective of, or hypothesis tested by, the study or observation; the research objective is often more sharply focused when stated as a question. Both the main and secondary objectives should be clear, and any prespecified subgroup analyses should be described. Provide only directly pertinent references, and do not include data or conclusions from the work being reported.

Methods

The Methods section should include only information that was available at the time the plan or protocol for the study was being written; all information obtained during the study belongs in the Results section.

Selection and Description of Participants

Describe your selection of the observational or experimental participants (patients or laboratory animals, including controls) clearly, including eligibility and exclusion criteria and a description of the source population. Because the relevance of such variables as age and sex to the object of research is not always clear, authors should explain their use when they are included in a study report—for example, authors should explain why only participants of certain ages were included or why women were excluded. The guiding principle should be clarity about how and why a study was done in a particular way. When authors use such variables as race or ethnicity, they should define

how they measured these variables and justify their relevance.

Technical Information

Identify the methods, apparatus (give the manufacturer's name and address in parentheses), and procedures in sufficient detail to allow others to reproduce the results. Give references to established methods, including statistical methods (see below); provide references and brief descriptions for methods that have been published but are not well-known; describe new or substantially modified methods, give the reasons for using them, and evaluate their limitations. Identify precisely all drugs and chemicals used, including generic name(s), dose(s), and route(s) of administration.

Authors submitting review manuscripts should include a section describing the methods used for locating, selecting, extracting, and synthesizing data. These methods should also be summarized in the abstract.

Statistics

Describe statistical methods with enough detail to enable a knowledgeable reader with access to the original data to verify the reported results. When possible, quantify findings and present them with appropriate indicators of measurement error or uncertainty (such as confidence intervals). Avoid relying solely on statistical hypothesis testing, such as *P* values, which fail to convey important information about effect size. References for the design of the study and statistical methods should be to standard works when possible (with pages stated). Define statistical terms, abbreviations, and most symbols. Specify the computer software used.

Results

Present your results in logical sequence in the text, tables, and illustrations, giving the main or most important findings first. Do not repeat all the data in the tables or illustrations in the text; emphasize or summarize only the most important observations. Extra or supplementary materials and technical detail can be placed in an appendix where they will be accessible but will not interrupt the flow of the text, or they can be published solely in the electronic version of the journal.

When data are summarized in the Results section, give numeric results not only as derivatives (for example, percentages) but also as the absolute numbers from which the derivatives were calculated, and specify the statistical methods used to analyze them. Restrict tables and figures to those needed to explain the argument of the paper and to assess supporting data. Use graphs as an alternative to tables with many entries; do not duplicate data in graphs and tables. Avoid nontechnical uses of technical terms in statistics, such as "random" (which implies a randomizing device), "normal," "significant," "correlations," and "sample."

Where scientifically appropriate, analyses of the data by such variables as age and sex should be included.

Discussion

Emphasize the new and important aspects of the study and the conclusions that follow from them in the context of the totality of the best available evidence. Do not repeat in detail data or other information given in the Introduction or the Results section. For experimental studies, it is useful to

begin the discussion by briefly summarizing the main findings, then explore possible mechanisms or explanations for these findings, compare and contrast the results with other relevant studies, state the limitations of the study, and explore the implications of the findings for future research and for clinical practice.

Link the conclusions with the goals of the study but avoid unqualified statements and conclusions not adequately supported by the data. In particular, avoid making statements on economic benefits and costs unless the manuscript includes the appropriate economic data and analyses. Avoid claiming priority or alluding to work that has not been completed. State new hypotheses when warranted, but label them clearly as such.

References

General Considerations Related to References

Although references to review articles can be an efficient way to guide readers to a body of literature, review articles do not always reflect original work accurately. Readers should therefore be provided with direct references to original research sources whenever possible. On the other hand, extensive lists of references to original work on a topic can use excessive space on the printed page. Small numbers of references to key original papers often serve as well as more exhaustive lists, particularly since references can now be added to the electronic version of published papers, and since electronic literature searching allows readers to retrieve published literature efficiently.

Avoid using abstracts as references. References to papers accepted but not yet published should be designated as “in press” or “forthcoming”; authors should obtain written permission to cite such papers as well as verification that they have been accepted for publication. Information from manuscripts submitted but not accepted should be cited in the text as “unpublished observations” with written permission from the source.

