

Relationship between resting metabolic rate and physical activity in adolescents: The PAHL study

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“For I know the plans I have for you, says the Lord. They are plans for good and not for disaster, to give you a future and hope”. **Jeremiah 29:11**

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No road is too long for him who advances slowly and does not hurry, and no attainment is beyond the reach of he who equips himself with patience to achieve it.

(Jean de La Bruyère)

The author

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Declaration

The co-authors of the articles which form part of this dissertation, Prof. S. J. Moss (supervisor) and Prof. M. A. Monyeki (co-supervisor) hereby give permission to the candidate, Miss S. N. Dube, to include the two articles as part of a Masters dissertation. The contribution, both supervisory and supportive, of these co-authors was kept within limits, thereby enabling the candidate to submit this dissertation for examination purposes. This dissertation, therefore, serves as partial fulfilment of the requirements for the MSc. Degree in Biokinetics within the School of Biokinetics, Recreation and Sport Science in the Faculty of Health Science at the North-West University, Potchefstroom Campus.

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The relationship between resting metabolic rate and physical activity in adolescents: The PAHL study

Obesity is affecting an increasingly larger proportion of adolescents in the world, and this can be attributed to low resting metabolic rate (RMR) as well as reduced physical activity (PA) levels. Little is known about objectively determined habitual PA and RMR in 16 year old African adolescents. The purpose of this study is twofold. Firstly, to determine the objectively measured PA status of adolescents and secondly, to determine the relationship that exists between RMR and PA in 16 year old adolescents.

Two hundred and twenty six (226) adolescents aged sixteen (16) wore the Actiheart® monitor, combined accelerometry and heart rate for seven (7) consecutive days. Six high schools were recruited to take part in the study: two from town (high socio-economic status) and four from the township (low socio-economic status) of the Potchefstroom area of the North West Province of South Africa. Times spent in moderate to vigorous physical activity, physical activity counts per minute (CPM), total energy expenditure (TEE), active energy expenditure (AEE) and physical activity levels (PAL) were assessed using the Actiheart®. The participants' RMR was measured by indirect calorimetry using the Fitmate Pro (Cosmed, Italy).

All data analyses were performed with the SPSS Version 20 software (IBM SPSS, II). The descriptive statistics (mean and standard deviations) as well as independent t-tests and Mann-Whitney U test were performed to determine differences between ethnicity and genders and to calculate practical significance. A Type I error rate of $p \leq 0.05$ was used for statistical significance. To investigate the relationship between RMR and physical activity regression analysis was performed with adjustment for gender, race and fat free mass.

Results: Significantly higher PAL (1.57 ± 0.15) were determined in girls compared to boys (PAL = 1.41 ± 0.10). Black adolescents indicated significant higher PAL (1.53 ± 0.14) compared to white adolescents (1.45 ± 0.16). On average, regardless of race or gender, the participants were more active on weekdays than weekends. The current study shows that girls spent more minutes/day in moderate to vigorous physical activity (MVPA) than the boys. The results show that 16.4% of the study sample was either overweight or obese. After adjustment

Conclusion: Objectively determined PA of adolescents in South Africa indicates that only one third of adolescents are meeting the recommended 60 minutes of daily MVPA. Gender and race specific interventions are needed to increase habitual physical activity levels in adolescents. Given the fact that the studied sample did not meet recommended daily physical activity and the adverse effect of inactivity and chronic diseases of life style, urgent strategies to inculcate the culture of regular physical activity as a preventative measure of chronic diseases of life style are needed. Behaviour that is carried on into adulthood is established during adolescence. Civic health efforts should focus on encouraging adolescent involvement in regular moderate-to-vigorous PA, which will subsequently increase RMR and lower the risk of the development of non-communicable chronic diseases such as obesity. Further local research is needed to confirm the association between RMR and PA in the local population.

Key Words: Physical activity, resting metabolic rate, adolescents, energy expenditure, obesity.

Die verwantskap tussen rustende metaboliese tempo en fisieke aktiwiteit in adolessente: die PAHL studie

Die populasie adolessente wat obesiteit het, is besig om proporsioneel te vermeerder. Die rede hiervoor kan as gevolg van 'n lae rustende metaboliese tempo (RMT) wees asook as gevolg van 'n afname in fisieke aktiwiteit (FA) vlakke. Daar is baie min bekend oor objektief bepaalde fisieke aktiwiteit in 16-jarige adolessente in Suid-Afrika. Daarom is die doel van hierdie studie tweeledig; Eerstens, om die objektief bepaalde fisieke aktiwiteitsvlakke van adolessente te bepaal en tweedens, om die verband tussen RMT en FA te bepaal in 16-jarige adolessente.

Twee honderd ses-en twintig (226) 16-jarige adolessente het vir sewe agterneenvolgende dae 'n Actiheart® monitor, gekombineerde versnelling en harttempo apparaat, gedra. Adolessente van ses hoërskole, twee in die dorpsgebied (hoog sosio-ekonomies) en vier van die lokasie (lae sosio-ekonomiese gebied) in die Potchefstroom area van die Noordwes Provinsie, is gewerf vir deelname in die studie. Die tyd wat op matig tot hoë intensiteit aktiwiteit spandeer is, fisieke aktiwiteit tellings per minute (cpm), totale energie spandering, (TEE), aktiwiteitsenergie spandering (AEE) en fisieke aktiwiteitsvlak (PAL) was met die Actiheart® gemeet. RMR was met behulp van die indirekte kalorimetrie gemeet (Fitmate Pro, Cosmed, Italy).

Data ontleding is met die SPSS Uitgawe 20 sagteware (IBM SPSS, II) gedoen. Die eienskappe van die deelnemers is met beskrywende statistiek gedoen (gemiddelde en standaard afwykings). Verskille tussen die etniese groepe en die geslagte is met behulp van onafhanklike t-toets en Mann-Whitney U toets gedoen. Statistiese betekenisvolheid is gestel vir $p \leq 0.05$. Die verband tussen die RMT en fisieke aktiwiteit is met behulp van regressie ontledings gedoen met korreksies aangebring vir geslag, etnisiteit en vet vrye massa.

Resultate: Betekenisvol hoër PAL (1.57 ± 0.15) het by die meisies voorgekom in vergelyking met die seuns (PAL = 1.41 ± 0.10). Die swart adolessente het ook betekenisvol hoër PAL (1.53 ± 0.14) in vergelyking met die wit adolessente getoon (1.45 ± 0.16). Die gemiddelde PAL waardes het toon dat ongeag ras of geslag, was die deelnemers die meeste aktief op weksdae in vergelyking met naweke. Die meisies het ook meer tyd as die seuns matig tot hoë intensiteit aktiwiteite gedoen. Verder toon die resultate dat 16.4% van die deelnemers oorgewig of obees is.

Die verband tussen RMT en matige tot hoë intensiteit fisieke aktiwiteit was betekenis vol nadat daar gekorrigeer is vir geslag, etnisiteit en vet vrye massa met die liniêre regressie ontleding ($r^2 = 0.46$ ($p < 0.05$)).

Gevolgtrekking: Fisieke aktiwiteit wat objektief bepaal is toon aan dat slegs een derde van die adolessente die aanbeveelde 60 minute van daaglike matige tot hoë intensiteit aktiwiteite bereik. Geslag en ras spesifieke intervensies behoort saamgestel te word om fisieke aktiwiteitsvlakke van adolessente te verhoog. In die lig van die deelnemers wat nie die aanbeveelde kriteria vir fisieke aktiwiteit behaal het nie, en die geweldige negatiewe gevolge van onaktiwiteit en kroniese siektes, is daar dringende strategieë nodig om kultuur spesifieke fisieke aktiwiteite vir leefstyl veranderinge te implementeer. Die gedrag van volwassenes is dit wat reeds in adolessensie gevestig is. Gesondheidsbevorderende pogings behoort adolessente te motiveer om hul vlakke van aktiwiteite te vermeerder, wat tot die gevolg kan hê dat die RMT ook verhoog kan word. 'n Voorkoming van nie-oordraagbare siektes soos obesiteit kan op hierdie wyse voorkom of bekamp word. Die verband tussen die RMT en FA behoort herhaal te word in ander populasies om die tendens te bevestig.

Sleutel terme: Fisieke aktiwiteit, rustende metaboliese tempo, adolessensie, energie spandering, obesiteit.

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List of Abbreviations

AEE	Activity energy expenditure
ANOVA	Analysis of variance
BMI	Body mass index
DIT	Diet induced thermogenesis
DLW	Doubly labelled water
ECG	Electrocardiogram
EE	Energy expenditure
FFM	Fat free mass
FM	Fat mass
HR	Heart rate
MET	Metabolic equivalent of exercise
MVPA	Moderate to vigorous physical activity
NEAT	Non-exercise activity thermogenesis
PA	Physical activity
PAEE	Physical activity energy expenditure
PAHLS	Physical activity and health longitudinal study
PAL	Physical activity level
REE	Resting energy expenditure
RMR	Resting metabolic rate
RQ	Respiratory quotient
SADHS	South African Demographic and Health Survey
SRSA	Sport and Recreation South Africa
TEE	Total energy expenditure
THUSA BANA	Transition & Health during Urbanisation of South Africans; BANA, children
VO ₂	Measurement of oxygen consumption
WHO	World Health Organisation
YRBS	Youth Risk Behaviour Study

INTRODUCTION

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1.1 INTRODUCTION

Little is known about the relationship between resting metabolic rate (RMR) and objectively measured physical activity in 16-year old South African adolescents. The data collected from this study may provide valuable information for future studies. RMR constitutes up to 80% of total energy expenditure hence understanding the trends of physical activity, and body composition in adolescents is important because it is associated with adverse effects on health and social repercussions in both adolescence and adulthood (Gilliat-Wimberly *et al.*, 2001:1181). In this chapter the problem statement for the relationship between resting metabolic rate and objectively measured physical activity in adolescents will be presented. The research questions, objectives and hypotheses on which the study is to be based will be discussed. The chapter will also give an over view of the structure of the dissertation.

1.2 PROBLEM STATEMENT

Obesity is a huge health problem arising in developing countries. An imbalance in energy intake and energy expenditure leads to obesity which is associated with increased chronic morbidities (e.g. heart disease, cancer, hypertension, diabetes, and metabolic syndrome) and mortality (Akbulut & Rakicioglu, 2012:1025). There is a decline in the level of physical activity among boys and girls during their adolescent years (Neumark-Sztainer *et al.*, 2003:803). Physical activity improves weight loss and is a good indicator of weight loss

management. RMR contributes 60-80% of an individual's total metabolism and it is the largest portion of metabolism that represents the amount of calories an individual utilizes daily. Other portions of metabolism include activity energy expenditure (AEE) and dietary intake thermogenesis (DIT). Indirect calorimetry is the commonly accepted criterion for measuring RMR (Compher *et al.*, 2005:1136).

It has been indicated that the resting metabolic rate of individuals could be influenced by levels of physical activity. Resting metabolic rate (RMR) is defined as energy expenditure of membrane turnover and thermogenesis of an individual measured after a 12-hour fast through 16 minutes of absolute rest in a supine position (Akbulut & Rakicioglu, 2012:1025). The extent to which body movement leads to energy expenditure is dependent on body size and body composition in terms of fat mass (FM) and fat free mass (FFM) (Plasqui & Westerterp, 2007:2371). During puberty, FFM and FM change quickly and these changes are influenced by sex and obesity. How these dramatic changes in body composition affect RMR is not completely understood (Molnar & Schutz, 1997:376).

Physical activity (PA) is defined as body movement, produced by skeletal muscles, resulting in energy expenditure (Riddoch *et al.*, 2004:86). Assessment of physical activity in adolescents in free living conditions is important for understanding relations between physical activity and health, however physical activity is inherently difficult to measure especially when people are undergoing everyday activities (Brage *et al.*, 2005:561). The measurement of resting metabolic rate and physical activity patterns in children and adolescents is probably even more difficult than in adults because many of the methods are of low subject appeal to them and are likely to induce behavioural changes in their spontaneous and natural activity patterns (Livingstone *et al.*, 1992:343). Methods of measuring habitual physical activity range from subjective (questionnaires) to objective (doubly labelled water, heart rate monitors, accelerometers). The ability to accurately track energy expenditure (EE) using objective methods is on the rise. The use of accelerometers provides an objective measure of PA and has the advantage of being able to estimate the duration and intensity of physical activity performed throughout the day (Hearst *et al.*, 2012:78). The energy cost of physical activity is measured in units called METs, which are multiples of resting metabolic rate. One MET is defined as $1 \text{ kcal.kg}^{-1}.\text{hour}^{-1}$ and is equivalent to the energy cost of sitting quietly, two METs indicate that the energy expended is twice than at rest, and three METs is triple the resting

energy expenditure (Sjöström *et al.*, 2002:123). The intensity of activity is assigned values of metabolic equivalent (METs) and is categorised as light (<3), moderate (3.0-6.0) or vigorous (>6.0) (Ainsworth *et al.*, 2000: 498).

According to the President's Council on Physical Fitness and Sports (PCPFS, 2008) children and adolescents require 60 minutes of moderate to vigorous intensity physical activity (MVPA) per day in order to derive health benefits. This period does not have to include 60 consecutive minutes; bouts of 10-15 minutes during the course of the day are also considered to be beneficial for their health (PCPFS 2008). Engelbrecht *et al.* (2004:41) reported that 73.3% of girls between the ages of 13-15-years old in the North-West Province of South Africa had low physical activity levels, and significant decreases of activity levels with increasing age up to 15 years were also found in the group. Aires *et al.*, (2007:871) reported that structured physical activity contributes not only to increasing moderate to vigorous physical activity (MVPA) levels, but also to combating the low levels of MVPA that occur during the days that adolescents do not participate in physical activity. Studies in South Africa have shown unsatisfactory levels of physical activity among adolescents (Sport and Recreation South Africa, SRSA, 2005).

FFM is a primary determinant of RMR; factors that influence RMR often do so through their effect on FFM (Gilliant-Wimberly *et al.*, 2001:1181). The scientific literature is not completely conclusive in this area, but it appears that PA may positively affect RMR in a variety of ways. PA affects energy expenditure (EE) in two ways. First, regular physical activity increases the amount of TEE. Secondly, exercise helps maintain FFM, which in turn helps to maintain a higher RMR (Gilliant-Wimberly *et al.*, 2001:1181).

The majority of studies that focus on the relationship of physical activity to RMR have reported a positive correlation between these variables (Gilliat-Wimberly *et al.*, 2001:1181; Hunter *et al.*, 2006:2018). Research suggests that as a result of acute exercise, a prolonged increase in post-exercise metabolic rate occurs. In addition, there may be a lasting increase in RMR associated with exercise training. Eventually a possible increase can be seen in energy expenditure (EE) during non-exercising periods. Furthermore, exercise helps maintain fat-free mass, which in turn helps maintain higher RMR (Akbulut & Rakicioglu 2012:1025; Gilliat-Wimberly *et al.*, 2001:1181).

Speakman (2003:621) studied physical activity and RMR in an adult population but did not answer the question of the relationship between RMR and physical activity in adolescents. Speakman's (2003:621) population focussed on the long and short term responses of RMR to specific training regimens; concentrating on the differences between animal and human studies. It is important to recognise the trend of physical activity and resting metabolic rate in adolescents as they have an effect on overall health and wellness in adolescence, leading up to adulthood.

Therefore the research questions to be answered with this study are:

1. What is the objectively measured PA and resting metabolic rate (RMR) status in an adolescent population?
2. What is the relationship between RMR and PA in adolescents in Potchefstroom?

A 2007 study performed by Mamabolo *et al.* revealed that 8.6% of Potchefstroom adolescents are either overweight or obese. If a meaningful relationship exists between RMR and PA, these variables could be addressed by professionals (physicians, exercise physiologists, etc.) to guard against the development of hypokinetic diseases such as hypertension, obesity and Type II diabetes (Williams, 2001:754). Studies during adolescence would add support to the primary assumptions given for early intervention to prevent risk factors of non-communicable diseases before behavioural patterns are fully established and resistant to change (Kovacs *et al.*, 2009:337).

1.3 OBJECTIVES

The objectives of this research are:

- To determine the objectively measured physical activity and resting metabolic rate (RMR) status of an adolescent population in the Tlokwe municipality of the North-West Province, South Africa.
- To investigate the relationship between RMR and physical activity of an adolescent population in the Tlokwe municipality of the North-West Province, South Africa.

1.4 HYPOTHESES

The study is based on the following hypotheses:

- Gender differences in RMR and PA exist, with boys having higher values for RMR and PA than female adolescents of the North West Province, South Africa; and
- A positive significant relationship between RMR and moderate to high PA is present in an adolescent population of the North-West Province, in South Africa.

These hypotheses will be tested by measuring the RMR and PA of adolescents in the Tlokwe municipality of the North West Province, South Africa.

1.5 STRUCTURE OF THE DISSERTATION

The dissertation will be presented in article format as approved by the senate of the North-West University, and it will be structured as follows:

Chapter 1: This is the introductory chapter where the problem statement, objectives and hypotheses of the study are stated. The list of references is proposed at the end of the chapter according to the Harvard guidelines adapted by the North West University (NWU).

Chapter 2: This is a review of the current literature and aims to discuss the resting metabolic rate and physical activity with particular emphasis on adolescents. The chapter reports on the correlation between resting metabolic and fat free mass. The list of references is proposed at the end of the chapter according to the Harvard guidelines adapted by the North West University (NWU).

Chapter 3: Objectively determined habitual physical activity in African adolescents: the PAHLstudy. (*Journal of physical activity and health*). The regulations of this journal will be attached as an appendix (Guidelines for authors) at the end of the dissertation.

Chapter 4: Association between resting metabolic rate and objectively measured physical activity in adolescents: the PAHL-study (*Journal of adolescent health*). The

regulations of this journal will be attached as an appendix (Guidelines for authors) at the end of the dissertation.

Chapter 5: Summary, conclusion, limitations, and recommendations. Chapter 5 consists of a general discussion, conclusion, limitations and general recommendations for the overall findings of the mentioned objectives. The list of references is proposed at the end of the chapter according to the regulations of the NWU Harvard method.

The method and results of this study will be incorporated in Chapters 3, 4 and 5, therefore, no separated method and results chapter will be presented in this thesis.

FIGURE 1: Structure of Dissertation



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RESTING METABOLIC RATE AND PHYSICAL ACTIVITY IN ADOLESCENTS

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2.1 INTRODUCTION

Obesity is affecting an increasingly larger proportion of adolescents in the world, which may be as a result of a decrease in habitual physical activity (PA) or a change in the resting metabolic rate (RMR) of adolescents (Speakman & Selman, 2003:621). The high occurrence of overweight and obesity amongst adolescents is a disturbing health problem worldwide (Kemp & Pienaar, 2011:1). There appears to be an increase in the prevalence of overweight or obesity in childhood and adolescence in South Africa (Puoane *et al.*, 2002:1038). A 2007 study performed by Mamabolo *et al.* (2007:1047) revealed that 8.6% of Potchefstroom adolescents in the North-West Province are either overweight or obese. The occurrence of overweight and obesity in South African children at present has been said to be on par with that of many industrialised nations and amongst the highest in Africa (Truter *et al.*, 2010:227).