Avoid citing a “personal communication” unless it provides essential information not available from a public source, in which case the name of the person and date of communication should be cited in parentheses in the text. For scientific articles, obtain written permission and confirmation of accuracy from the source of a personal communication.

Some but not all journals check the accuracy of all reference citations; thus, citation errors sometimes appear in the published version of articles. To minimize such errors, references should be verified using either an electronic bibliographic source, such as PubMed or print copies from original sources. Authors are responsible for checking that none of the references cite retracted articles except in the context of referring to the retraction. For articles published in journals indexed in MEDLINE, the ICMJE considers PubMed the authoritative source for information about retractions. Authors can identify retracted articles in MEDLINE by using the following search term, where pt in square brackets stands for publication type: Retracted publication [pt] in PubMed.

Reference Style and Format
The Uniform Requirements style for references is based largely on an American National Standards Institute style adapted by the NLM for its databases. Authors should consult NLM’s Citing Medicine for information on its recommended formats for a variety of reference types. Authors may also consult sample references, a list of examples extracted from or based on Citing Medicine for easy use by the ICMJE audience; these sample references are maintained by NLM.

References should be numbered consecutively in the order in which they are first mentioned in the text. Identify references in text, tables, and legends by Arabic numerals in parentheses. References cited only in tables or figure legends should be numbered in accordance with the sequence established by the first identification in the text of the particular table or figure. The titles of journals should be abbreviated according to the style used in the list of Journals Indexed for MEDLINE, posted by the NLM on the Library's Web site. Journals vary on whether they ask authors to cite electronic references within parentheses in the text or in numbered references following the text. Authors should consult with the journal to which they plan to submit their work.

Tables

Tables capture information concisely and display it efficiently; they also provide information at any desired level of detail and precision. Including data in tables rather than text frequently makes it possible to reduce the length of the text.

Type or print each table with double-spacing on a separate sheet of paper. Number tables consecutively in the order of their first citation in the text and supply a brief title for each. Do not use internal horizontal or vertical lines. Give each column a short or an abbreviated heading. Authors should place explanatory matter in footnotes, not in the heading. Explain all nonstandard abbreviations in footnotes, and use the following symbols, in sequence:

*, †, ‡, §, ||, ¶, **, ††, ‡‡, §§, ||||, ¶¶, etc.

Identify statistical measures of variations, such as standard deviation and standard error of the mean.

Be sure that each table is cited in the text.

If you use data from another published or unpublished source, obtain permission and acknowledge that source fully.

Additional tables containing backup data too extensive to publish in print may be appropriate for publication in the electronic version of the journal, deposited with an archival service, or made available to readers directly by the authors. An appropriate statement should be added to the text to inform readers that this additional information is available and where it is located. Submit such tables for consideration with the paper so that they will be available to the peer reviewers.

Illustrations (Figures)

Figures should be either professionally drawn and photographed, or submitted as photographic-quality digital prints. In addition to requiring a version of the figures suitable for printing, some journals now ask authors for electronic files of figures in a format (for example, JPEG or GIF) that will produce high-quality images in the Web version of the journal; authors should review the images of such files on a computer screen before submitting them to be sure they meet their own quality standards.

For x-ray films, scans, and other diagnostic images, as well as pictures of pathology specimens or photomicrographs, send sharp, glossy, black-and-white or color photographic prints, usually 127 x 173 mm (5 x 7 inches). Although some journals redraw figures, many do not. Letters, numbers, and symbols on figures should therefore be clear and consistent throughout, and large enough to

remain legible when the figure is reduced for publication. Figures should be made as self-explanatory as possible, since many will be used directly in slide presentations. Titles and detailed explanations belong in the legends--not on the illustrations themselves.

Photomicrographs should have internal scale markers. Symbols, arrows, or letters used in photomicrographs should contrast with the background.

Photographs of potentially identifiable people must be accompanied by written permission to use the photograph.

Figures should be numbered consecutively according to the order in which they have been cited in the text. If a figure has been published previously, acknowledge the original source and submit written permission from the copyright holder to reproduce the figure. Permission is required irrespective of authorship or publisher except for documents in the public domain.

For illustrations in color, ascertain whether the journal requires color negatives, positive transparencies, or color prints. Accompanying drawings marked to indicate the region to be reproduced might be useful to the editor. Some journals publish illustrations in color only if the author pays the additional cost.

Authors should consult the journal about requirements for figures submitted in electronic formats.

Legends for Illustrations (Figures)

Type or print out legends for illustrations using double spacing, starting on a separate page, with Arabic numerals corresponding to the illustrations. When symbols, arrows, numbers, or letters are used to identify parts of the illustrations, identify and explain each one clearly in the legend. Explain the internal scale and identify the method of staining in photomicrographs.

Units of Measurement

Measurements of length, height, weight, and volume should be reported in metric units (meter, kilogram, or liter) or their decimal multiples.

Temperatures should be in degrees Celsius. Blood pressures should be in millimeters of mercury, unless other units are specifically required by the journal.

Journals vary in the units they use for reporting hematologic, clinical chemistry, and other measurements. Authors must consult the Information for Authors of the particular journal and should report laboratory information in both local and International System of Units (SI). Editors may request that authors add alternative or non-SI units, since SI units are not universally used. Drug concentrations may be reported in either SI or mass units, but the alternative should be provided in parentheses where appropriate.

Abbreviations and Symbols

Use only standard abbreviations; use of nonstandard abbreviations can be confusing to readers. Avoid abbreviations in the title of the manuscript. The spelled-out abbreviation followed by the abbreviation in parenthesis should be used on first mention unless the abbreviation is a standard unit of measurement.

Journal of Science and Medicine in Sport

Official Journal of Sports Medicine Australia (SMA)

Guide for Authors

Contributors are invited to submit their manuscripts in English to the Editor for critical peer review. The *Journal of Science and Medicine in Sport* considers for publication manuscripts in the categories of:
- Original Research
- Review Article

The manuscripts must be in one of the following sub-disciplines relating generally to the broad sports medicine and sports science fields: sports medicine, sports injury (including injury epidemiology and injury prevention), physiotherapy, podiatry, physical activity and health, sports science, biomechanics, exercise physiology, motor control and learning, sport and exercise psychology, sports nutrition, public health (as relevant to sport and exercise), and rehabilitation and injury management. Manuscripts with an interdisciplinary perspective with specific applications to sport and exercise and its interaction with health will also be considered.

Only studies involving human subjects will be considered.

Authors must declare that manuscripts submitted to the Journal have not been published elsewhere or are not being considered for publication elsewhere and that the research reported will not be submitted for publication elsewhere until a final decision has been made as to its acceptability by the Journal.

PLEASE NOTE that papers will NOT be assigned for peer review until they are formatted as outlined in the Guide for Authors. In particular:
- Ensure that English is of good standard
- Ensure Ethics Committee details are as complete as possible
- Ensure all headings and subheadings conform to the Guide for Authors
- References, both in-text and reference list, must be formatted according to the Guide for Authors

- Provide the Figure Legends as part of the text file, at the end of the manuscript
- Include Acknowledgements – this is mandatory

The review process will consist of reviews by at least two independent reviewers. Contributors must suggest the names and full contact details of 3 possible reviewers. The reviewers must not be from the same institutions as the authors, and one must be from a country different to any of the authors. The Editor may, at his or her discretion, choose no more than one of those suggested. The reviewers will be blinded to the authorship of the manuscript. The Editor will make a final decision about the manuscript, based on consideration of the reviewers' comments.

The journal receives an ever-increasing number of submissions and unfortunately can only publish a small proportion of manuscripts. The journal's Editorial Board does not enter into negotiations once a decision on a manuscript has been made. The Editor's decision is final.

Papers accepted for publication become the copyright of Sports Medicine Australia. Authors will be asked to sign a transfer of copyright form, on receipt of the accepted manuscript by Elsevier. This enables the publisher to administer copyright on behalf of the authors and the society, while allowing the continued use of the material by the author for scholarly communication.