Body weight changes are a function of energy balance. Weight gain occurs when energy intake exceeds energy expenditure (EE), and weight loss occurs when EE exceeds energy intake (Montgomery *et al.*, 2004:591). Energy is expended through RMR, activity energy expenditure (AEE), and dietary intake thermogenesis (DIT). AEE accounts for 20-40% and is the most variable component of total daily EE, DIT accounts for 10% of total EE and RMR is

the largest component of EE, accounting for 60-70% of total daily EE. RMR is highly associated with body size and fat free mass (FFM), considerable variability exists among individuals after controlling for difference in FFM, fat mass (FM), age and sex (Montgomery *et al.*, 2004:591).

Little is known about the relationship between objectively determined habitual PA and RMR in 16-year old African adolescents. Although the relationship between PA and obesity is controversial and the protective mechanism of PA against obesity is unclear, any increases in RMR in response to exercise interventions is potentially of great importance (Speakman & Selman, 2003:621) as PA is hypothesized to protect individuals from the development of obesity by increasing EE and RMR thus leading to a favourable fuel utilisation (Andersen, 2009:281; Speakman & Selman, 2003:621).

Resting metabolic rate (RMR) has been measured in various populations with different experimental designs in order to determine factors that influence RMR. Researchers (Westerterp & Kester; 2003:865; Montgomery *et al.*, 2004:591) have found relationships between both PA and FFM to RMR, but due to differences in experimental design, physical activity and FFM did not always increase RMR (Mospan, 2009:1). Knowledge of RMR is important in clinical applications for defining appropriate nutritional support and determining caloric needs for energy balance and weight management.

Adolescence is known to be one of the four critical stages for human development as it constitutes the last possible growth spurt (Mamabolo *et al.*, 2007:1047). A lack of insufficient PA during adolescence is a precursor for the development of chronic diseases such as coronary heart disease, hypertension, obesity, diabetes, and certain cancers (Mamabolo *et al.*, 2007:1047). The correlation between RMR and physical activity is currently unclear for all populations (Westerterp, 2001:539), particularly children and adolescents, in part because of practical difficulties associated with the measurement of RMR and physical activity. The accelerometer easily and accurately measures PA and sedentary behaviour in children and adolescents. Data collected from accelerometers can provide important insights into the relationship between RMR and PA in paediatric populations (Montgomery *et al.*, 2004:592). The purpose of this chapter is to review current literature on RMR and PA among adolescents and terms relating thereto.

2.2 IMPLICATIONS OF RESTING METABOLIC RATE: OBESITY

Obesity results from chronic positive energy balance. Low RMR is likely to predispose one to obesity. Limited data is available for South African children (Puoane *et al.*, 2002:1038). In 1997, the World Health Organisation (WHO) highlighted that obesity is becoming a major health problem in many developing countries, particularly in adult women (WHO.1998). This presents a significant threat to the emergence of non-communicable diseases in the developing world as suggested by Reddy *et al.* (1998:596). In South Africa, obesity in women seems to start at a young age, data shows that 10% of women were obese at the ages 15-24 years (Puoane *et al.*, 2002:1038).

2.2.1 CAUSES AND CONSEQUENCES OF OBESITY

There is inconsistent evidence about the role of RMR and PA in the development of obesity (Mamabolo *et al.*, 2007:1047). It has been established that obesity results from a chronic state of positive energy balance, in which energy intake exceeds EE. A decline in PA plays a role in the increasing prevalence of childhood overweight (Ogden *et al.*, 2002:1728). Additionally, the decline in RMR during growth may be due to changes in body composition or to changes in the metabolic rate of individual organs and tissues (Hsu *et al.*, 2003:1506). Another aspect to be explored with regard to obesity is non-exercise activity thermogenesis (NEAT). It is the most variable aspect of an individual's TEE. NEAT includes activities such as dancing, gardening, working or playing and may be defined as the energy expenditure of all physical activities with the exemption of volitional sporting-like exercise. NEAT can differ significantly (by as much as 2000 kcal per day) between people of the same weight, with distinctly variable activity levels. Studies have revealed that on average, obese individuals are seated for 2.5 hours more, per day, than lean sedentary individuals (Levine *et al.*, 2000:729; Levine *et al.*, 2006:729). This indicates that low NEAT is likely to predispose an individual to obesity and that a concerted effort should be put into partaking in domestic or ambulatory activities more in order to combat obesity (Levine *et al.*, 2006:729).

Adolescence is an important time in which to study changes in the components of EE because it is such a critical period in the development of obesity (Spadano *et al.*, 2005:1102). Such a study is crucial for females because obesity in adolescence is more likely to persist into

adulthood in girls than in boys (Spadano *et al.*, 2005:1102). RMR is one of the many factors that could influence weight (Kirkby *et al.*, 2004:430). Knowledge of RMR is important in clinical applications for identifying suitable nutritional support and determining caloric needs for energy balance and weight management.

Obesity is associated with chronic diseases of lifestyle such as hypertension, heart disease, diabetes and metabolic syndrome (Aubertin-Leheudre *et al.*, 2008:53). Although a variety of solutions for weight control and maintenance have been availed through published texts and professional interventions, controlling this disease has proved to be extremely difficult (Aubertin-Leheudre *et al.*, 2008:53). One suggestion to resolve the epidemic may be to monitor patients/clients RMR while they attempt to make appropriate lifestyle changes (e.g., increasing PA (Hurley & Roth, 2000:249).

2.2.2 PREVALENCE OF OBESITY

The overall prevalence of overweight (BMI >25kg/m²) and obesity (BMI >30 kg/m²) is high in South Africa, with over 29% of men and 56% of women categorised as overweight or obese. These figures are higher than those detailed for other African countries, particularly in women, since nearly 30% of South African women aged between 30-59 years are obese (Goedecke *et al.*, 2005:95). The first South African Demographic and Health Survey (SADHS), undertaken in 1998 and published in 2002, included a sample of 13,089 South Africans aged 15-95 years old. In a sample of 7,726 South African women aged 15-95 years old, black women had the highest prevalence of overweight and obesity (58.5%), followed by women of mixed ancestry (52%), white women (49.2%) and then Indian women (48.9%) (Puoane *et al.*, 2002:1038). A different pattern was seen in men. In a sample of 5,401 South African men aged 15-95 years, the prevalence of overweight and obesity was highest in white men (54.5%), followed by Indian men (32.7%) and men of mixed ancestry (31%), with the lowest prevalence in African men (25%). Older men and those living in urban areas had significantly higher BMIs than younger men and men living in rural areas (Puoane *et al.*, 2002:1038).

A major public health concern is that obesity and overweight are not limited to the adult South African population but have also been well documented in adolescents and young people. For example, 10% of South African women surveyed in the SADHS, aged between

15-24 years, were already considered obese (Puoane *et al.*, 2002:1038). In addition, the Youth Risk Behaviour Survey (n=9 054), conducted in 2002, found that over 17% of adolescents were overweight, and 4.2% were obese (Reddy *et al.*, 2002). In a regional school-based health and fitness survey of nearly 5,000 children aged 12-18 years, it was estimated that the future prevalence of obesity in black girls at the age of 18 to be 37%, compared to 10% and 20% for white girls, and girls of mixed ancestry, respectively (Goedecke *et al.*, 2005:95). Overall, current South African research suggests a significant problem of over-nutrition in adults and young women, and that urban black women are at greatest risk.

In a study of 256 adolescents Monyeki *et al.* (2012:374) reported 17.3% obesity in girls and 8% obesity in boys. Additionally, Monyeki *et al.* (2012:374) reported a BMI of 21.4 kg/m² in girls and 19.7 kg/m² in boys. The THUSA BANA study on 10-15-year-old children from five different regions in the North-West province found the BMI and percentage body fat of black children (17.4 kg/m², 19.9%, respectively) and mixed origin (16.8 kg/m², 17.6%) to be lower than those of white (19.0 kg/m², 20.8%) and Indian children (17.5 kg/m², 20.2%) (Schutte *et al.*, 2003:97). Body fat was significantly higher in girls of all races (23%) than in boys (15.2%). Results from this study suggest that ethnicity and gender affect BMI and body fat percent in South African children. In contrast, Monyeki *et al.* (1999:287) found that the prevalence of obesity and overweight in rural children aged 3-10 years from Limpopo province was low (0-2.5% and 0-4.3% in boys and girls, respectively). Therefore, urbanisation appears to influence the prevalence of obesity in South African children.

Variations in TEE and physical activity level (PAL) are mainly a consequence of variations in moderate-intensity PA. This observation is important because, if generally applicable, it indicates that public health recommendations to increase light and moderate-intensity activity (rather than vigorous-intensity activity) should be made to prevent and treat obesity (Westerterp, 2001:539). In contrast, a topical meta-analysis (Erlichman *et al.*, 2002:273) suggested that more participation in intense PA might be necessary to alter TEE and energy balance significantly.

Plans to prevent and treat childhood obesity require a better understanding of the relationship between the pattern of PA and RMR (Montgomery *et al.*, 2004:591). The role of physical activity in the prevention and management of overweight and obesity is linked, in part, to the

impact of physical activity on EE, body composition, metabolism and substrate oxidation (Montgomery *et al.*, 2004:591). PA has the ability to be a powerful agent of change in the prevention and management of overweight and obesity (Goedecke *et al.*, 2005:95).

2.3 RESTING METABOLIC RATE

Resting metabolic rate is defined as the rate of fuel-energy consumption by a resting individual determined without the effects of meal consumption, physical activity, and physiological or mental stress. RMR accounts for about two-thirds of total energy consumption of normal sedentary individuals; therefore, it is the most important determinant of the daily food-energy requirement (Ainslee *et al.*, 2003:683). There is limited data in the South African context with regard to RMR in particular adolescents.

Total energy expenditure (TEE) consists of resting metabolic rate (RMR), dietary intake thermogenesis (DIT) and activity energy expenditure (AEE) (Katch *et al.*, 2011:238). RMR is the minimum energy requirement to sustain vital functions during absolute rest. RMR includes the energy expended in ventilation, blood circulation, intestinal contraction, and the activities of internal organs and maintenance of thermal equilibrium (Katch *et al.*, 2011:238). Another source has described RMR as the energy expended while an individual is resting quietly in a supine position (Institute of Medicine of the National Academics, 2005).

FFM is considered to be the best single predictor of RMR. FFM explains 70–85% of the variation in RMR (Buchholz *et al.*, 2001:641). A low RMR expressed in relation to FFM, is a risk factor for weight gain (Buchholz *et al.*, 2003:371). It is common practice to adjust RMR per unit FFM to compare individuals of different body size or to estimate RMR from body composition (Weinsier *et al.*, 1992:790). Standardisation of RMR by using an RMR-per-FFM ratio implies that FFM contributes to RMR consistently over the full range of FFM down to zero. However, in adolescents and adults the association does not regress through the zero intercept (Weinsier *et al.*, 1992: 790). Fukagawa *et al.* (1990:233) reported a lower average RMR in old men than in young men, even after adjusting for FFM, suggesting that aging is associated with a decline in the metabolic activity of FFM.

In recent years, a global epidemic of paediatric obesity has affected both children and adolescents. Reduced TEE and RMR, in addition to a decline in physical activity could be contributing factors (Reilly *et al.*, 2004:211). Physical inactivity (e.g. video gaming, watching television, lounging at home and other sedentary activities), accounts for about one-third of an adolescent's waking hours. Partaking in PA more regularly, could considerably boost the total daily energy expenditure (TDEE) and RMR of the adolescent population. Achieving this potential depends on the duration, intensity and type of PA performed (Katch *et al.*, 2011:242).

2.3.1 FACTORS AFFECTING RESTING METABOLIC RATE

RMR in adults is influenced by FFM and fat mass (FM), and is significantly higher in men than in women. Limited data exists, on the physiologic determinants of RMR in adolescents (Goran, 1994:362).

Several factors including thermic effect of food, anxiety, stimulants, diurnal variation, pharmaceuticals and elevated post exercise oxygen consumption can affect the measured metabolic rate (Reed & Hill, 1996:164). For this reason, standard conditions to measure RMR have been developed. RMR is measured while the subject at rest in a supine posture, at thermo-neutral temperatures, using indirect calorimetry to quantify O₂ consumption rates that are then converted to energy using the known or estimated RQ. Standard conditions for measuring RMR are described as an 8-12-hour fast coupled with a 12-hour abstinence from exercise (Haugen *et al.*, 2003:1141). The necessity of a 12-hour fast before RMR is measured is often a barrier to measuring RMR (Haugen *et al.*, 2003:1141).

The determinants of RMR in adults are well documented. Dietary composition, aerobic activity and resistance training have been reported to influence RMR (Gilliat-Wimberly *et al.*, 2001:1181). Birth weight was recently reported by Eriksson *et al.* (2002:72) to correlate inversely with EE. There is also a genetic component, but FFM remains the principal determinant of RMR across all age ranges. The organs (for example, brain, lungs, digestive tract, kidney and heart) contribute approximately 60% to the energy utilised by fat free tissue, and muscle is accountable for the remaining 40% (Illner *et al.*, 2000:308).

2.3.2 INFLUENCE OF BODY SIZE ON RESTING METABOLIC RATE

Body surface area provides a common denominator for expressing resting metabolism. A strong positive relationship between RMR and body weight exists among humans with widely ranging body sizes. The correlation coefficients are in the range of 0.85-0.98 (Stensel *et al.*, 2001:369).

RMR (expressed as $\text{kCal}\cdot\text{min}^{-1}$) is about 5-10% lower in females than with males of all ages. A female's larger percentage body fat and smaller muscle mass in relation to body size helps explain her lower metabolic rate per unit surface area. A person's RMR in $\text{kCal}\cdot\text{min}^{-1}$ can be estimated and converted to a total daily resting requirement with the value for RMR combined with the appropriate surface area value (Katch *et al.*, 2011:238).

Cross-sectional studies examining RMR in obese and non-obese children have yielded discrepant findings (Stensel *et al.*, 2001:369). Usually, RMR is found to be higher in obese than in non-obese children when absolute values (kJ/d) are compared (Maffeis *et al.*, 1995:15; Molnár & Schutz, 1997:376; Treuth *et al.*, 1998:440), but there are exceptions. After controlling for FFM, most studies reported that RMR did not differ significantly between obese and non-obese children (Maffeis *et al.*, 1995:15, Schutz *et al.*, 1999:857, Treuth *et al.*, 1998:440) although some studies still reported higher RMR values in the obese children (Bandini *et al.*, 1990:198, Molnár & Schutz, 1997: 376). The main finding of Stensel's (2001:369) study was that after FM and FFM were controlled for, RMR did not differ significantly between the obese and non-obese boys. This is consistent with previous results of cross-sectional studies which did not show a lower RMR in obese than in non-obese children (Maffeis *et al.*, 1995:15; Molnár & Schutz, 1997:376; Treuth *et al.*, 1998:440; Schutz *et al.*, 1999:857)

FM makes a small but important contribution to RMR (Tataranni & Ravussin, 1995:102). A large FM is expected to raise RMR. This is supported by the finding of Stensel's study (2001:369). Both FFM and FM predicted RMR when analysis of covariance was performed.

A study carried out on adults by Thielecke (1997: 310) showed that overweight men and women have higher RMR and higher total energy expenditure (TEE) compared to their lean

counterparts. The lower physical activity level (PAL) index of obese adults suggests a lower level of physical activity (Thielecke *et al.*, 1997:310).

Existing data is inconsistent with regard to why the ratio of RMR to metabolically active tissue mass (RMR/FFM ratio), is greater subjects with a small FFM than it is in subjects with a large FFM (Heymsfield *et al.*, 2002:132). A study by Heymsfield (2002) tested the hypothesis that a higher RMR/FFM ratio in subjects with a small body mass and FFM can be explained by a larger proportion of FFM (high metabolic rate tissues) compared with that seen in heavier subjects. An important observation, however, was that the ratio of RMR to body mass was not constant but decreased as body weight increased (Elia, 1992:19). Subjects with a small FFM have a greater RMR/FFM ratio than subjects with a large FFM, suggesting a body size difference in relative EE and requirements (Heymsfield *et al.*, 2002:132). In addition, Wang (2000:539), stated that a higher RMR/FFM ratio and thus a relatively higher metabolic rate in low-body-weight human subjects can be explained by a larger proportion of FFM as high-metabolic-rate tissues compared with heavy subjects with a greater FFM (Wang *et al.*, 2000:539).

The results of Heymsfield's (2002:132) study demonstrated the previously reported lowering of RMR relative to metabolically active tissue, as defined by FFM, in subjects with greater metabolically active tissue mass (Wang *et al.*, 2000:539). An immediate implication of Heymsfield's (2002:132) study is that RMR (adjusted for FFM) should be interpreted with caution. The observed pattern of changes suggests that the greater magnitude RMR/FFM ratio observed in low-body mass subjects can be attributed to the high proportion of FFM as residual mass and low proportion as fat-free adipose tissue, skeletal muscle, and bone (Heymsfield *et al.*, 2002:132).

2.3.3 RESTING METABOLIC RATE AND FAT FREE MASS

The relationship between RMR and metabolically active FFM is a cornerstone in the study of physiological aspects of body weight regulation and human energy requirements (Wang *et al.*, 2000: 539). All living organisms expend energy for the maintenance of cellular homeostasis. RMR measured at rest after an overnight fast, is usually the largest portion (60–70%) of total energy expenditure. Most investigators have reported that, for healthy adult humans, the

relationship between RMR and FFM is fit by a linear function: i.e. as one rises, so too does the other.

RMR is a basic biological parameter with implications for energy requirements, energy balance, and energy stores. Equations based on body weight (Hsu *et al.*, 2003:1506) have been superseded by models based on the energy requirements of two distinct body-composition compartments: FFM or FM, which have markedly different specific energy requirements. FM is the principal contributor to energy requirements while total body FFM is commonly used as a surrogate for metabolically active tissue.

Many authors focusing on RMR not only measure RMR, but also FFM, based on the idea that FFM is metabolically active (Hurley & Roth, 2000:249; Aubertin-Leheudre *et al.*, 2008:53; Javed *et al.*, 2010:907). Studies by Hurley & Roth (2000:249), Aubertin-Leheudre *et al.* (2008:53), show how FFM is correlated with RMR. These authors even suggest that FFM is the single most predictive component of RMR.

FM has a low rate of energy expenditure ($4.5 \text{ kcal} \cdot \text{kg}^{-1} \cdot \text{d}^{-1}$), and its mass varies more than all other major tissues in the body (Carrasco *et al.*, 2007:608). Compared with the RMR of skeletal muscle ($14.5 \text{ kcal} \cdot \text{kg}^{-1} \cdot \text{d}^{-1}$), the metabolic rate of the heart and kidneys is 33-fold higher ($440 \text{ kcal} \cdot \text{kg}^{-1} \cdot \text{d}^{-1}$), that of the brain is 18-fold higher ($240 \text{ kcal} \cdot \text{kg}^{-1} \cdot \text{d}^{-1}$), and that of the liver is 15-fold higher ($200 \text{ kcal} \cdot \text{kg}^{-1} \cdot \text{d}^{-1}$) (Elia, 1992:61). Collectively, the brain, liver, heart, and kidneys account for 60-75% of RMR in adults, whereas their combined weight is less than 6% of total body weight (Javed *et al.*, 2010: 907). Skeletal muscle comprises 40–50% of total body weight and accounts for only 20–30% of RMR (Gallagher *et al.*, 1998: 249).

The results of Javed's (2010:907) study highlight the important contribution that high metabolic rate organs (HMROs), such as the liver, kidneys, spleen, heart and brain, have on RMR and support the notion that although they constitute a minor portion of total FFM, much of the variation in RMR commonly thought to be attributable to sex, race, and even age can be explained by variation in the components of FFM, specifically these select HMROs (Javed *et al.*, 2010:907). RMR clearly depends on the amount of metabolizing tissue with independent effects of FFM and FM observed in many studies (Weinsier *et al.*, 1992:790).

2.3.4 RESTING METABOLIC RATE AND GENDER

RMR has been shown to be significantly higher in adult men than in women, by an average 209 kJ/d. This disparity is irrespective of differences in body composition and aerobic fitness (Kirkby *et al.*, 2004:430). A sex difference in RMR was also reported in pre-pubertal children (Goran *et al.*, 1994:362). However, inadequate sample sizes or inappropriate methodology often limit RMR studies in young children (Bitar *et al.*, 1995:308).

It is generally assumed that the relationship between EE and FM, which is not considered to contribute significantly to EE, reflects co-correlation of fat with lean body mass. In elderly individuals, the higher RMR reported among men is thought to be partially explained by higher levels of sympathetic nervous system activity (Poehlman *et al.*, 1997:23). In younger adults, it was suggested that the greater thermogenic effect of androgens compared with estrogens might also contribute to the sex difference (Kirkby *et al.*, 2004:240). Goran *et al.* (1995:308) investigated the determinants of RMR in pre-pubertal children aged between 4-7 years and likewise found an independent effect of sex on RMR. However, the RMR measurements in that study were not carried out in the fasting state and inevitably incorporated the unpredictable energy cost of meal-induced thermogenesis. A sex difference in RMR that was observed in Kirkby's (2004:240) study indicates that the obesity epidemic is known to affect girls more than boys (Kirkby *et al.*, 2004:240).

Griffith *et al.* (1990:76) compared the RMR of 25 children (15 boys and 10 girls) of obese and non-obese parents at ages 3-5 years and evaluated their BMIs 12 years later. In the boys, baseline metabolic rates were significantly associated with subsequent BMI, whereas in the girls, the differences were in the same direction, but did not reach significance levels. Pre-obese female children have a faster decline in RMR per kilogram of body weight and a subsequent increased rate of growth and development (Griffith *et al.*, 1990:76). Garn *et al.* (1996: 879) reported that this increased adiposity remains at least into the early 30s. Thus pre-pubertal differences in RMR may have a lasting impact on obesity through the influence of the timing of pubertal maturation.

2.3.5 RESTING METABOLIC RATE AND AGE

RMR is an important basic biological measure and is the focus of continuing clinical relevance. When interpreting RMR, the influence of sex, race, age, fat, and fat-free mass (FFM) is taken into consideration because these factors account for 50-70% of the variability in RMR (Gallagher *et al.*, 2006:1062). RMR per kilogram body mass or per kilogram FFM varies across the life span (Bosy-Westphal *et al.*, 2003:2356). Visser *et al.* (1995:772) suggests that RMR is likely to decrease with age.

There are milestones in which RMR is increased or decreased (for example, infancy, childhood, and adulthood, elderly). Compared with adults, children have a higher RMR per kilogram body weight or per kilogram FFM (Hsu *et al.*, 2003:1506) that declines steadily during the growth years. Whether this decline in RMR is due to changes in body composition or due to changes in the metabolic rate of individual organs and tissues remains unknown. Cross-sectional and intervention studies measuring currently active older individuals have been used to better understand why RMR may decrease as individuals age (Mospan, 2009:1).

Several researchers theorize that RMR decreases with age (Visser *et al.*, 1995:772; Rothenberg *et al.*, 2000:319). One theory suggests that energy expenditure is decreased with age due to a decline in physical activity (Sullo *et al.*, 2004:202). With a decreased energy expenditure (from lack of physical activity), RMR is also likely to decrease (Visser *et al.*, 1995:772). Another reason cited that RMR decrease with age is based on a decrease in metabolically active FFM, particularly muscle, due in part to a decrease in PA (Aubertin-Leheudre *et al.*, 2008:53; Sullo *et al.*, 2004:202; Gilliat-Wimberly *et al.*, 2001:1181). These authors have acknowledged that physical activity is a factor in RMR, but may not be the only one. Furthermore, Gilliat-Wimberly *et al.* (2001:1181) suggested that aging is associated with a 1-2% decrease in RMR per decade based on the loss of FFM and gain in FM.

Age has been suggested to have a direct effect on tissue RMR (Roberts & Dallal, 1998:975). This progressive decline in RMR is thought to be due to an age-related reduction in the mass of tissues that have a comparatively high metabolic rate: skeletal muscle mass and vital organs (Bosy-Westphal *et al.*, 2003:2356).

Gender is also a factor as women typically have lower FFM than men (Gilliat-Wimberly *et al.*, 2001:1181). The decrease in FFM may lead to a decrease in RMR. For example, Wilson

and Morley (2003:1728) suggest that a decrease in RMR of between 13-20% occurs between the ages of 30-80 years. Additionally, since FFM accounts for more than half of the variability in measuring RMR, the decrease in FFM may not only be attributed to decreased EE, but also to sarcopenia (decrease in muscle mass associated with aging) (Wilson & Morley, 2003:1728).

Gallagher, (1998:249) hypothesized that the decrease in RMR during growth and development is secondary to changes in body composition. In the first year of life, organs grow in proportion to body weight; thereafter, organ growth rates decelerate. By the age of five years, total brain volume has reached $\approx 95\%$ of adult size (Giedd *et al.*, 1999:4), and by the age of six, the heart's diameter is 80% of adult values (Hsu *et al.*, 2003:1506). Skeletal muscle mass increases at a faster rate than body weight after the first year of life. A reduction in organ growth coupled with an increase in skeletal muscle growth could account for a decrease in whole-body RMR adjusted for FFM. This has been the basis for the hypothesis that the decline in RMR during growth is a result of a decrease in the proportion of the more metabolically active FFM components (Hsu *et al.*, 2003:1506).

The results from Hsu's (2003:1506) study are consistent with the hypothesis that a decrease in the proportion of the more metabolically active organ mass may account for a decline in RMR per kilogram body weight or per kilogram FFM during growth, as suggested by Elia (1992:61), Weinsier (1992:790) & Bitar (2000:157). The implication, therefore, is that other age-related factors, possibly hormonal (Björntorp *et al.*, 1996:329), are additional significant determinants of RMR.

Additional theories on the decrease of RMR with aging include hormonal changes and a change in EE due to an altered mechanical efficiency or increased body weight (Visser *et al.*, 1995:772; Voorrips *et al.*, 1993:15). Voorrips *et al.* (1993:15) also explained that orthopaedic problems in the elderly may impair an individual which could decrease energy expended through physical activity and lead to further weight gain. Additionally, an increased body weight could decrease mobility, ultimately causing a decrease in PA. Mechanical efficiency issues may cause an individual to be limited in the type or amount of PA in which they can safely participate which could cause a decrease in RMR (Visser *et al.*, 1995:772; Voorrips *et al.*, 1993:15). Whether it is simply a lack of PA (decreased EE), or a lower level of PA

causing the loss of FFM and gain of FM, PA seems to play a major role in the maintenance of RMR.

Weight gain is a major concern when an individual has a RMR that is decreasing. Continuous weight gain, without intervention or lifestyle changes, will lead to overweight or obesity. Obesity is an emerging chronic disease affecting many South African's, and may be caused by low energy expenditure; especially low levels of physical activity and reduced RMR (Mamabolo, 2007:1047). It is important to determine whether a lack of physical activity is truly a main cause of RMR decreasing with age, or if other factors are also of concern in order to provide individuals with successful interventions (Mospan, 2009:1).

Visser *et al.* (1995:772) measured EE of different age groups to determine the differences between young (20-33 years old; men: 27 ± 2 years, women: 23 ± 2 years) and elderly (63-87 years old; men: 73 ± 6 years, women: 72 ± 5 years) subjects. The objective was to determine whether there was an age effect even with a regular PA routine. In the study, Visser (1995:772) found that overall RMR is lower in elderly subjects compared with young subjects regardless of activity level (Visser *et al.*, 1995:772).

Physical activity generally declines with age and consequently TEE and RMR will decrease (Visser *et al.*, 1995:772). Visser's (1995:772) study showed a relationship between age and RMR, independent of body composition, in men and women.

2.3.6 RESTING METABOLIC RATE AND ETHNICITY

Although obesity is a complex condition, its development almost always involves an imbalance of the energy equation (intake versus output) (Albu *et al.*, 1997:531). RMR is one component of energy output that has been widely studied. Cross-sectional studies have shown that RMR is determined principally by the amount of FFM (Albu *et al.*, 1997:531). Sex and age contribute to RMR primarily through their influences on the amount of FFM (Welle *et al.*, 1992:14).

The prevalence of obesity has increased in recent decades, and 22% of American children are overweight (Gidding *et al.*, 1995: 868). Racial differences are apparent in South African

trends, with the prevalence of obesity being greater in black adolescents than in white adolescents (Hoops, 2011:1). The National Household Food Consumption Survey reported that 17.1% of urban children in South Africa (1-9 yrs) were overweight or obese (Goedecke & Jennings, 2005:546). The Second South African National Youth Risk Behaviour Survey (2008) indicated that nationally, 19.7% of adolescents were overweight, with significantly more girls (27.8%) than boys (11.2%) being overweight (Reddy *et al.*, 2010:38). When ethnicity and gender were taken into account, significantly more black girls (28.9%) were overweight when compared to black boys (9.5%) (Reddy *et al.*, 2010:38). With regards to obesity, the national prevalence of obesity was 5.3%, with significantly more girls (7.2%) being classified more obese than boys (Reddy *et al.*, 2010:38).

RMR has been reported to be a familial trait. Children of obese mothers are more likely to become obese than children of non-obese mothers, and mothers of black children are significantly heavier than white mothers (Morrison *et al.*, 1996:637; McVeigh *et al.*, 2004:982). The underlying cause for the observed racial difference in obesity is not clear. The racial differences in RMR observed in Morrison's (1996:637) study are consistent with the local findings of Mamabolo *et al.* (2007:1047) and could contribute to observed racial differences in the onset of puberty and differences in obesity in black and white adolescents.

Data from the second National Health and Nutrition Examination Survey (NHANES II) indicate that in the United States, obesity is more prevalent in black women than in non-Hispanic white women (Burke *et al.*, 1992:1621). The percentage of black women classified as overweight is approximately twice that of white women (Welle *et al.*, 1992:14; Albu *et al.*, 1997:531). The RMR study in African-American children showed that the RMR in African children was 14% lower than in Caucasian children after adjusting for age, gender, body weight, FFM and FM (Kaplan *et al.*, 1996:643). On the other hand, a study of the RMR of Colombian children aged 2-16 years suggested that ethnicity was an insignificant contributor in determining resting energy expenditure (Spurr *et al.*, 1992:623). However, another study in ethnic differences showed that RMR in Beninese and Indonesian children is lower than in the United States and Europe (Torun *et al.*, 1996:37).

Morrison (1996:637) carried out a study on 47 black and 51 white children (6-16 years) to evaluate racial differences in their RMR. The results of his study revealed that there was no

significant difference in total RMR between the two study cohorts (1284 kcal/day [white girls] vs. 1207 kcal/day [black girls]), but black girls had significantly lower RMR per kilogram of body weight (40.3 kcal/day per kilogram [white girls] vs. 35.5 kcal/day per kilogram [black girls], $p = 0.001$). The results of Morrison (1996:637) showed that total RMR was highly, positively, and significantly correlated with age, height, weight, FFM, FM, percent body fat, bone density, and total bone mass. The analysis indicated that there is a significant difference in RMR between white and black girls (white girls higher than black girls) after accounting for the effects of lean body mass and pubertal maturation (Morrison *et al.*, 1996:637).

Pima Indians are an ethnic group which has been found to have an extreme incidence of obesity. Low RMR in Pimas has been proven to be a predisposing cause for potential weight gain (Albu *et al.*, 1997:531). (Albu *et al.*, 1997:531). Pima Indians have a greater prevalence of overweight and non-insulin-dependent diabetes mellitus than white Americans (Albu *et al.*, 1997:531). Comparisons of RMR and body composition in Pima Indians and white youths indicated that Pima Indians did not have a lower metabolic rate when RMR was adjusted for FFM (Albu *et al.*, 1997:531). This suggests that the increased body fat of the Pima Indian youths is related to either increased energy intake, decreased physical activity or both. Albu's (1997:531) study did not assess pubertal maturation.

Goran *et al.* (1994:362) compared RMR between white and Mohawk children ages 4 to 8 years and reported that there were no differences in RMR. DeLong *et al.* (1995:67) evaluated RMR and body composition in 46 fifth-graders, including black and white boys and girls. They found that RMR was similar in groups based on levels of fatness; however, the independent effects of sex, race, and pubertal maturation were not evaluated.

It is well documented that adult black women have a higher prevalence of obesity than white women (Morrison *et al.*, 1996:637). Results of Morrison's study indicate that there is a racial difference of RMR in girls and that this difference is most pronounced in the pre-pubertal stage. Racial differences in RMR observed could contribute to racial differences in adiposity observed in black and white women (Morrison *et al.*, 1996:637). Young black girls appear to have lower RMR, despite having higher FFM, indicating that lower RMR may result in faster accumulation of body mass and therefore earlier sexual maturation. The timing of maturation

may be an important factor in the ultimate development of obesity. Several researchers have shown that earlier-maturing girls are heavier, fatter, and have a higher BMI than late maturing girls (Wellens *et al.*, 1992:783, Griffith *et al.*, 1990:76). It has been shown that black girls have an earlier onset of puberty than white girls, and black women ultimately have a higher prevalence of obesity than white women (Morrison *et al.*, 1996: 637).

Possible explanations for racial differences in RMR include differences in body size and bone mass. Bone is metabolically a less active tissue than lean body mass. Black girls have been shown to have greater bone mass and hence lower lean body mass than white girls for any given level of fat-free mass. It appears as though the most important body composition factor for explaining the variance of RMR is FFM (Morrison *et al.*, 1996: 637).

2.4 PHYSICAL ACTIVITY IN ADOLESCENTS

Physical activity may be defined broadly as all bodily actions produced by the contraction of skeletal muscle that increase energy expenditure above basal level (Butte *et al.*, 2012:5). Literature describes physical activity (PA) as a comprehensive concept, including movement, fitness, exercise and training. PA includes a spontaneous component, such as fidgeting, sitting, standing and walking; an obligatory component, such as occupation, household and daily living activities; and a voluntary component, such as participation in sports (Levine *et al.*, 2000:1451).

There are four categories of physical activity (Bull *et al.*, 2004:730): i) work; ii) domestic; iii) transport; and iv) discretionary. The level of, physical activity in each category for any population is dependent on economic, technological, social, cultural and religious factors interacting at the individual, community and national level. For example, in a developed society where water and electricity are supplied to homes, the demands to be physically active in the domestic domain are reduced. Additionally, in a disadvantaged community with low car ownership, the demands to be physically active in the transport domain are likely to be high due to the need to walk or cycle to destinations. Within a developed economy setting, less PA is likely to be expended in the work category due to technological innovation, whereas, in a developing/disadvantaged economy setting, lots of PA may be dedicated to the work category due to labour in agricultural or heavy industry (Bull *et al.*, 2004:730).

An American expert panel recommends that adolescents participate in 60 minutes of moderate to vigorous physical activity (MVPA) daily; however, data suggest that few adolescents are meeting that benchmark (US Department of Health & Human Services 1996). In a recent study carried out by Troiano *et al.* (2008:112), only 8% of adolescents aged 12-15 years met the recommendation of 60 minutes or more of moderate-to-vigorous PA (MVPA) on five of seven days. In addition, a 2007 study performed by Mamabolo *et al.* (2007:1047) revealed that 8.6% of Potchefstroom adolescents are either overweight or obese.

As adolescents move into adulthood their PA levels continue to decline (Dowda *et al.*, 2003:15). This notion was supported by Nader (2008:295) who stated that PA levels suffer a marked decline during adolescence with the most dramatic decline occurring in early adolescence (Nader *et al.*, 2008:295). Low PA and high sedentary behaviour may have serious proximal and distal health and psychosocial implications for adolescents including elevated blood pressure, unhealthy blood lipid profiles and increased risk for obesity (Craig *et al.*, 1996:389). Adiposity, particularly central adiposity, obesity, and other biomarker changes are associated with an increase in cardiovascular disease risk factors tracking into adulthood (Rowlands *et al.*, 2000:479). Traditionally, these morbidities have been the specific burden of adulthood, but their diagnosis in the young is now increasing (Sinaiko *et al.*, 2002:509). Some have suggested that, as is true for adults, children are becoming less physically active (Reilly *et al.*, 2004:211), and that changes in lifestyle, including declining levels of PA, may help explain why childhood metabolic diseases are becoming more common. Thus, because PA appears to track from childhood through to adulthood (Tammelin *et al.*, 2003:22), and because genetic effects are potentially more discernible at a young age, comprehending the antecedents of physical inactivity in the young is important for the prevention of inactivity and related disease at all ages.

2.4.1 BENEFITS OF PHYSICAL ACTIVITY

Physical activity has important health benefits in youth. The biological effects found in relation to high physical activity levels in children are: lower blood pressure, more favourable serum lipid and lipoprotein levels, increased insulin sensitivity, and decreased adiposity (Dietz, 1998:518). There is convincing evidence of the effectiveness of regular physical

activity in the primary and secondary prevention of several chronic diseases (e.g. cardiovascular disease, diabetes, cancer, hypertension, obesity, depression and osteoporosis) and premature death (Warburton, 2006:801).

Physical fitness on the other hand, refers to a physiologic state of well-being that allows one to meet the demands of daily living or provides the basis for sport performance, or both. Health-related physical fitness involves the components of physical fitness related to health status, including cardiovascular fitness, musculoskeletal fitness, body composition and metabolism. In large epidemiologic investigations, PA and physical fitness are often used interchangeably, with fitness commonly being treated as a more accurate (albeit indirect) measure of physical activity than self-report (Williams, 2001:754). Physical fitness appears to be similar to PA in its relation to morbidity and mortality (Erikssen, 2001:571) but is more strongly predictive of health outcomes than physical activity (Williams, 2001:754).

PA increases energy spending, develops endurance, agility, flexibility, attenuates aggressiveness and may teach application of self-discipline, especially in collective games. If the physical activity is sufficiently invasive and takes a sufficient period of time then, it may lead to an increase in resting metabolism (Taliánová, 2009:21). Routine PA is also associated with improved psychological well-being (e.g. through reduced stress, anxiety and depression (Dietz, 1998:518). Psychological well-being is particularly important for the prevention and management of cardiovascular disease, but it also has important implications for the prevention and management of other chronic diseases such as diabetes, osteoporosis, hypertension, obesity, cancer and depression (Warburton, 2006:801).

Health and fitness benefits such as muscular strength, cardio-respiratory and muscular endurance, flexibility as well as reduced body fat, which contribute positively to general wellbeing and quality of life are obtained with regular participation in PA (Tudor-Locke *et al.*, 2004b:281). In light of these compelling benefits, it is surprising that 20-30% of South Africans in the Western Cape (Kruger *et al.*, 2005:491) and 25% of the American population do not engage in regular physical activity (Berlin *et al.*, 2006:1137).