PREPARATION OF MANUSCRIPTS

- Microsoft Word is the preferred software program. Use Arial or Times New Roman font, size eleven (11) point.
- Manuscript is double-spaced throughout (including title page, abstract, text, references, tables, and legends).
- Margins are 1 inch or 2.5 cm all around
- Include page and line numbers for the convenience of the peer reviewers.
- Number the pages consecutively, beginning with the title page as page 1 and ending with the Figure legend page.
- All headings (including the Title) should be in sentence-case only, not in capital letters.
- Sub-headings are generally not accepted. Incorporate into the text if required.
- Footnotes are not acceptable.
- Keep the use of tables, figures and graphs to a minimum.
- See notes on Tables, Figures, Formulae and Scientific Terminology at the end.

WORD COUNT LIMITS

Original Research papers

- 3000 word count limit (excluding title, abstract, tables/figures, figure legends, Acknowledgements, and References)
- Maximum number (combined) of tables and figures is 3
- Long tables should only be included as supplementary material and will be made available on-line only
- Maximum number of references is 30
- A structured abstract of less than 250 words (not included in 3000 word count) should be included with the following headings: Objectives, Design, Method, Results, and Conclusions

Review articles

- 4000 word count limit (excluding title, abstract, tables/figures, figure legends, Acknowledgements, and References)
- Maximum number (combined) of tables and figures is 3
- Long tables should only be included as supplemental files and will be available online only

- Maximum number of references is 60
- A structured abstract of less than 250 words (not included in 4000 word count) should be included sticking as closely as possible to the following headings: Objectives, Design, Method, Results, and Conclusions

SUBMISSION OF MANUSCRIPTS
All manuscripts, correspondence and editorial material for publication should be submitted online via the Elsevier Editorial System at http://www.ees.elsevier.com/jsams.

Authors simply need to "create a new account" (i.e., register) by following the instructions at the website, and using their own e-mail address and selected password. Authors can then submit manuscripts containing text, tables, and images (figures) online. The entire peer-review process will be managed electronically to ensure timely review and publication. Authors can expect an initial decision on their submission within 8 weeks.

Following registration, enter the "Author area" and follow the instructions for submitting a manuscript, including the structured Abstract, suggested reviewers, Cover letter, Tables, Figures, and any supplementary material.

If you wish to publish colour figures and agree to pay the "colour charge", tick the appropriate box. Colour illustrations incur a colour charge of 312 US dollars for the first page and 208 US dollars for every additional page containing colour. Figures can be published in colour at no extra charge for the online version. If you wish to have figures in colour online and black and white figures printed, please submit both versions.

The entire peer-review process will be managed electronically to ensure timely review and publication. Authors can expect an initial decision on their submission within 6 weeks.

Note: the online manuscript submission program requires separate entries of some information that also appears in the manuscript. These separate entries are needed to manage processing and review of your manuscript and correspondence.

Regulatory requirements
- *Research protocol*: Authors must state that the protocol has been approved by the appropriate ethics committee. Name the committee.
- *Human investigation*: The Ethical Guidelines followed by the investigators must be included in the Methods section of the manuscript.

STRUCTURE OF THE MANUSCRIPT (in order):

1. Cover Letter - Every submission, regardless of category must include a letter stating:
- the category of article: Original Research or Review article
- the *sub-discipline*: sports medicine, sports injury (including injury epidemiology and injury prevention), physiotherapy, podiatry, physical activity and health, sports science, biomechanics, exercise physiology, motor control and learning, sport and exercise psychology,sports nutrition, public health (as relevant to sport and exercise), rehabilitation and injury management, and others having an interdisciplinary perspective with specific applications to sport and exercise and its interaction with health.

- Sources of outside support for research (including funding, equipment and drugs) must be named.
- Financial support for the project must be acknowledged, or "no external financial support" declared.

- The role of the funding organisation, if any, in the collection of data, their analysis and interpretation, and in the right to approve or disapprove publication of the finished manuscript must be described in the Methods section of the text.

- When the proposed publication concerns any commercial product, either directly or indirectly, the author must include a statement (1) indicating that he or she has no financial or other interest in the product or distributor of the product or (2) explaining the nature of any relation between himself or herself and the manufacturer or distributor of the product.

- Other kinds of associations, such as consultancies, stock ownership, or other equity interests or patent-licensing arrangements, also must be disclosed. Note: If, in the Editor's judgment, the information disclosed represents a potential conflict of interest, it may be made available to reviewers and may be published at the Editor's discretion; authors will be informed of the decision before publication.