PA in childhood and adolescence is also important to attain and maintain appropriate bone strength, and it contributes to normal skeletal development (Dietz, 1998:518). It is apparent that physical activity is essential in the prevention of chronic disease and premature death

(Lee & Skerrett, 2001:459). However, doubt remains over the optimal “volume” (frequency, duration and intensity of exercise) and the minimum volume for health benefits, in particular the effects of intensity (for example, moderate versus vigorous) on health status. Early work by Paffenbarger and associates (1986:605) revealed that regular physical activity (expending > 2000 kcal [8400 kJ] per week) was associated with an average increase in life expectancy of 1 to 2 years by the age of 80 and that the benefits were linear even at lower levels of energy expenditure. Subsequent studies have shown that an average energy expenditure of about 1000 kcal (4200 kJ) per week is associated with a 20-30% reduction in all-cause mortality (Williams, 2001:754; Erikssen, 2001:571; Lee & Skerrett, 2001:459). Recently, investigators have postulated that even lower levels of weekly energy expenditure may be associated with health benefits, particularly for people who are extremely out of condition or frail and elderly (Warburton, 2006:801).

2.4.2 OBJECTIVELY MEASURING PHYSICAL ACTIVITY

PA is one of the most important environmental moderators of metabolism, and habitual physical inactivity was early identified as a major cause of metabolic diseases such as Type II diabetes and heart disease (Sallis *et al.*, 1993:99). However, PA is inherently difficult to measure precisely, especially when people are undergoing everyday activities (Westerterp 2009:823; Butte *et al.*, 2012:5).

The ability to accurately track energy expenditure (EE) using objective methods is of increasing interest due to growing evidence that physical activity plays an important role in preventing and controlling many chronic diseases (Westerterp 2009:823). Most studies quantify physical activity through the use of questionnaires, and significant errors may occur due to difficulty in recalling light and moderate activities performed by participants, thus decreasing the accuracy of the estimate of physical activity (Westerterp 2009:823; Butte *et al.*, 2012:5). A consistent problem in epidemiologic and intervention studies of physical activity in children is the need for valid and reliable methods of measuring or recording children's

actual activity throughout the day. Methods used to assess PA in children include: use of heart rate monitors, use of motion sensors (Epstein *et al.*, 1996:1157), direct observation (Going *et al.*, 1999:788), doubly labelled water (DLW) and self-report through interviews, questionnaires, or diaries (Riddoch & Boreman, 1995:84). Various methodological difficulties have been reported with the use of each of these approaches.

2.4.2.1 Heart Rate Monitors and Accelerometers

To date, heart rate monitoring remains the most common single sensor physiologic monitor. Throughout the range of moderate through vigorous physical activity, heart rate increases linearly and proportionately with the intensity of movement and the volume of oxygen consumed by the contracting skeletal muscle, making it a sensitive indicator of activity intensity and useful in estimating physical activity energy expenditure. Additionally, heart rate is a well understood and defined phenomenon and there is greater agreement in standards for measuring, filtering, and storing heart rate data (Chen *et al.*, 2012). Riddoch and Boreman (1995:84) reviewed 13 studies that used heart rate to determine activity levels in children and concluded that heart rate monitoring can provide valid estimates of energy expenditure at higher exercise intensities, when heart rates tend to be high.

Objective monitors such as accelerometers and heart rate (HR) monitors are able to estimate the duration and intensity of physical activity performed throughout the day; however, accelerometers are generally worn on the hip which limits their ability to detect upper body movements. In addition, they are also unable to detect changes in grade during walking, or when an individual is carrying objects (Chen *et al.*, 2012; Butte *et al.*, 2012:5). HR has the advantage of being a physiological variable that is directly related to oxygen consumption, but errors in estimates of EE can occur during sedentary and light activities because HR can be elevated due to other factors such as stress, hydration, fear, excitement, emotional state and environmental factors (Pangrazi *et al.*, 1996:38; Butte *et al.*, 2012:5). Heart rate is also affected by training; children who are physically fit have lower resting heart rates and less of an exercise response than children who are less fit (Pangrazi *et al.*, 1996:38; Butte *et al.*, 2012:5).

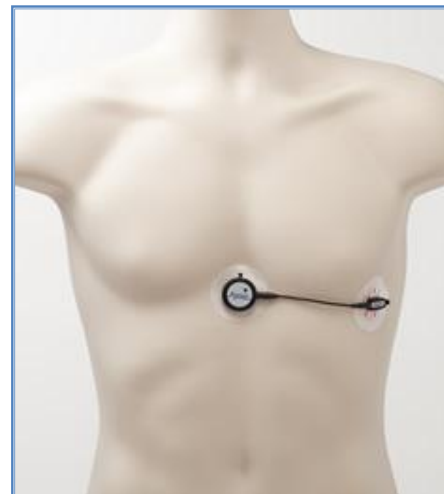
2.4.2.2 The Actiheart®

The simultaneous use of HR and motion sensors can provide accurate estimates of EE during free-living activities (Brage *et al.*, 2005:561; Butte *et al.*, 2012:5). The Actiheart® (Figure 2.1) is a compact, chest-worn monitoring device. It is the first commercially available device that combines a HR monitor and accelerometer into a single light-weight waterproof unit. The Actiheart® has two clips which attach directly to standard ECG electrodes. Usually one electrode is adhered at the fourth inter-costal space and the second electrode is placed approximately 10cm away on the left side at V4 or V5, although this placement can be adjusted to be comfortable for the subject (Figure 2.2). An internal accelerometer senses the frequency and intensity of the subject's torso movements (Crouter *et al.*, 2008:704).

Figure 2.1 The Actiheart®



Figure 2.2 Actiheart® Position



The Actiheart® has been shown to provide accurate estimates of low to moderate activities performed in a laboratory setting as well as treadmill walking and running in adults (Brage *et al.*, 2005:561) and children (Corder *et al.*, 2007:2180; de Bock *et al.*, 2010:2237). The validation of the Actiheart was performed against doubly labelled water (DLW) in adolescents (Campbell *et al.* 2012:589). Results showed a comparatively low level of concurrence between the Actiheart and DLW for measuring habitual physical activity energy expenditure in adolescents. However, results from Campbell's study should be interpreted with caution as the RMR values used to estimate physical activity energy expenditure from DLW derived TEE were computed from standardised equations and not direct measurement (Campbell, *et al.*, 2012:589). RMR prediction equations have previously been shown to under

estimate RMR by up to 3% (Slinde, *et al.*, 2003:1923). In another study carried out on a sample of 36 nine-year old children, Wilson *et al.* (2011:426) reported that the Actiheart® proved too fragile for children and difficult to mend in the field. The excessive sweating due to the tropical climate caused poor adherence of the electrode pads, requiring a pad change midway through and extra pads to be provided. However, according to Brage *et al.* (2005:561) the Actiheart® is a reliable and valid tool for the measurement of movement and HR during standardised technical conditions of rest, walking and running. As such, Actiheart® has the potential to more accurately assess physical activity energy expenditure than existing devices and thus may aid our understanding of the behavioural antecedents of metabolic dysfunction.

2.4.2.3 Motion Sensors

Researchers have tended to use motion sensors along with other methods to quantify physical activity in children, particularly when many children must be monitored (Going *et al.*, 1999:788; Chen *et al.*, 2012). The disadvantages of most accelerometers are a potential for tampering, especially when used with children, and an inability to record motion while the subject is seated (Janz, 1994:369; Chen *et al.*, 2012). In addition, they are not waterproof and therefore cannot be used to measure activities such as swimming.

2.4.3 PHYSICAL ACTIVITY, AGE, ETHNICITY AND GENDER

The methods used in various descriptive studies of PA in adolescents have been varied; therefore comparison of the estimates of absolute activity levels across these studies is difficult (Ainslie *et al.*, 2003:683). However, most of these studies have reported activity observations by age and gender categories. Therefore, it is possible to examine age and gender-related trends within and across the various studies (Sallis *et al.*, 1993:99). While there is a considerable level of inter-study variability, it has been consistently observed that males are more active than females and that activity levels tend to decline with increasing age during childhood and adolescence. Sallis' global conclusion was that males are about 15-25% more active than females and that, during the school-age years, activity levels decline at a rate of about 2.7% per year in males and 7.4% per year in females (Sallis *et al.*, 1993:99).

In the study carried out by Engelbrecht *et al.* (2004:42) in the North West Province, Indian girls (94.1%) were the most inactive group followed by those from mixed ancestry (87.5%), then Africans (73.0%) and Caucasians (61.0%). African girls were involved in moderate physical activity (23.2%) and Caucasian girls in high physical activity (16.6%). Caucasian girls participated mostly in organised school sport (athletics), while traditional games and house chores were the main source of activity among Africans. Walking slowly was an activity enjoyed by all racial groups (Engelbrecht *et al.*, 2004:42) (Table 2.1).

Table 2.1: Physical activity levels of each racial group and percentage of the girls from the different racial groups classified in each PA level (Engelbrecht *et al.*, 2004:45).

Race Groups	N	SD	PA Low %	PA Mod. %	PA High %
Black	215	0.53	73	23.2	3.7
Coloured	16	0.54	87.5	6.2	6.2
Indian	17	0.24	94.1	5.8	0.0
White	42	0.77	61.0	21.4	16.6

N=Number of participants. *SD*=Standard deviation; *PA*=Physical activity

On rural farms in the North West Province, physical activity was high among 9-16 year old children. The patterns were accounted for by walking, daily chores, tasks to be carried out on the farm, games played and few hours of watching television (TV) (Prinsloo & Pienaar, 2005:112). Furthermore, in the North West Province children's physical activity was higher on weekends than on weekdays, with boys being more active than girls. Both genders were least active on weekdays due to low involvement in school activities and sport and increased hours of watching TV (Kruger *et al.*, 2005:491). Another study on 951 high school learners in public schools showed that 32% of the participants did not meet the requirements of participating in physical activity for three-and-a-half-hours per week in order to be classified as active. The mean time of participants who participated in moderate and vigorous physical activity was 2.8 h/week and 4.16 h/week respectively (Franz, 2006:77).

Although AEE directly reflects the energy spent in activity, the energy cost of many activities is influenced by body weight (Schoeller *et al.*, 2002:97). Consequently, absolute AEE is not the most appropriate indicator of relative physical activity. Several different approaches have

been advocated to correct AEE for differences in body size and composition (Schoeller *et al.*, 2002:97). PAL, AEE per kg of FFM or per kg of body weight, and AEE adjusted for FFM or weight in statistical models have all been used. Westerterp (2001:539) showed that the fraction of the day spent in activities of moderate intensity significantly predicts PAL, whereas no relation was found between PAL and the time spent in high-intensity activity, presumably because of its relatively short duration. If this observation in adults is broadly applicable, then TEE and PAL are more likely influenced by the interaction between the relative proportions of time spent in low to moderate intensity activity than by the time spent in vigorous activity (Westerterp, 2001:539). Previous findings of a positive influence of body weight on the MET values of walking (Spadano *et al.*, 2005:1102) indirectly support the notion that body weight influences PAL, because both PAL and MET share the assumption that dividing EE by RMR removes the influence of weight. In addition, in separate models estimated in the current study, both weight and FFM were significantly related to the changes in PAL with age (Spadano *et al.*, 2005:1102).

2.4.4 PHYSICAL ACTIVITY PATTERNS IN ADOLESCENTS

It is commonly assumed that children today are less active than their predecessors because of increased time spent in sedentary activities (Going *et al.*, 1999:788; Westerterp, 2009:823) and that this inactivity has contributed to the rise in childhood obesity. Although these assumptions are plausible, there is conflicting information on children's levels of activity (Pangrazi *et al.*, 1996:38), most likely because of the difficulties associated with assessing physical activity levels in children (Going *et al.*, 1999:788).

According to a pioneer study conducted by Ross & Gilbert (1985:45), it was reported that the actual types of physical activities in which adolescents participate generally include bicycling, swimming, and ball sports; all of which appear to be the predominant physical activities. The types of physical activity and level of intensity do show some variability across age, gender, and setting (in or out of school) (Ross & Gilbert, 1985: 45). Ross & Gilbert's study demonstrated that the majority of physical activity in the adolescent population occurs outside of school. Although there is a downward trend across adolescence, the majority spend more than three hours a week in leisure time activities outside school (Ross & Gilbert, 1985:45).

In a more recent study by Cheschini *et al.* (2009:301) the authors classified more than 60% of the adolescents as physically inactive according to the international recommendation of at least one hour of moderate or vigorous physical activity each day; this is confirmed by the review of Strong *et al.* (2005:732). The 1997 Health Survey for England reported that 78% of boys and 70% of girls participate in at least 60 minutes of moderate activity on at least five days of the week. The National Diet and Nutrition survey reported that 44% of the boys and 31% of the girls aged 15-18 years achieved 60 minutes of moderate activity per day. It can be clearly seen that these figures are much lower than the objectively measured estimates observed in the European Youth Heart Study (Riddoch *et al.*, 2004:86), but comparable to the study of Cheschini *et al.* (2009:301). The likely explanation for this discrepancy is that moderate to vigorous activity tends to be more sporadic, not planned, and therefore less memorable and quantifiable, especially in children. It is likely that children may engage in considerably more moderate-intensity physical activity than previously thought. The increasing prevalence of overweight and obesity in children suggests that physical activity levels have decreased over time, and that a substantial number of children are insufficiently active (Andersen, 2009:28).

Longitudinal and cross-sectional questionnaire data have shown a decline in leisure time and vigorous physical activity, respectively, during adolescence in females (Kimm *et al.*, 2002:709). Cross-sectional accelerometry data from children in Grades 1–12 showed an inverse relation between school grade and the number of minutes per day of moderate to vigorous physical activity (Spadano *et al.*, 2005:1102).

As pointed out by McKune (2006:13), physical activity is a modifiable risk factor for obesity and other chronic diseases, therefore, with the increasing prevalence of obesity and other chronic diseases of lifestyle in South Africa, it is expected that South Africans are not physically active enough to meet the minimum requirements to achieve health benefits. At least 60% of the global population fails to achieve the minimum recommendation of 30 minutes of moderate intensity physical activity daily (Reddy, 2005:176).

2.5 LINK BETWEEN RESTING METABOLIC RATE AND PHYSICAL ACTIVITY

PA is the largest contributor to RMR. The majority of studies that focus on the relationship of physical activity to RMR have reported a positive correlation between these variables (Gilliat-Wimberly *et al.*, 2001:1181; Byrne & Wilmore, 2001:15; Hunter *et al.*, 2006:2018). In a population where physical activity typically decreases sharply, it is necessary to determine if this is consistent for all individuals.

PA by definition results in an increase in EE due to the cost of the activity itself and is also hypothesized to increase RMR (Miller *et al.*, 2005). These increases in EE are likely to decrease the likelihood of positive energy balance. PA affects EE in two ways. First, regular physical activity increases the amount of TEE. Secondly, exercise helps maintain FFM, which in turn helps to maintain a higher RMR (Gilliant-Wimberly *et al.*, 2001:1181). RMR represents 60-75% of TEE therefore playing a substantial role in maintaining a healthy body weight. Because FFM is a primary determinant of RMR, factors that influence RMR often do so through their effect on FFM (Gilliant-Wimberly *et al.*, 2001:1181).

The effects of PA on RMR have been extensively studied (Miller *et al.*, 2005:215; Speakman & Selman 2003:621; Pannemans & Westerterp 1995:571). The scientific literature is not completely conclusive in this area, but it appears that PA may positively affect RMR in a variety of ways. A cross-sectional longitudinal study found that persons who increase their physical activity also increase their RMR (Pannemans & Westerterp 1995:571). The results of Pannemans (1995:571) pioneer study reflect the well-established fact that RMR remains somewhat elevated for several hours after an exercise session. Supporting this theory is another study which showed that increased RMR in physically active individuals declined after three days of detraining (Tremblay, *et al.*, 1998:511). Low RMR has been shown to be a predictor of obesity. In addition, reduction in RMR (presumably caused by loss of lean muscle tissue) further compounds the decrease in RMR induced by energy restriction (Gilliant-Wimberly *et al.*, 2001:1181).

The use of interventions when measuring RMR is important because researchers are able to determine whether RMR increases when physical activity is increased in individuals who are either sedentary or participate in low levels or amounts of physical activity. Resistance

training and aerobic training have both been studied with the aging population to determine whether one type of exercise is more important or has more impact in maintaining RMR. Both have been shown to be successful by improving many variables related to RMR (for example, weight loss, fat loss, or maintenance, or increase in FFM) (Mospan, 2009:1).

2.6 SUMMARY

Total energy expenditure (TEE) consists of resting metabolic rate (RMR), the dietary intake thermogenesis (DIT) and activity energy expenditure (AEE). RMR is the minimum energy requirement to sustain vital functions during absolute rest (Katch *et al.*, 2011:238). RMR in able-bodied individuals accounts for about 60-70% of TEE and is largely determined by body size and FFM (Buchholz *et al.*, 2003:371). FFM is considered to be the best single predictor of RMR and explains 70–85% of the variation in RMR (Buchholz *et al.*, 2001:641). In addition, aerobic activity, resistance training and dietary composition are reported to influence RMR (Gilliat-Wimberly *et al.*, 2001:1181). The organs (e.g., digestive tract, kidney, lungs, heart and brain) together contribute around 60% to the energy expended by fat-free tissue, and muscle is responsible for the remaining 40% (Javed *et al.*, 2010:907).

There is a strong, positive relationship between RMR and body weight among people with widely ranging body sizes (Stensel *et al.*, 2001:369). RMR averages 5-10% lower in females compared with males at all ages (Katch *et al.*, 2011:238). Wang *et al.* (2000:539) reported that, for healthy adult humans, the relationship between RMR and FFM is a linear one. Studies by Hurley & Roth (2000:249), Aubertin-Leheudre *et al.* (2008:53), show how FFM is correlated with RMR. These authors even suggest that FFM is the single most predictive component of RMR. RMR per kg body mass or per kilogram FFM varies across the life span (Bosy-Westphal *et al.*, 2003:2356). Visser *et al.* (1995:772) suggests that RMR is likely to decrease with age. Whether this decline in RMR is due to changes in body composition, or to changes in the metabolic rate of individual organs and tissues remains unknown (Mospan, 2009:1). Literature findings suggest that black girls have a significantly lower RMR per kilogram of body weight than white girls after accounting for the effects of lean body mass and pubertal maturation (Morrison *et al.*, 1996:637; Kaplan *et al.*, 1996:643; Albu *et al.*, 1997:531).

The high occurrence of overweight and obesity amongst adolescents is a disturbing health problem worldwide (Kemp & Pienaar, 2011:1). The occurrence of overweight and obesity in South African children at present has been said to be on par with that of many industrialised nations and among the highest in Africa (Truter *et al.*, 2010:227). Physical activity may be defined broadly as all bodily actions produced by the contraction of skeletal muscle that increase energy expenditure above basal level (Butte *et al.*, 2012:5). Recent studies in South Africans have shown unsatisfactory levels of physical activity, overweight and obesity among children and adolescents (McVeigh *et al.*, 2004:982; Kruger, *et al.*, 2012:491). Only 42% of young South Africans participate in sufficient MVPA (McVeigh *et al.*, 2004:982).