- The *Ethical Guidelines* that have been followed must be stated clearly. Provide the Ethics Committee name and approval number obtained for Human investigation.

- *Authors must declare* that manuscripts submitted to the Journal have not been published elsewhere or are not being considered for publication elsewhere and that the research reported will not be submitted for publication elsewhere until a final decision has been made as to its acceptability by the Journal.

Permission from the publisher (copyright holder) must be submitted to the Editorial Office for the reproduction of any previously published table(s), illustration(s) or photograph(s) in both print and electronic media or from any unmasked participants appearing in photographs.

2. Title Page (first page) should contain:
a. *Title*. Short and informative
b. *Authors*. List all authors by first name, all initials and family name
c. *Institution and affiliations*. List the name and full address of all institutions where the study described was carried out. List departmental affiliations of each author affiliated with that institution after each institutional address. Connect authors to departments using alphabetical superscripts.
d. *Corresponding author*. Provide the name and e-mail address of the author to whom communications, proofs and requests for reprints should be sent.
e. *Word count* (excluding abstract and references), the Abstract word count, the number of Tables, the number of Figures.

3. Manuscript (excluding all author details) should contain: (in order)

a. *Abstract* - must be structured using the following sub-headings: Objectives, Design, Methods, Results, and Conclusions. Avoid abbreviations and acronyms.

b. *Keywords* - provide up to 6 keywords, with at least 4 selected via the Index Medicus Medical Subject Headings (MeSH) browser list: http://www.nlm.nih.gov/mesh/authors.html. These keywords should not reproduce words used in the paper title.

c. Main body of the text.

For Original Research papers, text should be organised as follows:

i. *Introduction* - describing the (purpose of the study with a brief review of background

ii. *Methods* - described in detail. Include details of the Ethics Committee approval obtained for Human investigation, and the ethical guidelines followed by the investigators. This section is not called Materials and Methods, and should not include subheadings. Do not use the term "subjects" - use terms such as "participants", "patients" or "athletes", etc.

iii. *Results* - concisely reported in tables and figures, with brief text descriptions. Do not include subheadings. Use small, non-italicized letter p for p-values with a leading zero, e.g. 0.05; Measurements and weights should be given in standard metric units. Do not replicate material that is in the tables or figures in the text.

iv. *Discussion* - concise interpretation of results. Cite references, illustrations and tables in numeric order by order of mention in the text. Do not include subheadings.

v. *Conclusion*

vi. *Practical Implications* - 3 to 5 dot (bulleted) points summarising the practical findings derived from the study to the real-world setting of sport and exercise - that can be understood by a lay audience. Avoid overly scientific terms and abbreviations. Dot points should not include recommendations for further research.

vii. *Acknowledgments* - this section is compulsory. Grants, financial support and technical or other assistance are acknowledged at the end of the text before the references. All financial support for the project must be acknowledged. If there has been no financial assistance with the project, this must be clearly stated.

viii. *References* - authors are responsible for the accuracy of references.

ix. *Tables* - may be submitted at the end of the text file, on separate pages, one to each page.

x. *Figure Legends* - must be submitted as part of the text file and not as illustrations.

4. Figures - must be submitted as one or more separate files that may contain one or more images.

5. Supplementary material (if any) - tables or figures to be viewed online only

REFERENCES

- References should be numbered consecutively in un-bracketed superscripts where they occur in the text, tables, etc, and listed numerically (e.g. "1", "2") at the end of the paper under the heading "References".

- For Original Research papers, no more than three references should be used to support a specific point in the text.

- All authors should be listed where there are three or fewer. Where there are more than three, the reference should be to the first three authors followed by the expression "et al".

- Book and journal *titles* should be in *italics*.

- Conference and other abstracts should not be used as references. Material referred to by the phrase "personal communication" or "submitted for publication" are not considered full references and should only be placed in parentheses at the appropriate place in the text (e.g., (Hessel 1997 personal communication). References to articles submitted but not yet accepted are not encouraged but, if necessary, should only be referred to in the text as "unpublished data".

- Footnotes are unacceptable.

- Book references:
Last name and initials of author, chapter title, chapter number, italicised title of book, edition (if applicable), editor, translator (if applicable), place of publication, publisher, year of publication.