PA is difficult to measure precisely, especially objectively, during everyday activities (Westerterp 2009:823; Butte *et al.*, 2012:5). Methods used to assess PA in adolescents include heart rate monitors, motion sensors (Epstein *et al.*, 1996:1157; Chen *et al.*, 2012:13), doubly labelled water (DLW), and self-report through interviews, questionnaires, or diaries (Riddoch & Boreman, 1995:84). Literature suggests that PA decreases with age and that boys are generally more physically active than girls (Sallis *et al.*, 1993:99; Engelbrecht *et al.*, 2004:42). Literature is controversial regarding PA and ethnicity where some researchers report high levels of PA among black people (Walker *et al.*, 2001:370) while others report high levels among white people (McVeigh *et al.*, 2004:985). Further research should be conducted to address this discrepancy.

Literature suggests that PA has two distinct effects on RMR. Firstly, PA results in the growth of lean tissue; secondly, the increase in lean tissue/FFM resulting from PA may result in the increase of RMR (Albu *et al.*, 1997:531). If a meaningful relationship exists, physical activity and RMR could be variables that professionals (physicians, exercise physiologists, etc.) observe in adolescent populations to guard against the development of hypokinetic diseases such as hypertension, obesity and Type II diabetes (Williams; 2001:754).

In conclusion, the lack of knowledge on RMR and PA in adolescents may be complemented by further investigations in specific ethnic populations. Furthermore, in South Africa further research should be carried out to objectively determine the habitual physical activity of adolescents.

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Chapter 2

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OBJECTIVELY DETERMINED HABITUAL PHYSICAL ACTIVITY IN AFRICAN ADOLESCENTS: THE PAHL STUDY

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ABSTRACT

Background: Limited data on objectively determined habitual physical activity in African adolescents is evident. Therefore, we determine habitual physical activity (PA) objectively in adolescents from the North West Province of South Africa. **Methods:** Adolescents (137 girls, 89 boys) from the on-going Physical Activity and Health Longitudinal Study (PAHLS) at age 16 years were included in the study. Body composition was measured by means of skinfolds and habitual PA was objectively recorded with heart rate and accelerometer data combined (Actiheart®) over a period of seven consecutive days. Activity energy expenditure (AEE), physical activity level (PAL), activity counts per minute (CPM) and time spent in sedentary, light-intensity and moderate-vigorous-intensity physical activity (MVPA) according to gender and race was assessed with descriptive analyses. **Results:** Significantly higher PAL (1.57 ± 0.15) were determined in girls compared to boys (PAL = 1.41 ± 0.10). Black adolescents indicated significant higher PAL (1.53 ± 0.14) compared to white adolescents (1.45 ± 0.16). **Conclusion:** Objectively determined PA of adolescents in South Africa indicates that only one third of adolescents are meeting the recommended 60 minutes of daily MVPA. Gender and race specific interventions are needed to increase habitual physical activity levels in adolescents.

Keywords: Physical activity, active energy expenditure, obesity, African adolescents

INTRODUCTION

Adolescence is a period characterised by rapid physical growth as well as changes in physiological and behavioural patterns.^{1,2} Recent studies in South Africa have shown unsatisfactory levels of physical activity (PA), overweight and obesity among children and adolescents.^{2,3,4} Only 42% of young South Africans participate in sufficient moderate-to-vigorous physical activity (MVPA).^{3,5} There is increasing evidence that PA during childhood and adolescence has an important impact on long-term health and behaviour outcomes.⁶

The PA guidelines for adolescents from various organisations vary in intensity, duration and frequency. The most recent PA recommendation for American children aged 6-18 years is 60 minutes or more per day of MVPA.⁶ Other recommendations call for 30 – 60 min of daily MVPA.^{7,8} The accurate measurement of PA in epidemiological studies still poses a major challenge in terms of feasibility and validity of the methods proposed.⁹ When assessed by accelerometry, PA has also been shown to decrease with age whereas activity energy expenditure (AEE) and physical activity levels (PAL) increase with age during childhood and adolescence.¹⁰ Very limited PA data exists for representative samples of children and adolescents with even fewer objectively collected data¹¹, especially in Africa.

In South Africa, there are currently very few studies which objectively quantify PA in adolescents. Cook (2012) reported on the use of pedometers to objectively measure PA in developing African countries.¹² Most studies that contain important information about the PA of South African adolescents have used self-report methods to assess PA.^{3,12,13} The use of objective instrumentation to determine PA characteristics objectively, would give a clearer understanding of the habitual physical activity patterns of South African adolescents.

In recent years, the measurement of PA with accelerometers has become more widely used. These instruments quantify body movement at 60-second intervals over periods up to 21 days, thereby enabling patterns of movement or inactivity to be measured. The Actiheart® has been validated against the doubly labelled water method; and it emerged a reliable tool for PA assessment.¹⁴

Globally, it has been constantly observed that males are more active than females and that PA tends to decline with increasing age during childhood and adolescence.¹⁵ Sallis' (1993) global conclusion was that males are approximately 15-25% more active than females and that, during adolescence, PA levels decline at a rate of 2.7% per annum in males and 7.4% per annum in females.¹⁵

Studies reporting PA levels of different racial groups indicate inconsistent results.^{13,16} McVeigh et al.³ found significant differences in patterns of PA in South African school children of different races.³ White adolescents were found to be physically more active, more likely to participate in physical education classes at school and watched less television than black adolescents.^{3,4,17} However, Dunn and Wang¹⁸ found no significant racial differences in total PA among college students.

A need exists for a more precise knowledge of the pattern and amount of PA in adolescents determined by objective means.¹⁹ Baseline data from the Physical Activity and Health Longitudinal Study (PAHLS) may provide valuable information on objective physical activity patterns in adolescents for future studies on intervention strategies. Therefore, the purpose of the study was to objectively determine habitual PA of adolescents in the North West Province of South Africa by race and gender.

METHODS

Study Design and Subjects

This is an observational cohort study following a cross-sectional research design. The PAHL study is an observational multi-disciplinary longitudinal study that was started in 2010. The aim of the PAHL-study is to describe the development of PA and determinants of health risk factors in 14 to 18 year old adolescents. More details about the study is published elsewhere.² Male and female adolescents aged 16 years in the 2012 calendar year and of sound mental and physical health were included in this part of the study.

Demographic Characteristics

A sample of 226 adolescents (137 girls and 89 boys) aged 16 years, participated in the study. One hundred and sixty eight (168) of the participants were black and fifty eight (58) were white. The participants were from six schools of which two were from a high socio-economic area and four from the township, a low socio-economic area within the Tlokwe Local Municipality of the North West Province of South Africa.

Anthropometric Measurements

Weight, height and skinfolds were determined as described by the International Society for the advancement of Kinanthropometry.²⁰ Weight was measured to the nearest 0.1 kilograms (kg) on a calibrated scale (Seca, Germany) with the subject standing barefoot. Triceps and subscapular skinfolds were measured to the nearest 0.1 mm with a skinfold calliper (Harpenden, UK) and the average of two measurements was used. Height was measured by means of a stadiometer with participants standing bare foot with their head aligned in a Frankfurt plane.²⁰ Variability was reduced by having all measurements taken by Level 2 ISAK anthropometrists. The internationally accepted Slaughter (1988) equation, approved for use in adolescents of different ethnicities was used to compute percentage body fat (%BF).²¹

Objectively Measured Physical Activity-Actiheart®

Time spent in different intensities of PA and sedentary behaviour was measured with the Actiheart® (Cambridge Neurotechnology Ltd, Cambridge, UK). The particulars of the Actiheart® are described in detail elsewhere.¹⁴ PA was measured in 60-second epochs over seven consecutive days. Measurements were obtained for total energy expenditure (TEE), activity energy expenditure (AEE) in kCal/day, PAL/day as well as METs in minutes/day. Specific MET cut-off points describe the intensity level of PA: Sedentary (<1.5METs); Light (1.5 METs-3.0METs); Moderate (3.0-6.0 METs) and Vigorous (>6.0METs). Recorded MET minutes/day of MVPA were weighed up against the current PA recommendations for children.

PROCEDURES

Prior to the study permission to conduct the measurements was granted by the District Manager of the Department of Basic Education in Potchefstroom as well as the Ethics Committee of the Potchefstroom Campus of the North West University (Ethics number: NWU-0058-01-A1). The participating schools were briefed about the purpose of the study and informed consent was given by school authorities, parents and pupils of participating schools. All measurements were performed in one day with the anthropometric and body composition measurements taken first. The Actiheart® device was placed on the chest of the participants.¹⁴ After seven days the device was removed and the data downloaded to a database using the accompanying commercial software (Version 2. 132, Cambridge Neurotechnology Ltd. Cambridge, UK).

STATISTICAL ANALYSIS

Data analysis was performed using SPSS Version 20 software (IBM SPSS, II). The descriptive statistics (mean and standard deviations) were performed to determine the characteristics of the participants. Independent t-tests and Mann-Whitney U test were performed to determine differences between ethnicity and genders and calculate practical significance. A Type I error rate of $P \leq 0.05$ was used for statistical significance.

RESULTS

The characteristics of the study sample are presented in Table 3.1. Body mass, stature and BMI differed significantly ($p < 0.05$) by race. White adolescents were significantly heavier and taller than black adolescents. 16.4% of the study sample were underweight, while 19.4% were either overweight or obese irrespective of race and gender. The data indicates that girls recorded a significantly higher %BF (15.5 ± 5.0 %) than boys (9.3 ± 3.7 %; ($p = 0.001$)). Significant differences in fat mass (FM) and fat free mass (FFM) were observed between the different ethnicities and genders, with black adolescents recording a lower FM (7.6 ± 5.0 kg) than white adolescents (9.4 ± 5.9 kg; $p = 0.24$) and boys recording a higher FFM (54.9 ± 11.6 kg) than the girls (48.2 ± 8.9 kg; $p = 0.0001$).

Table 3.1: Characteristics (means and SD) for all subjects and stratified by gender

Variable	All (n=226) Mean ±SD	p-value (race)	d-value Effect size (Ethnic)	Boys (n=89) Mean ±SD	Girls (n=137) Mean ±SD	p-value (gender)	d-value Effect size (gender)
Age	15.7 ± 0.8	0.200	-0.08	15.8 ± 0.7	15.7 ± 0.9	0.613	-0.01
Black (n = 168)	15.8 ± 0.9			15.84 ± 0.8	15.7 ± 0.5		
White (n = 58)	15.7 ± 0.5			15.65 ± 0.1	15.7 ± 0.5		
Stature (cm)	163 ± 0.1**	0.0001	-0.49	169 ± 0.1	158 ± 0.1*	0.0001	-0.59
Black (n = 168)	160.1 ± 0.1			166.1 ± 0.1	157.2 ± 0.1		
White (n = 58)	171.2 ± 0.1			177.2 ± 0.1	165.1 ± 0.1		
Body Mass (kg)	59.1 ± 4.1**	0.0001	-0.46	61.4 ± 15.1	57.6 ± 13.2*	0.047	-0.13
Black (n = 168)	55.3 ± 11.0			54.5 ± 8.7	55.8 ± 12.1		
White (n = 58)	69.9 ± 16.3			74.2 ± 16.2	64.9 ± 15.2		
%Body Fat	13.1 ± 5.5	0.870	-0.01	9.3 ± 3.7	15.5 ± 5.04*	0.0001	-0.66
Black	13.1 ± 5.6			8.5 ± 2.3	15.5 ± 5.4		
White	12.9 ± 5.0			10.8 ± 5.1	15.5 ± 3.5		
Fat Mass (kg)	8.1 ± 5.3**	0.024	-0.19	6.1 ± 4.6	9.4 ± 5.4*	0.0001	-0.48
Black	7.6 ± 5.0			4.7 ± 1.9	9.1 ± 5.4		
White	9.4 ± 5.9			8.7 ± 6.6	10.4 ± 4.9		
Fat Free Mass (kg)	50.9 ± 10.6**	0.0001	-0.49	54.9 ± 11.6	48.2 ± 8.9*	0.0001	-0.32
Black	47.6 ± 7.8			49.4 ± 7.5	46.7 ± 7.8		
White	60.3 ± 11.9			65.5 ± 10.6	54.5 ± 10.6		
BMI (kg/m²)	22.3 ± 4.7**	0.004	-0.21	21.1 ± 4.2	22.9 ± 4.9*	0.004	-0.22
Black (n = 168)	21.7 ± 4.5			19.8 ± 0.8	22.7 ± 4.8		
White (n = 58)	23.8 ± 5.2			23.7 ± 5.0	24.0 ± 5.6		
BMI Categories	All			Boys	Girls	Black	White
Underweight	37 (16.4%)			25.8%	10.2%	21.4%	1.7%
Normal	145 (64.2%)			62.9%	65.0%	61.9%	70.7%
Overweight	27 (11.9%)			6.7%	15.3%	10.1%	17.2%
Obese	17 (7.5%)			4.5%	9.5%	6.5%	10.3%

RMR = resting metabolic rate; n = number; %BF = percentage body fat; ± = standard deviation; Values represented as; mean ± SD (standard deviation)

* Significant difference (between girls and boys), P <0.05;

** Significant difference (between black and white), P <0.05

Means and standard deviations of the participants' average daily energy expenditure and PAL are shown in Table 3.2. There are marked differences between ethnicities and genders in all aspects of energy expenditure and PA. Boys (2459 ± 289 kCal/day) showed a significantly ($p=0.0001$) higher TEE than girls (2229 ± 316 kCal). The same trend was observed for average weekday and average weekend TEE with girls recording a significantly lower average weekday ($p=0.0001$) and weekend TEE ($p=0.0001$) than boys. The girls AEE (589.7 ± 225 kCal/day) was significantly ($p=0.0001$) higher than that of the boys (477.1 ± 160 kCal/day). PAL is calculated by dividing TEE by the resting metabolic rate (RMR). Girls profiled a significantly ($p=0.0001$) higher average PAL value (1.57 ± 0.15) than boys (1.41 ± 0.10). PAL index categories show that only 29.2% of the study sample were moderately active or above irrespective of race or gender. The average activity in counts per minute (cpm) of the study sample was 51.7 ± 26.2 cpm. Boys averaged a significantly ($p=0.0001$) higher 64.2 ± 31.0 cpm than girls (43.6 ± 18.6 cpm).

Figure 3.1 shows the results of the time spent (minutes/day) by the participants at the different levels of intensity ranging from less than 1.5 METs (sleep/sedentary); 1.5 – 3.0 METs (Low); 3.0 – 6.0 METs (Moderate) and above 6.0 METs (Vigorous). Results show that girls spent a significantly (61.1 minutes/day; $p=0.0001$) higher amount of time per day in MVPA than boys (35.0 minutes/day). Black adolescents (47.87 min/day) spent less time per day in MVPA than white adolescents (59.50 minutes/day).

Table 3.3 shows the correlations that exist between activity counts per minute (CPM) and body composition variables. Results show that significant ($p=0.001$) negative correlation exists between activity CPM and BMI, weight, %BF and FM irrespective of race and gender.

The compliance of the adolescents in this study to the recommendation of 60min/day of MVPA (Figure 3.2) indicates that only 36% of the study sample participates in 60min/day of MVPA.

Table 3.2: Average daily energy expenditure by gender and ethnicity.

Variable	All (n=226) Mean±SD	p-value	d-value Effect size	Black Mean±SD	White Mean±SD	p-value	d-value Effect size
TEE(kCal/day)	2320.0 ± 379.8			2247.0± 310.3	2534 ± 474.2**	0.0001	-0.27
Boys (n=89)	2459.0 ± 380.6*	0.0001	-0.33	2317.0± 288.7	2725.0 ± 392.9		
Girls (n=137)	2229.0 ± 352.1			2209.0 ± 316.0	2314.0 ± 469.8		
AEE (kCal/day)	545.4 ± 209.1			550 .1± 194.2	530.7 ± 248.9**	0.0001	-0.09
Boys (n=89)	477.1 ± 160.1*	0.0001	-0.26	469.8 ± 152.0	491.0 ± 177.8		
Girls (n=137)	589.7 ± 225.0			593.1 ± 201.3	577.1 ± 308.6		
Average Weekday TEE (kCal/day)	2344.0 ± 405.9			2270.0 ± 339.9	2559.0 ± 498.9**	0.0001	-0.27
Boys (n=89)	2482.0 ± 400.4*	0.0001	-0.30	2323.0 ± 291.9	2779.0 ± 409.0		
Girls (n=137)	2255.0 ± 385.5			2243.0 ± 360.9	2306.1 ± 477.3		
Average Weekend TEE (kCal/day)	2248.0 ± 388.9			2188.1 ± 349.3	2424.1 ± 444.7**	0.0001	-0.23
Boys (n=89)	2383.1 ± 400.9*	0.0001	-0.33	2256.0 ± 347.6	2620.1 ± 390.8		
Girls (n=137)	2161.0 ± 356.2			2152.1 ± 346.5	2199.0 ± 398.3		
Activity (Counts/minute)	51.7 ± 26.2			56.6 ± 26.7	37.3 ± 18.3**	0.0001	
Boys (n = 89)	64.2 ± 31.0*	0.0001		75.4 ± 29.6	43.2 ± 21.4		
Girls (n = 137)	43.6 ± 18.6			46.8 ± 18.7	30.6 ± 11.0		
PAL	1.51 ± 0.15			1.53 ± 0.14	1.45 ± 0.16**	0.001	-0.26
Boys (n=89)	1.41 ± 0.09*	0.0001	-0.52	1.73 ± 0.09	1.39 ± 0.09		
Girls (n=137)	1.57 ± 0.15			1.58 ± 0.14	1.53 ± 0.18		
PAL Index Categories	All	Boys	Girls	Black	White		
Sedentary	1.3%	0.0%	2.2%	1.8%	0.0%		
Low	69.5%	88.8%	56.9%	64.3%	84.5%		
Moderate	25.2%	11.2%	34.3%	29.2%	13.8%		
Active	1.8%	0.0%	2.9%	2.4%	0.0%		
High	2.2%	0.0%	3.6%	2.4%	1.7%		

n= number; TEE = total energy expenditure; AEE = active energy expenditure; PA = physical activity; DIT = dietary intake thermogenesis.

Values represented as; mean ± SD (standard deviation)

* Significant difference (between girls and boys), $P \leq 0.05$;

** Significant difference (between black and white), $P \leq 0.05$

Figure 3.1: Daily physical activity (METmin/day) at different intensity levels.