Example:
Wilk KE, Reinold MM, Andrews JR. Interval sport programs for the shoulder, Chapter 58, in *The Athlete's Shoulder*, 2nd ed., Philadelphia, Churchill Livingstone, 2009

- Journal references:
Last name and initials of principal author followed by last name(s) and initials of co-author(s), title of article (with first word only starting in capitals), abbreviated and italicised title of journal, year, volume (with issue number in parenthesis if applicable), inclusive pages.

For guidance on abbreviations of journal titles, see Index Medicus at www.nlm.nih.gov/tsd/serials/lji.html.

Example:
Hanna CM, Fulcher ML, Elley CR et al. Normative values of hip strength in adult male association football players assessed by handheld dynamometry. *J Sci Med Sport* 2010; 13(3):299-303.

- Internet references should be as follows:
Health Care Financing Administration. 1996 statistics at a glance. Available at: http://www.hcfa.gov/stats/stathili.htm. Accessed 2 December 1996.

- Articles in Press are cited using a DOI: http://www.doi.org. The correct format for citing a DOI is as follows: doi:10.1016/j.jsams.2009.10.104.

TABLES
- Tables should be part of the text file, placed on separate sheets (one to each page) after the References section. Do not use vertical lines.
- Each table should be numbered (Arabic) and have a title above. Legends and explanatory notes should be placed below the table.
- Abbreviations used in the table follow the legend in alphabetic order.
- Lower case letter superscripts beginning with "a" and following in alphabetic order are used for notations of within-group and between-group statistical probabilities.
- Tables should be self-explanatory, and the data should not be duplicated in the text or illustrations**.**

FIGURE LEGENDS

- Figure legends should be numbered (Arabic) and double-spaced in order of appearance, beginning on a separate page.
- Identify (in alphabetic order) all abbreviations appearing in the illustrations at the end of each legend.
- All abbreviations used on a figure and in its legend should be defined in the legend.
- Cite the source of previously published (print or electronic) material in the legend.
- Figure legends must be submitted as part of the text file and not as illustrations.

FIGURES AND ILLUSTRATIONS

- Images or figures are submitted online as one or more separate files that may contain one or more images.
- Within each file, use the figure number (e.g., Figure 1A) as the image filename.
- The system accepts image files formatted in TIF and EPS. PowerPoint (.ppt) files are accepted, but you must use a separate PowerPoint image file for each PowerPoint figure.
- Symbols, letters, numbers and contrasting fills must be distinct, easily distinguished and clearly legible when the illustration is reduced in size.
- Black, white and widely crosshatched bars are preferable; do not use stippling, gray fill or thin lines.
- Written permission from unmasked patients appearing in photographs must be obtained by the authors and must be surface mailed or faxed to the editorial office once the manuscript is submitted online.

FORMULAE, Equations and Statistical Notations

- Structural formulae, flow-diagrams and complex mathematical expressions are expensive to print and should be kept to a minimum.
- Present simple formulae in the line of normal text, where possible. Use a slash (/) for simple fractions rather than a built up fraction. Do not use italics for variables.
- In statistical analyses, 95% confidence intervals should be used, where appropriate. Experimental design should be concisely described and results summarised by reporting means, standard deviations (SD) or standard errors (SE) and the number of observations. Statistical tests and associated confidence intervals for differences or p-values should also be reported when comparisons are made. Only use normal text for statistical terms: do not use bold, italics or underlined text.

SCIENTIFIC TERMINOLOGY

- To enable consistency, authors should generally follow the technical guidelines of Medicine and Science in Sports and Exercise, unless otherwise stipulated in these Instructions.
- Following are some examples of the Journal style in the most basic cases and some general SI unit guidelines.

- Mass: 10 g, 2 kg
- Temperature: 20 o C
- Distance: 10 cm, 4 m, 20 km
- Time: 10 s, 20 min, 2 hr, 5 wk, 1 y
- Power: 10 W
- Energy: 400 J, 10 kJ.

- The centigrade scale (C) and the metric units (SI) must be used, except in the case of heart rate (beats per min: bpm), blood pressure (mmHg) and gas pressure (mmHg).

- When opening a sentence, numbers should be expressed in words, e.g.: Forty-seven patients were contacted by phone.
- The 24-hour clock should be used.