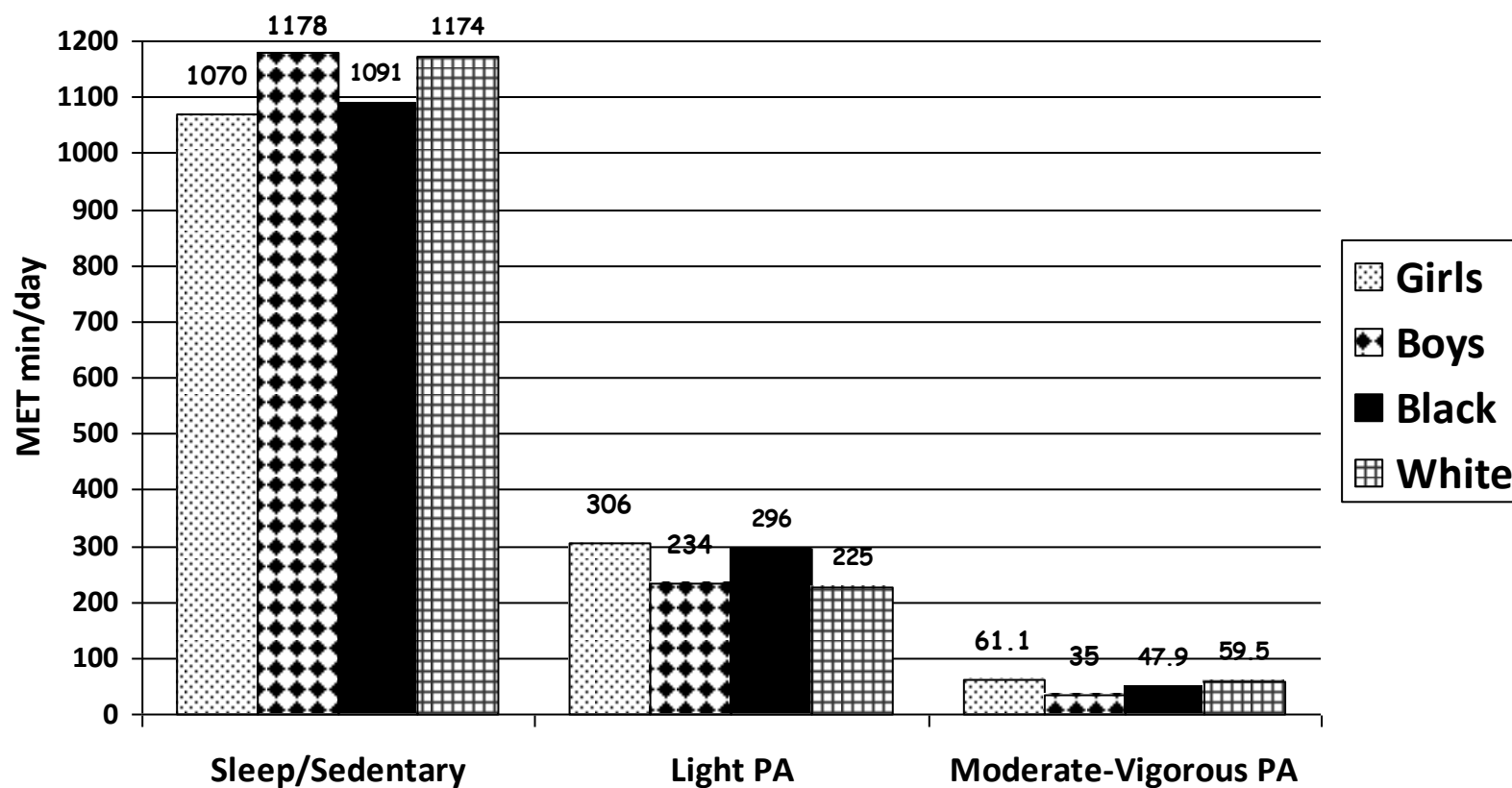


Table 3.3: Correlation between activity counts per minute and body composition

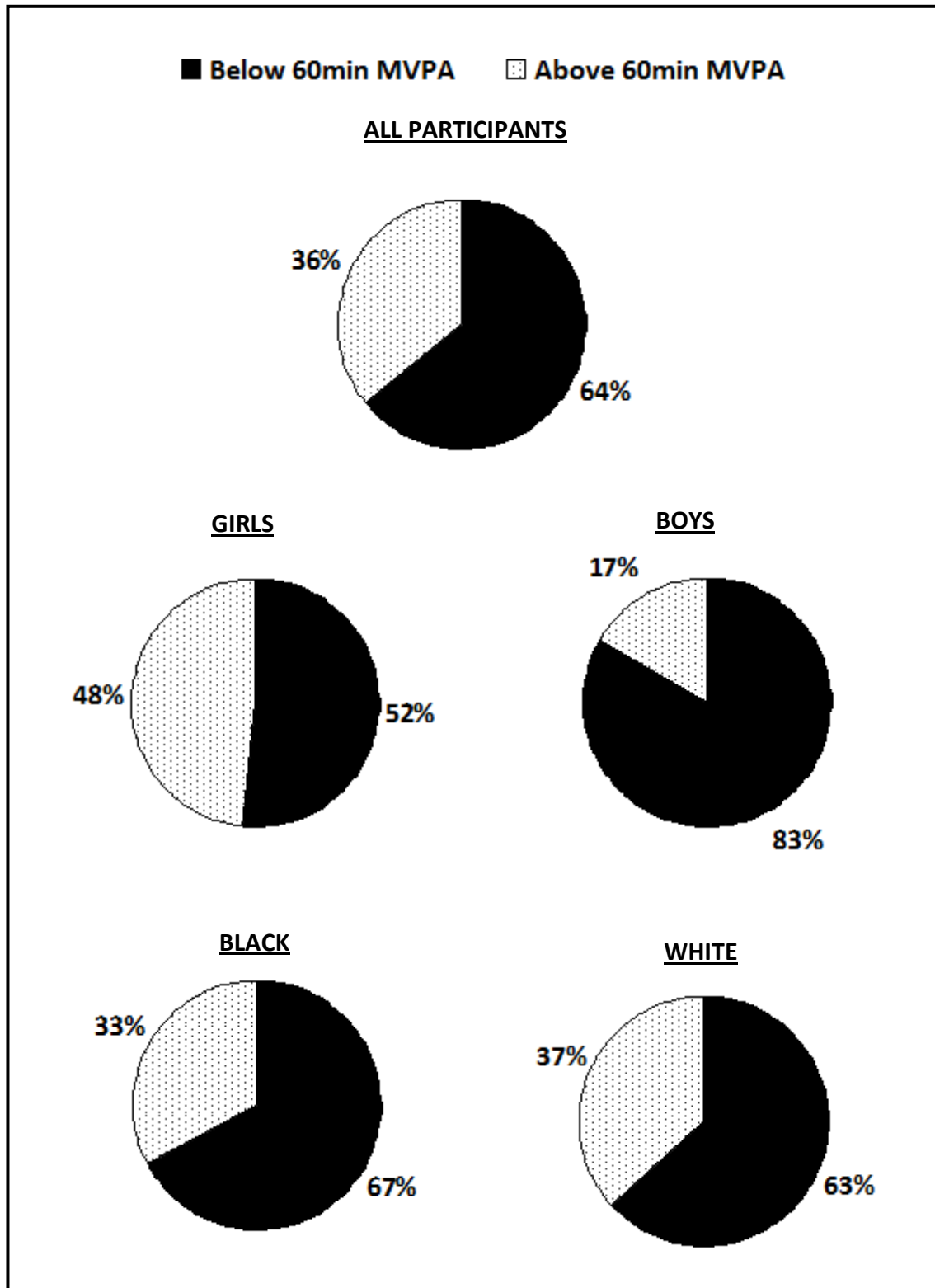
	Activity Counts per Minute All	Activity Counts per Minute Girls	Activity Counts per Minute Boys
Weight			
(R)	-0.173**	-0.117	-0.356**
P value	0.009	0.173	0.001
BMI			
(R)	-0.157*	0.012	-0.218*
P value	0.018	0.890	0.041
% Body Fat			
(R)	-0.268**	0.006	-0.180
P value	0.001	0.942	0.091
Fat Mass			
(R)	-0.251**	-0.068	-0.263*
P value	0.001	0.431	0.013
Fat Free Mass			
(R)	-0.103	-0.134	-0.346**
P value	0.123	0.117	0.001

BMI= body mass index; % Body fat= Percentage body fat

*Correlation is significant at the 0.05 level

** Correlation is significant at the 0.01 level

Figure 3.2: Representation of the participants who meet the recommendation of 60 min daily MVPA



DISCUSSION

Physical inactivity and obesity are reaching epidemic proportions in many countries. There are currently over 1 billion adults globally with a body mass index (BMI) above 25 kg/m² (the cut-off for overweight).²² One of the most compelling findings of this study is its consistency with the international phenomenon of low physical activity in adolescents.^{23,24} Accelerometry combined with heart rate is an objective method of PA assessment that has not been used in South Africa with a substantial sample size. Up until now most of the studies in South Africa on habitual physical activity were done using questionnaires.¹⁷ Other objective measures such as pedometers have been used to assess PA in South Africa.¹² To our knowledge this study is the first to report objectively measured PA using the Actiheart in a representative sample of South African adolescents over a period of seven consecutive days.

Keating (2005) reported that more than 40% of students were physically inactive in the USA.²⁵ The present study reported that 64% of the adolescents were inactive, irrespective of ethnicity and gender. This means that only 36% of the current study population met the recommended 60 minutes of MVPA per day.

White adolescents were found to be heavier, taller, and have higher FM, FFM and BMI than black adolescents. These findings are in agreement with Kaplan et al. (1996); Gallagher et al. (2005) and Torriani & Grinspoon, (2005).^{26,27,28} In the present study, girls had a higher BMI, %BF and FM than the boys. This is consistent with Monyeki et al. (2012) and DeLany et al. (2006).^{2,29} 16.4% of the adolescents aged 16 years in the present study were underweight, while 19.4% were overweight or obese. When they were 14 years old, 35.9% of the same study sample were underweight, while only 13.7% were either overweight or obese.² With regard to gender, the trend of TEE and activity CPM in this study are consistent with international studies^{24,30} which found that boys have significantly higher TEE and activity CPM than girls. Results of the study revealed a significant negative correlation between physical activity CPM and body composition variables such as weight, BMI, %BF and FM. This is in agreement with earlier studies which view physical activity as a tool to decrease weight and lower BMI, %BF and FM.^{1,2,22,31} The higher percentage of metabolically active FFM in boys compared to girls explains their higher TEE. Bratteby³² and Livingstone³³ reported higher TEE values for their

adolescent populations than the present study. The difference in TEE between the adolescent groups may be partially explained by the non-exercise activity thermogenesis (NEAT). Adolescents from developed (affluent) societies tend to spend more time in the discretionary PA domain which may often involve active leisure, thereby boosting TEE.³⁴

Analysis of the whole group revealed that on average, the participants were more active on weekdays than weekends irrespective of ethnicity and gender. These findings are in agreement with Steele (2010)³⁵ and Rowlands (2008).³⁶ It is possible that walking to school (NEAT transport domain) or the mandatory physical education/scheduled sport is the reason behind higher weekday TEE in adolescents.³⁴ Conversely, Mamabolo's (2007) study revealed that adolescents were more active on weekends than on weekdays.¹⁷ The disparity may be due to the fact that Mamabolo used questionnaires and not objective means to assess PA.

70.8% of the entire study sample falls into the low and sedentary PAL categories. With regard to gender, girls demonstrated higher PAL scores than the boys. A higher percentage of girls occupied the moderate, active and high PAL index categories than boys. These findings are in agreement with Livingstone (1992) who also reported higher PAL in 15 year old girls than boys.³³ However the study by Bratteby (1998) gave disparate findings as boys recorded a higher PAL than girls.³² The peculiarity of the results of the current study may be attributed to the extensively higher number of girls (n=137) than boys (n=89) in the study. With regard to ethnicity, the present study found that black adolescents demonstrated significantly higher ($p<0.0001$) PAL than white adolescents. The results of this study contradict those of other studies,^{17,37} all of which indicate lower PAL in black adolescents, or no difference at all between the ethnic groups. According to NEAT, black adolescents from disadvantaged communities tend to spend more time in work, transport and domestic domain of PA than white adolescents from affluent communities. This may explain their higher PAL.³⁴

The present study found that the mean daily time spent in MVPA was 61.13 minutes/day for girls and 35.02 minutes/day for boys. The MVPA results of the current study are higher than those recorded in the United Kingdom, (15-year old girls) where MVPA was 53 ± 19 minutes/day.³⁸ The findings of the present study are contradicted by Miller (2005) who suggested that females are more likely than males to participate in moderate activity only and not

in vigorous activity.¹⁶ Leslie (1999) found lower levels of vigorous PA among girls than boys³⁷ whereas Hoos (2003) found no significant difference in the PAL of boys and girls, but did show a difference between the genders in AEE with boys recording higher scores.³⁰ The present study also found girls to have higher AEE. The higher AEE observed in girls may be an indirect derivative of their higher FM which has been shown to also influence energy expenditure.

The limitation of the present study (which should be noted when interpreting the findings) is the cross-sectional nature, which limits data to a particular point in time. A longitudinal design would be more advantageous in terms of providing more definitive conclusions. Besides the limitations, it is interesting to note that this study managed to objectively measure physical activity in a larger number of participants of South African adolescents. Instruments such the Actiheart® can provide physical activity data at a level of accuracy and specificity that has not been achieved before.

CONCLUSION

Habitual assessed physical activity in black and white adolescents from the Tlokwe Municipality in the North West Province indicated that less than 40% of the adolescents reached the recommended 60minutes of daily physical activity. Even though the adolescents in the present study could not meet recommended daily physical activity, girls reported the highest level of MVPA for all race and gender groupings. Given the fact that the studied sample did not meet recommended daily physical activity and the adverse effect of inactivity and chronic diseases of life style, urgent strategies to inculcate the culture of regular physical activity as a preventative measure of chronic diseases of life style are needed.

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ASSOCIATION BETWEEN RESTING METABOLIC RATE AND OBJECTIVELY MEASURED PHYSICAL ACTIVITY IN ADOLESCENTS: THE PAHL STUDY

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ABSTRACT

Purpose: To determine the association between resting metabolic rate (RMR) and objectively determined physical activity (PA) in 16-year old adolescents and furthermore, to identify PA patterns and energy expenditure (EE) in 16-year old adolescents.

Methods: Adolescents (29 boys, 32 girls) from the on-going **Physical Activity and Health Longitudinal Study (PAHLS)** were included in the study. RMR was measured by indirect calorimetry following an overnight fast. PA was assessed over seven days using the Actiheart® (Cambridge, UK). Data analysis consisted of independent t-tests, Mann-Whitney U test and regression analysis using SPSS version 20 statistical software.

Results: The results show that 16.4% of the study sample was either overweight or obese. Boys had a significantly higher ($p < 0.05$) RMR than girls and white adolescents had a higher RMR than black adolescents although the difference was not significant. Girls demonstrated significantly higher physical activity levels (PAL) and spent significantly ($p < 0.05$) more minutes/day in moderate-vigorous PA than boys. Black adolescents recorded significantly higher ($p < 0.05$) activity counts/minute compared to white adolescents; while boys scored significantly higher ($p < 0.05$) activity counts/minute than girls. After adjustment for gender, ethnicity and FFM, linear regression between RMR and moderate-to-vigorous PA yielded an $r^2 = 0.46$ ($p < 0.05$.)

Conclusion: Behaviour that is carried on into adulthood is established during adolescence. Civic health efforts should focus on encouraging adolescent involvement in regular moderate-to-vigorous PA, which will subsequently increase RMR and lower the risk of the development of non-communicable chronic diseases such as obesity.

Key words: Habitual physical activity, resting metabolic rate, obesity, adolescents, PAHL study

Implications and contribution

Adolescent obesity in Sub-Saharan Africa is growing at an alarming rate. Little is known about RMR and objectively determined habitual PA of adolescents. If PA improves RMR, then urgent strategies to inculcate the culture of regular PA as a preventative measure of chronic diseases of life style are needed.

INTRODUCTION

The prevalence of overweight and obesity amongst adolescents is a disturbing health problem worldwide [1,2]. The occurrence of overweight and obesity in South African adolescents at present has been said to be on par with that of many industrialised nations and amongst the highest in Africa [3]. A recent study of 3511 children and adolescents from rural villages in Mpumalanga showed a relatively high prevalence of overweight and obesity in girls, reaching 20-25% in late adolescence [4]. In the North West Province, a 17.3% prevalence of obesity in 14 year old female adolescents was reported in 2012 [5]. Factors assumed to play a role in the gender disparity of obesity prevalence include the differences in the total energy expenditure (TEE), resting metabolic rate (RMR), physical activity (PA) and timing of sexual maturation [4]. Fundamentally, obesity is the result of energy imbalance. Energy expenditure (EE) is dependent on activity energy expenditure (AEE), RMR, and dietary intake thermogenesis (DIT) [1].

Being overweight during adolescence is strongly associated with an increased risk of adulthood overweight and obesity [2]. PA is hypothesized to protect individuals from developing obesity by increasing EE and RMR [2]. PA affects EE in two ways: Firstly, habitual PA increases the amount of TEE. Secondly, PA helps maintain fat free mass (FFM), which in turn helps to maintain a higher RMR [7]. RMR represents 60-75% of TEE therefore playing a substantial role in maintaining a healthy body weight. Because FFM is a primary determinant of RMR, factors that influence RMR often do so through their effect on FFM [7].

Although the effects of RMR on PA have been extensively studied, scientific literature is not completely conclusive in this area [2,8]. Some researchers indicate that PA may

positively affect RMR and that low RMR is a predictor of obesity [2,7,8]. The decrease in RMR as a result of a decline in lean muscle mass further exacerbates the fall in RMR brought on by energy restriction [7]. A longitudinal study found that persons who increase their PA also increase their RMR [8]. The results of a pioneer study reflect the well-established hypothesis that RMR remains elevated for several hours after exercise [8].

The modern day inactive lifestyles of adolescents contribute to a positive energy balance and early development of obesity, as well as a lowered motivation to participate in organised sport [9,10]. Currently, the majority of South African adolescents are failing to engage in the recommended levels of PA associated with positive health outcomes [11]. One study reported that only 42% of South African adolescents participate in sufficient moderate to vigorous physical activity (MVPA) [12], while another revealed that 73% of black adolescents and 61% of white adolescents from the North West Province of South Africa are physically inactive [13]. In a study using the Actical to objectively measure PA, it was reported that on average, participants spent only 9.6 minutes/day in MVPA [9].

In South Africa the relationship between RMR and PA has not been extensively studied in adolescents. Despite reported low levels of physical activity and increasing overweight and obesity, insufficient information exists on the relationship between RMR and PA in adolescents attending high schools in town and township areas within the North West Province of South Africa. The purpose of this study was twofold; (1) To determine the association between resting metabolic rate (RMR) and objectively determined physical activity (PA) in 16-year old adolescents; (2) To identify physical activity (PA) patterns and energy expenditure (EE) in 16-year old adolescents. This is the first study to use indirect calorimetry to measure resting metabolic rate and combined accelerometry and heart rate to objectively measure physical activity in South African adolescents.

METHODS

Study design

This is an observational cohort study following a cross-sectional research design within the Physical Activity and Health Longitudinal Study. The PAHLS is an observational multi-disciplinary longitudinal study which started in 2010. The general aim of the study was to describe the development of physical activity and determinants of health risk factors in 14

year old adolescents. Of the 61 adolescents in the cohort, 61 (100%) had their RMR measured successfully and wore the Actiheart over seven consecutive days. Prior to the study permission to conduct the measurements was granted by the District Manager of the Department of Education in Potchefstroom. The protocol was approved by the Ethics Committee of the North-West University (*Ethics number: NWU-0058-01-A1*) of the Potchefstroom campus. Parents/guardians of the adolescents gave signed informed consent. The adolescents also gave consent to participate in this study. The participating schools were contacted and briefed about the purpose of the study and subsequently the informed consent was given by the school authorities, the parents and the pupils of the participating school. All participants in the study completed an informed consent form and the study protocol was explained to them. Consent was obtained from the parents of the adolescents recruited for participation.

Participants

Male and female adolescents aged 16 years in the 2012 calendar year and of sound mental and physical health were included in the study. The cohort provided demographic information including age, gender, race, socio-economic background (township or town). Stature and weight were measured using established ISAK protocol [14]. Body mass index (BMI) was computed by dividing weight (kilograms)/height² (meters). The internationally accepted Slaughter (1988) equation, approved for use in adolescents of different ethnicities was used to compute percentage body fat (%BF) [15]. Fat free mass (FFM) was calculated using the Yuhasz (1977) equation which distinguishes between male and female [16]. Sources of variability associated with estimation of body fatness include the investigator conducting the measurements, the callipers used, the number of sites measured, and the regression equation used for calculation. Variability was reduced by having all measurements taken by Level 2 ISAK anthropometrists. 61 adolescents aged ≈ 16 years, voluntarily participated in the study (32 girls; 29 boys). Forty six (46) of the participants were black (residing in the township) and fifteen (15) were white (residing in town). The participants were from 6 schools (2 town, high socio-economic) and 4 township (low socio-economic) within the Tlokwe Local Municipality of the North West Province of South Africa.

Resting metabolic rate

RMR was measured by indirect calorimetry using the Fitmate Pro (Cosmed, Italy). Participants were familiarized with the equipment and given a briefing on the experimental protocol before the day of the measurement. They were advised to avoid medication, caffeine, smoking, alcohol and strenuous exercise the evening before testing. RMR was measured after a fasting period of 10-12 hours. The participants were requested to lie in the supine position for 10 minutes prior to the test [17]. Sampling was done for 16 minutes. The first minute of measurement was discarded to ensure that the participants breathed normally and continuously through the Fitmate mask during sampling. The Fitmate uses standard metabolic formulas to calculate oxygen uptake. The Fitmate includes an oxygen analyser but no carbon dioxide analyser, calculating RMR by assuming a respiratory quotient of 0.85. This assumption, however, introduces little error in estimating RMR, as verified in previous studies [17]. The Fitmate has been validated with the Douglas bag method and proven to accurately measure RMR [17]. RMR was reported in kCal/day.

Objectively measured physical activity

The Actiheart® (CamnTech, Cambridge, UK) is a chest mounted, combined-unit, synchronized heart rate (HR) monitor and accelerometer capable of storing time-sequenced data. Activity counts per minute (CPM), physical activity levels (PAL) as well as minutes per day spent in sedentary, low and moderate to vigorous physical activity (MVPA) were measured using the Actiheart® (CamnTech, Cambridge, UK). The Actiheart® was programmed to use the GroupCalJAP2007 energy model, then the unit was clipped onto two ECG electrodes adhered to the participants chest [18]. The Actiheart® was placed on the left side of the chest according to the manufacturer's instructions and recommendations detailed elsewhere [18]. PA was measured in 60 second epochs over the seven consecutive days that the participants wore the Actiheart®. The Actiheart® device was fixed to the chest of the participants for seven consecutive days after which it was removed and the data downloaded into a database using the accompanying commercial software (Version 2.132, Cambridge Neurotechnology Ltd. Cambridge, UK). The same software was used to recover missing data and check if the participant wore the Actiheart consistently for 7 days. Specific MET cut-off points describe the intensity level of physical activity: Sedentary (<1.5METs); Light (1.5 METs-3.0METs); Moderate (3.0-6.0 METs) and Vigorous (>6.0METs). PAL is calculated by dividing TEE by RMR. The PAL cut off

points as described by the United Nations Food and Agriculture Organisation, 2001 are as follows; Sedentary (<1.40); Light (1.40-1.60); Moderate (1.61-1.99); Heavy (2.00-2.40) and Extremely heavy (>2.40) [19]. The participants were instructed to carry on with their habitual lifestyle, keep the monitor on at all times, when awake and asleep and only remove it when bathing, swimming or partaking in high impact sport (like rugby). The Actiheart has been validated against doubly labelled water (DLW) in adults [18] and adolescents [20]. The equations used by the Actiheart to estimate EE in adolescents were derived using data from thirty nine, 12-13 year old children during a treadmill [21]. There exists a need to develop adolescent-specific prediction equations for adolescents [20] as some authors question the ability of the Actiheart to accurately measure EE in adolescents [20,22]. However, results from Campbell's study should be interpreted with caution as the RMR values used to estimate physical activity energy expenditure from DLW derived TEE were computed from standardised equations and not direct measurement [20].

STATISTICAL ANALYSIS

All data analyses were performed with the SPSS Version 20 software (IBM SPSS, II). Descriptive statistics comprised means and standard deviations. Independent t-tests were used to determine the differences in descriptive variables between the two genders and ethnicities and Mann-Whitney U test was used to calculate practical significance. Significance level was set at $p=0.05$ for all statistical tests. To study the relationship between RMR and PA (MET min/day spent in various intensities of PA), regression analyses adjusted for ethnicity and fat free mass was performed.

RESULTS

Participant characteristics

Mean ($\pm$ SD) age and BMI of the adolescents was 15.74 ± 0.79 years and 22.21 ± 5.49 kg/m² respectively. Prevalence of overweight and obesity was 10% in the study sample, 7% among girls and 3% among boys. The mean age was 15.78 ± 0.87 years for girls and 15.69 ± 0.71 years for boys with no significant difference in age. Boys (59.74 ± 45.61 kg; $p=0.05$) were significantly heavier than girls (59.15 ± 14.54 kg) and white (71.3 ± 17.21 kg; $p=0.0001$) adolescents. The traits largely differed by gender, with girls recording a significantly higher BMI, %BF and FM than boys. When the analysis was carried out

Table 4.1: Characteristics of the sample by total group by ethnicity and gender

	Total (n=61)	Girls (n=32)	Boys (n=29)	<i>p</i> -value	<i>d</i> -value (gender)	Black(n=46)	White (n=15)	<i>p</i> -value	<i>d</i> -value (ethnicity)
Age (years)	15.74 ± 0.79	15.78 ± 0.87	15.69 ± 0.71	0.61	0.10	15.80 ± 0.85	15.47 ± 0.52	0.13	0.39
Body mass (kg)	59.40 ± 14.93	59.20 ± 14.54	59.74 ± 15.61 *	0.05	-0.04	55.01 ± 11.95	71.30 ± 17.21 **	0.05	-0.95
Stature (m)	1.64 ± 0.10	1.59 ± 0.08	1.69 ± 0.079 **	0.0001	-1.25	1.61 ± 0.09	1.70 ± 0.08 **	0.05	-1.00
BMI (kg/m²)	22.21 ± 5.49	23.50 ± 5.68	20.78 ± 4.99 **	0.004	0.48	21.40 ± 5.17	24.47 ± 6.03	0.07	-0.51
BF (%)	12.69 ± 6.02	16.08 ± 4.90	8.95 ± 4.77 **	0.0001	1.46	12.61 ± 5.88	12.96 ± 6.63	0.85	-0.05
FM (kg)	8.02 ± 6.20	9.92 ± 5.78	5.92 ± 6.06 **	0.0001	0.65	7.36 ± 5.38	10.06 ± 8.12	0.14	-0.33
FFM (kg)	51.35 ± 10.40	49.3 ± 10.10	53.7 ± 10.47**	0.0001	-0.42	48.10 ± 8.30	61.31 ± 10.21 **	0.05	-1.29
BMI Categories	All	Girls	Boys			Black	White		
Underweight	12 (19.7%)	4 (12.5%)	8 (27.6%)			12 (26.1%)	0 (0.0%)		
Normal	39 (63.9%)	21 (65.6%)	18 (62.1%)			28 (60.9%)	11 (73.4%)		
Overweight	5 (8.2%)	3 (9.4%)	2 (6.9%)			3 (6.5%)	2 (13.3%)		
Obese	5 (8.2%)	4 (12.5%)	1 (3.4%)			3 (6.5%)	2 (13.3%)		
Gender									
Male	29 (47.54%)					20 (32.79%)	9 (14.75%)		
Female	32 (52.46%)					26 (42.62%)	6 (9.84%)		
Ethnicity									
Black	46 (75.41%)								
White	15 (24.59%)								

± = standard deviation; n = number; BMI = body mass index; %BF = percentage body fat; FM = fat mass; FFM = fat free mass

* Significant difference (between girls and boys), *P* < 0.05

** Significant difference (between black and white), *P* < 0.05

Table 4.2: Physical activity and RMR status of 16 year old South African adolescents

	Total (n=61)	Girls (n=32)	Boys (n=29)	<i>p</i>	<i>d</i> -value (gender)	Black (n=46)	White (n=15)	<i>p</i>	<i>d</i> -value (Ethnicity)
RMR (kCal/day)	1453.1 ± 299.7	1293.1 ± 223.0	1630.0 ± 275.0*	0.0001	-1.23	1411.0 ± 264.4	1582.1 ± 369.4	0.112	-0.46
TEE (kCal/day)	2343.0 ± 401.6	2269.0 ± 413.0	2425.3 ± 379.1	0.132	-0.38	2262.2 ± 334.1	2591.0 ± 494.5 **	0.005	-0.67
AEE (kCal/day)	541.0 ± 243.4	609.0 ± 279.0	467.1 ± 171.1 *	0.022	0.51	538.2 ± 231.1	553.2 ± 286.3	0.839	-0.05
Activity counts/min	53.0 ± 27.6	43.8 ± 24.6	63.2 ± 27.6 *	0.005	-0.70	58.3 ± 27.9	36.7 ± 19.6 **	0.007	0.78
PAL	1.50 ± 0.17	1.58 ± 0.19	1.4 ± 0.1 *	0.0001	0.95	1.5 ± 0.17	1.56 ± 0.18	0.327	0.27
METs(min)/day <1.5 (Sed)	1121.0 ± 128.6	1059.0 ± 131.0	1189.2 ± 85.1*	0.0001	-0.99	1108.1 ± 117.9	1162.0 ± 154.1	0.155	-0.35
METs(min)/day 1.5-3(Low)	269.1 ± 95.9	312.7 ± 95.1	221.3 ± 72.7 *	0.0001	0.97	281.2 ± 85.6	233.1 ± 118.7	0.094	0.40
METs(min)/day 3-6 (Mod.)	49.0 ± 46.9	67.1 ± 52.2	29.1 ± 30.5 *	0.001	0.73	50.0 ± 48.3	45.9 ± 43.6	0.768	0.09
METs(min)/day >6 (Vig.)	2.7 ± 4.1	2.9 ± 4.8	2.4 ± 3.1	0.617	0.11	2.1 ± 3.3	4.3 ± 5.6	0.076	-0.38
METs(min)/day >3 (MVPA)	51.7 ± 48.7	69.7 ± 54.8	31.5 ± 30.9 *	0.01	0.70	52.2 ± 50.7	50.1 ± 43.6	0.891	0.02

± Standard deviation; RMR=resting metabolic rate; TEE=total energy expenditure; AEE=active energy expenditure; DIT=dietary intake thermogenesis; PAL= physical activity level; Sed. = sedentary; Mod. = moderate; Vig. = vigorous; MVPA = moderate to vigorous physical activity;

* Significant difference (between girls and boys), $P < 0.05$

** Significant difference (between black and white), $P < 0.05$

independently by ethnicity, white adolescents (61.3 ± 10.21 kg; $p=0.0001$) exhibited significantly higher FFM than black (48.12 ± 8.305 kg) adolescents. In the study sample of 61 adolescents, 47.5% were boys, 52.5% were girls, 75.4% were black and 24.6% were white ($p < 0.05$, Table 1).

Resting metabolic rate and physical activity status of participants

Mean ($\pm$ SD) RMR of the adolescents was 1453 ± 299.7 kCal/day. RMR differed significantly between girls and boys ($p < 0.05$, Table 2). Mean ($\pm$ SD) PA counts/min and PAL was 53.0 ± 27.6 counts/minute and 1.50 ± 0.17 respectively. PAL differed significantly ($p=0.0001$) between the genders, with girls recording a higher PAL values than the boys. Activity counts/minute differed between genders and ethnicity, with boys recording significantly higher ($p < 0.05$) activity counts/minute than girls, and black adolescents recording significantly higher ($p < 0.05$) activity count/minute than white adolescents. Mean ($\pm$ SD) MET (minutes/day) spent in MVPA was 50.9 ± 40.38 minutes/day. Girls recorded significantly higher ($p < 0.05$) minutes/day of MVPA than boys, while the difference between ethnicity was not significant.

Relationship between resting metabolic rate and physical activity

After adjustment for gender, ethnicity and FFM, linear regression between resting metabolic rate and MVPA yielded an $r^2 = 0.46$ ($p < 0.05$, Table 3). Forty six percent of the variation in RMR can be explained by the confounding variables. The remaining fifty four percent may be attributed to inherent variability or to differences in the components of FFM (high metabolic rate organs – HMRO such as liver, kidneys, brain, heart) which have been shown to be the most metabolically active.

Table 4.3: Regression coefficients (β) between RMR and the categories of PA for adolescents adjusted for ethnicity and FFM.

Outcome and variable	Regression coefficient	Sig.	R ² (adjusted, %)
RMR	β	<i>p</i>	
Gender	120.37	.154	0.46
Ethnicity	-232.06	.042	
Age	-52.85	.157	
BMI	-25.87	.019	
Fat free mass	23.05	.000	
<1.5 MET (min) Sedentary	.025	.452	
RMR			
Gender	110.04	.194	0.47
Ethnicity	-238.32	.036	
Age	-54.67	.141	
BMI	-26.82	.013	
Fate free mass	23.33	.000	
1.5-3 MET (min) Light	-.356	.302	
RMR			
Gender	145.670	.071	0.46
Ethnicity	-232.882	.042	
Age	-55.540	.140	
BMI	-30.046	.011	
Fate free mass	24.085	.000	
3-6 MET (min) Moderate	.395	.599	
RMR			
Gender	140.278	.080	0.46
Ethnicity	-237.591	.041	
Age	-54.899	.143	
BMI	-28.266	.009	
Fate free mass	23.443	.000	
>6 MET (min) Vigorous	4.070	.579	
RMR			
Gender	145.633	.071	0.46
Ethnicity	-234.172	.042	
Age	-55.683	.139	
BMI	-30.138	.011	
Fate free mass	24.105	.000	
3-6 MET (min) MVPA	.399	.578	

DISCUSSION

Energy expenditure

The aim of this study was to assess the association between RMR and the components of PA for an adolescent population adjusted for ethnicity and FFM in the Tlokwe Municipality of the North West Province of South Africa. In addition, this study identified EE and PA patterns of 16year old adolescents. This study was the first to explore the relationship between RMR and objectively measured PA (using accelerometry) in South African adolescents. The results of the current study illustrate the existing gender and ethnical differences in the RMR and PA status of 16 year old adolescents. This study showed that black adolescents have a lower RMR than white adolescents although the difference is not statistically significant. This result is consistent with the findings of a previous study which reported that the RMR of black adolescents was 14% lower than that of white adolescents [23]. Previous studies ascribe the lower RMR in black adolescents to differences in body composition with particular regard to FFM [23,24,25]. Studies highlight the important contribution that high metabolic rate organs (HMROs), such as the liver, kidneys, spleen, heart and brain, have on RMR and support the notion that although HMRO's constitute a minor portion of total FFM, much of the variation in RMR commonly thought to be attributable to gender, ethnicity, and age may be explained by variation in the components of FFM, specifically these select HMROs [26]. The current study found boys to have a significantly higher ($p=0.001$) RMR than girls. This may be explained by the higher metabolically FFM that boys have. These results are in agreement with the previous findings which reported that boys have a higher RMR than girls, even after adjustment for differences in body weight [27,28].

Physical activity behaviour

PAL is calculated by dividing TEE by RMR. In the current study girls were found to have a significantly higher ($p < 0.05$) PAL boys. This is in agreement with previous studies which both reported higher PAL in 15 year old girls than boys [30, 31]. The higher PAL reported by girls may be the result of their lower TEE to RMR ratio. It is probable that domestic chores and active transportation are responsible for the higher and maintained

PAL of girls. Black adolescents recorded a higher PAL than white adolescents although it was not statistically significant. The results of this study contradict those of other studies that indicate lower PAL in black adolescents or no difference at all between the ethnical groups [2,32]. The assumption underlying the use of PAL is that by adjusting for RMR and expressing the data as a ratio the potential influence of body weight and composition is removed, thus allowing comparisons of the relative energy cost of physical activities between individuals and populations. Thus, it is hardly surprising that comparisons of PAL between boys and girls have shown very inconsistent results, with many reporting no difference between the two groups [27].

The current study shows that girls spent more time in MVPA than boys. These findings conflict with another study which found that 12-year old boys spent more time in MVPA than girls [33]. This suggests that girls are engaging in more moderate intensity physical activity than boys, possibly due to greater awareness of the health and aesthetic benefits associated with physical activity. It may also indicate greater participation in school or club sport. Additionally, literature has suggested that females are more likely than males to participate in moderate activity only and not in vigorous activity [2] while a different study found lower levels of vigorous physical activity among women than men [34]. In a study on 15 year old adolescents from the North West province which the use of questionnaires; boys were found to engage in more MVPA than girls [11]. Additionally, by means of questionnaire, in a sample of 9 year olds, boys were found to engage in more MVPA than girls and white adolescents were found to engage in more MVPA than black adolescents [12].

Relationship between resting metabolic rate and physical activity

The present results showed significant direct relationships between RMR and physical activity. The observed positive relationship may be a reflection of high physical activity related to high RMR. As such, the observed findings may suggest that a shift from time spent in sedentary behavior towards light, moderate and vigorous physical activity might be an ideal and promising strategy for increasing TEE in adolescents [35]. Additionally, the present findings may one way or the other agree with the recommendation to increase light and moderate intensity activity to prevent and treat obesity [36]. Literature from a

meta-analysis suggests that greater engagement in intense physical activities might be necessary to alter TEE and energy balance significantly [37].

The strength of the present study lies in the uniqueness of the analysis within a South African context, which will hopefully provide further impetus for more analyses of this kind. Rather than providing definitive results, our findings suggest the need for future studies of a longitudinal nature. Additionally, young people's physical activity is very intermittent, with up to 96% of activity bouts shorter than 10 seconds, with the majority lasting between 3-22 seconds [38]. Future studies should factor in shorter epochs of 15-30 seconds in order to capture more accurate data on vigorous PA. In addition further longitudinal research is needed to assess the effect of age and maturation on the relationship between RMR and PA.

CONCLUSIONS AND FUTURE DIRECTIONS

Gender and to a lesser extent ethnicity, show consistent and strong correlates of overall RMR and PA during adolescence. Although still controversial, purposeful physical exercise may influence resting metabolic rate in adolescents. The findings of the study show a fairly strong relationship between RMR and MVPA after adjustments for FFM, gender and ethnicity.

STRENGTHS AND LIMITATIONS

Strengths of this study is the application of accelerometry combined with heart rate to obtain objectively determined activity energy expenditure in order to determine the association between physical activity and resting metabolic rate in adolescents. Physical activity patterns are complicated and are dependent on a barrage of environmental, social and domestic factors. To increase chances of success, national policy as well as societal intercessions should focus on holistically shifting patterns of physical activity behaviour by promoting organised sport and increasing mandatory school physical education classes. Further studies should examine the relationship between RMR and PA longitudinally as well as on a national scale in order to have a representative analysis of the effect of RMR on PA in South African adolescents.

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SUMMARY, CONCLUSIONS, LIMITATIONS & RECOMMENDATIONS

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5.1 SUMMARY

In Chapter 1, the introduction and outline of the problem statement are presented. The objectives of this research study were firstly to determine objectively measured physical activity and resting metabolic rate (RMR) status in an adolescent population of the Tlokwe Municipality. The second objective was to investigate the relationship between RMR and physical activity in the adolescent population. This chapter gives the general findings of this study, conclusions, limitations and recommendations.

Chapter 2 consists of a literature review on resting metabolic rate and physical activity among adolescents and related terms. From the reviewed literature it was found that RMR is the minimum energy requirement to sustain vital functions during absolute rest (Katch *et al.*, 2011:238) and that it accounts for about 60-70% of TEE. RMR is largely determined by body size and FFM (Buchholz *et al.*, 2003:371). Aerobic activity, resistance training and dietary composition are reported to influence RMR (Gilliat-Wimberly *et al.*, 2001:1181).

There is a strong, positive relationship between RMR and body weight among people with widely ranging body sizes (Stensel *et al.*, 2001:369). RMR averages 5-10% lower in females compared with males at all ages (Katch *et al.*, 2011:238). Studies suggest that FFM is the single most predictive component of RMR and that RMR per kilogram FFM varies across the life span. RMR is suggested to decrease with age (Bosy-Westphal *et al.*, 2003:2356). Literature findings suggest that black girls have a significantly lower RMR per kilogram of

body weight than white girls after accounting for the effects of lean body mass and pubertal maturation. The occurrence of overweight and obesity in South African adolescents at present has been said to be on par with that of many industrialised nations and amongst the highest in Africa (Truter *et al.*, 2010:227).

Recent studies in South Africa have shown unsatisfactory levels of PA, overweight and obesity among children and adolescents (McVeigh *et al.*, 2004:982; Kruger, *et al.*, 2012:491). Only 42% of young South Africans participate in sufficient MVPA (McVeigh *et al.*, 2004:982). PA is inherently difficult to measure precisely, especially when people are undergoing everyday activities (Butte *et al.*, 2012:5). Methods used to assess PA in adolescents include heart rate monitors, motion sensors (Chen *et al.*, 2012:13), doubly labeled water (DLW) and self-report through interviews, questionnaires, or diaries (Riddoch & Boreman, 1995:84). Literature suggests that PA decreases with age and that boys are generally more physically active than girls (Engelbrecht *et al.*, 2004:42). Literature is controversial regarding PA and ethnicity where some researchers report high levels of PA among black people (Walker *et al.*, 2001:370) while others report high levels among white people (McVeigh *et al.*, 2004:985). Literature suggests that PA has two distinct effects on RMR. Firstly, PA results in the growth of lean tissue; and secondly, the increase in lean tissue/FFM resulting from PA may result in the increase of RMR (Albu *et al.*, 1997:531).

From the literature studied, there is a lack of information with regards to objectively determined PA levels in South African adolescents. Together with this gap in the knowledge base, it is also still controversial as to the relationship between RMR and PA. This led to the investigation to determine RMR together with objectively determined PA in adolescents. The investigation was performed as part of the larger PAHL study. The findings were presented in the form of 2 manuscripts prepared for publication, Chapter 3 (titled: “The association between resting metabolic rate and objectively measured physical activity in adolescents: the PAHL study”) and Chapter 4 (titled: “The association between resting metabolic rate and objectively measured physical activity in adolescents: the PAHL study”). The conclusion to this study will be based on the results obtained in the two manuscripts.

5.2 CONCLUSIONS

The conclusions that are drawn from this research project are presented in accordance with the hypotheses presented in Chapter 1.

Hypothesis 1: Gender differences in resting metabolic rate (RMR) and physical activity (PA) exist, with boys having higher values for RMR and PA than female adolescents of the North West Province, South Africa

In line with the hypothesis, there was a significant ($p=0.0001$) gender difference in RMR with the boys recording a higher mean RMR of 1630 kCal/day than the girls of 1293 kCal/day. The variables of physical activity examined were PAL and time per day spent in MVPA. Physical activity level (PAL) is a derivative of TEE and RMR. It is calculated by dividing TEE by RMR. Contrary to the hypothesis, girls scored a significantly higher mean PAL (1.57; $p=0.0001$) than the boys (1.41; $p=0.0001$). Additionally, the girls also registered significantly higher minutes spent in MVPA per day (61.13 minutes/day; $p=0.01$) than the boys (35.02minutes/day). It is apparent that although the boys have a higher RMR than the girls, in terms of PAL and MVPA, the girls, by far, were physically more active compared to the boys. Therefore, with reference to the first half of the hypothesis which refers to gender differences in RMR and PA, the hypothesis is accepted. However, on the basis of the results, the last part of the hypothesis which makes reference to boys recording having higher PA than girls is rejected.

Hypothesis 2: A significant relationship between RMR and physical activity is present in an adolescent population of the North West Province, in South Africa

After adjustment for gender, ethnicity and FFM, linear regression analysis between RMR and moderate-to-vigorous PA yielded an $r^2 = 0.46$ ($p < 0.05$.) This r^2 value indicates a moderate positive trend between RMR and physical activity. Therefore, *the second hypothesis is accepted.*

5.3 LIMITATIONS & RECOMMENDATIONS

This study is presented with a few limitations that should be discussed. The sample size used to investigate the relationship between RMR and physical activity (61) was not very large. A larger sample should be included in follow up studies.

Wearing the Actiheart® may have caused the participants to consciously alter their usual physical activity regimen in an attempt to record higher scores. In addition, due to the delicate nature of the Actiheart®, during swimming and contact sports such as rugby, it must be removed. These periods of often intense PA thus go unmonitored resulting in a gross underestimation of MVPA. Furthermore, due to the reported itching under the skin covered by the ECG pads, some adolescents did not wear the Actiheart® for the full seven days and removed it prematurely. The cross-sectional nature of the study might have affected the conclusions made. As such, it is recommended that future studies must investigate the RMR and PA over a longer period of time so as to determine their longitudinal associations.

In light of the findings of this study, further recommendation is given to increase the daily amount of light PA as well as MVPA in adolescents. There is much research published on RMR and PA but only a limited amount using the Fitmate Pro® (Cosmed, Italy) and the Actiheart® (CamNtech, UK). In addition, there are no studies that the primary investigator is aware of that used the Actiheart® to compare physical activity to RMR as measured by the Cosmed Fitmate Pro.

Finally, additional research using the same equipment is needed in this field to understand how it can be utilized in populations that would like to change their lifestyles, enhance their current exercise program, or learn about their physical activity routine. There is much research published on RMR and PA, but only a limited amount using the Cosmed Fitmate and the Actiheart®.

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APPENDIX A

GUIDELINES FOR AUTHORS (JPAH)

JOURNAL OF PHYSICAL ACTIVITY AND HEALTH

GENERAL POLICY

JPAH is a peer-reviewed journal. Manuscripts reporting Original Research, Public Health Practice, Technical Notes, Brief Reports, or Reviews will be reviewed by at least two reviewers with expertise in the topical field, and the review process usually takes from 6 to 8 weeks. A double-blind method is used for the review process, meaning authors and reviewers remain unknown to each other. All types of manuscripts submitted to *JPAH* are judged on the following primary criteria: adherence to accepted scientific principles and methods, the significant or novel contribution to research or practice in the field of physical activity, clarity and conciseness of writing, and interest to the readership. There are no page charges to contributors. Manuscripts generally should not exceed 25 pages (~5000 words including everything *except* title and abstract pages). Reviews should not exceed a total of 30 pages and Brief Reports should not exceed 15 pages. Major exceptions to these criteria must be approved through the **Editorial Office** before submission. Submissions should not include more than 10 tables/graphics, and should follow the Uniform Requirements for Manuscripts Submitted to Biomedical Journals (visit www.icmje.org/index.html for more detail).

SUBMISSION OF MANUSCRIPT

Manuscripts must be electronically submitted to mc.manuscriptcentral.com/hk_jpah in Microsoft Word® (*.doc) or rich text (*.rtf) format only. Do not submit a .pdf file. Graphics should be submitted in .tif or .jpg formats only. Before submitting, authors should complete the Manuscript Submission Checklist (see below). Authors may be asked to provide Human Kinetics with photo-ready graphics and/or hard copy of the text. Authors are responsible for confirming the accuracy of the final copy, particularly the accuracy of references, and to retain a duplicate copy to guard against loss. Final review of the pre-published text is the responsibility of the authors. Authors of manuscripts accepted for publication must transfer copyright to Human Kinetics as applicable.

Appendices

COVER LETTER: Submissions must include a cover letter stating that the manuscript has not been previously published (except in abstract form), is not presently under consideration by another journal, and will not be submitted to another journal before a final editorial decision from JPAH is rendered. Full names, institutional affiliations, and email addresses of all authors, as well as the full mailing address, telephone number, and fax numbers of the corresponding author, must be provided. Authors must also provide a statement disclosing any relevant financial interests related to the research.

TITLE PAGE: The manuscript must include a title page that provides the full title, a brief running head, manuscript type (see definitions below), three to five key words not used in the title of the manuscript, abstract word count, manuscript word count (inclusive of all pages except the abstract and title page), and date of manuscript submission. Do not include author names on the title page. The order of submission must be 1) Title page, 2) Abstract, 3) Text, 4) Acknowledgments, 5) Funding source, 6) References, 7) Tables, 8) Figures/Graphics.

MANUSCRIPT TYPES

ORIGINAL RESEARCH: A manuscript describing the methods and results of a research study (quantitative or qualitative), including the background and purpose of the study, a detailed description of the research design and methods, clear and comprehensive presentation of results, and discussion of the salient findings.

REVIEWS: Manuscripts that succinctly review the scientific literature on a specific topic. Traditional narrative reviews are discouraged. However, well-conducted systematic reviews and meta-analyses are highly encouraged. The Editorial Office may recruit reviews on specific topics. All review articles must have approval from the Editorial Office prior to submission.

PREPARATION OF MANUSCRIPT

ABSTRACT: All manuscripts must have a structured abstract of no more than 200 words. Required headings are 1) Background, 2) Methods, 3) Results, and 4) Conclusions.

TEXT: The entire manuscript must be double-spaced, including the abstract, references, and tables. Line numbers must appear on each page in the left margin. A brief running head is to be included on the upper right corner of each page; page numbers must appear on the bottom right corner of each page. For studies involving human subjects, the Methods section must

include a statement regarding institutional approval of the protocol and obtaining informed consent. For studies using animals, the Methods section must include a statement regarding institutional approval and compliance with governmental policies and regulations regarding animal welfare.

REFERENCES: For reference lists, authors must follow the guidelines found in the American Medical Association Manual of Style: A Guide for Authors and Editors (10th ed.).

ACKNOWLEDGMENTS: Provide the names, affiliations, and the nature of their contribution for all persons not included as an author, who played a critical role in the study.

FUNDING SOURCE/TRIAL REGISTRATION: Details of all funding sources for the work should be provided (including agency name, grant numbers, etc.). Provide the registry name and registration number for all clinical trials

TABLES: Each table must be accompanied by an explanatory title so that it is intelligible without specific reference to the text. Column headings and all units of measure must be labeled clearly within each table; abbreviations and acronyms must be fully explained in the table or footnotes without reference to the text.

FIGURES/GRAPHICS: Graphics should be prepared with clean, crisp lines, and be camera-ready. For shading, stripe patterns or solids (black and white) are better choices than colors. Graphics created on standard computer programs will be accepted. Graphics should be submitted in *.tif* or *.jpg* formats only. Each figure and photo must be properly identified. A hard copy may be requested. If photos are used, they should be black and white, clear, and show good contrast.

AUTHORSHIP CRITERIA: All authors must be willing to certify that they have contributed substantially to the 1) conception, design, analysis, and/or interpretation of the data; 2) drafting of the manuscript; 3) revision of the manuscript; and 4) approval of the final version. Each author must provide any relevant information upon request to substantiate their contributions.

APPENDIX B

GUIDELINES FOR AUTHORS (JAH)

JOURNAL OF ADOLESCENT HEALTH

MANUSCRIPT PREPARATION

Manuscripts are submitted to the journal electronically. Manuscript documents must comply with layout and length requirements outlined below. Due to page limitations, the editors may decide that figures, appendices, tables, acknowledgements, and other materials be published online only and referenced in the print edition of the Journal. The text of original articles and briefs should usually - but not necessarily - be divided into the following sections: Introduction, Methods, Results, and Discussion. Additionally, the Journal requests an Implications and Contribution summary statement.

ONLINE SUBMISSION

Manuscripts must be submitted online via the Elsevier Editorial System (EES). To access EES, go to <http://ees.elsevier.com/jah/> and register as a new user. You will be guided stepwise through the creation and uploading of the various files and data. Once the uploading is done, the system automatically generates an electronic (PDF) proof, which is then used for reviewing. All correspondence regarding submitted manuscripts will be handled via e-mail through EES.

TITLE PAGE/ACKNOWLEDGEMENTS

The title page should contain a concise but informative title (titles are limited to 150 characters). Include the full names of all authors, as well as the highest academic degrees and the departmental and institutional affiliation of each. One author must be designated as the corresponding author, and should provide a complete postal address, telephone number, fax number, and e-mail address. The title page should also include an Acknowledgements section, listing any sources of support such as grants, equipment, or drugs; and any acknowledgements of persons who have made a substantive contribution to the study. Previous oral or poster presentations at local, regional, national or international meetings should be reported here.

The **ABSTRACT** should be provided in a structured table format with the following bolded headings: Purpose, Methods, Results and Conclusions. Three to ten key words or short phrases should be identified and placed below the abstract.

IMPLICATIONS AND CONTRIBUTION:

In addition to the abstract, please include a summary statement at the beginning of your manuscript. This summary should be no more than 50 words in length and should describe the significance of your study's findings and its contribution to the literature in plain language.

The **INTRODUCTION** should clearly state the purpose(s) of the article and summarize the rationale for the study of observation. Only pertinent references should be used.

The **METHODS**, apparatus, and procedures used should be described in enough detail to allow other workers to reproduce the results. References should be provided for established methods, including statistical methods. Methods that are not well known should be concisely described with appropriate references. Any new or substantially modified method(s) should be carefully described, reasons given for its use, and an evaluation made of its known or potential limitations.

The **RESULTS** should be presented in a logical sequence in the text, table(s), and illustration(s). Only critical data from the table(s) and/or illustrations(s) should be repeated in the text.

Emphasis in the **DISCUSSION** section should be placed on the new and important aspects of the study and the conclusions that can be drawn. The discussion should include the implications and limitations of the findings and should relate the observations to other relevant studies. The link between the conclusion(s) and the goal(s) of the study should be carefully stated, avoiding unqualified statements and conclusions not completely supported by the data. Recommendations, when appropriate, may be included.

POTENTIAL REVIEWERS

Appendices

To assist with a prompt, fair review process, authors are asked to provide the names, institutional affiliations, and e-mail addresses of 5 potential reviewers who have the appropriate expertise to evaluate the manuscript. Failure to provide 5 potential reviewers may result in delays in the processing of your manuscript. Authors may also provide the names of persons who should not be asked to review the manuscript. Ultimately, the Editors reserve the right to choose reviewers.

JOURNAL STYLE

All aspects of the manuscript (tables, illustrations, and references) should be prepared according to the International Committee of Medical Journal Editors (ICMJE) requirements. Grammar, punctuation, and scientific writing style should follow the AMA Manual of Style, 10th edition.

Authors should provide a list of **ABBREVIATIONS** on the title page. All acronyms in the text should be expanded at first mention, followed by the abbreviation in parentheses.

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.

Reference style should follow that of the 10th edition, as shown in the following examples. The titles of journals should be abbreviated according to the style used in the list of Journals AMA Manual of Style Indexed for MEDLINE, posted by the NLM on the Library's web site. <http://www.nlm.nih.gov/tsd/serials/lji.html>

TABLES should be submitted as separate and individual files. Tables should be numbered consecutively, in order of citation in the text. Each table should be given a brief title; explanatory matter should be placed in a table footnote.

MANUSCRIPT SUBMISSION

Appendices

- (1) Review author guidelines, article requirements, and instructions for submitting manuscripts through the Elsevier editorial system, located at <http://ees.elsevier.com/jah/>
- (2) Cover letter
 - Disclosure of any prior publications or submissions with any overlapping information
 - A statement that the work is not under consideration elsewhere
 - Disclosure of any potential conflict of interest, real and perceived, for all named authors
- (3) Names and contact information for 5 potential reviewers
- (4) Title page:
 - Article title
 - Full names, academic degrees, and affiliations of all authors
 - Name, address, e-mail address, telephone and fax number of the corresponding author
 - Sources of funding and acknowledgements of support and assistance
 - Disclosure of potential conflicts, real and perceived, for all named authors
 - Clinical trials registry site and number
 - List of abbreviations
- (5) Abstract, structured for original articles and briefs, summary for review articles and clinical observations
- (6) List of keywords
- (7) Manuscript
 - Please double-space
 - Implications summary statement
 - IRB statement in the Methods section
 - References should be on a new page
 - Figure legends should be on a new page
- Tables, including title and legend, each saved as a separate document
- Figures, each saved as a separate file
- Copies of prior and/or in press publications related to the current submission can be uploaded as separate files or e-mail to the Managing Editor at tor.berg@ucsf.edu

Tor D. Berg, Managing Editor
Phone: 415-502-1373
E-mail: tor.berg@ucsf.edu

Research Center for Childhood & Adolescence
3333 California Street, Suite 245
San Francisco, California 94118-6210

APPENDIX C

LETTER TO SCHOOLS



NORTH-WEST UNIVERSITY
YUNIBESITHI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

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E-mail: andries.monyeki@nwu.ac.za
19 July 2012
<http://www.nwu.ac.za>

The School Principal

.....
.....

A SECOND FOLLOW-UP MEASUREMENT (PAHLS) IN YOUR SCHOOL

Dear Sir/Madam

The research team in the PAHLS would like to take this opportunity to thank the school authority, learners and parents for their continuous willingness in the study, it is greatly appreciated. Since the study is for 5 years the results of the study will not be pronounced at this stage so as to avoid any effect on the data. The results will however be made available to the school after the final measurement of the study. Learners as well as the school that participated in the project (since 2012) received incentives in the form of mathematical instruments as a way of helping them with Math skills development. In 2011, participants in the PAHLS were provided with some writing materials, and the school received sport balls etc. For the year 2012, the school is provided with few calculators so that they can be of aid during the math and science classes. In addition, sport balls were also provided as part of the school incentives. The learners were given their incentives during the time of measurement.

Since the PAHLS project is for 5 years, we would like to make a follow up visit in your school again this year around August/September to put some Actiheart instruments on the learners who are participants in the project. In short, an Actiheart is an objective measure of physical activity and energy expenditure. An Actiheart will be put on a child for a period of 7 days of which the procedures will be explained during the visit. An Actiheart is scientifically proven to have no side effect what so ever.

We are making the following special requisitions that:

1. Help to organize all learners who are participants in the PAHL study on this day for Actiheart.
2. The Actiheart will be collected from them on this day of 2010.

Your cooperation in this regard will be highly appreciated.

Appendices

Yours sincerely,

Thank you

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

.....
Prof. Hanlie Moss
Director: Focus Area for Physical Activity,
Sports & Recreation, NWU-Potchefstroom

APPENDIX D CONSENT FORM

(Parent/Guardian Copy)



NORTH-WEST UNIVERSITY
YUNIBESITHI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

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

I,, father/mother/guardian of agree to permit my child to provide the information on physical activity (i.e. by questionnaire and Actiheart 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's school. I understand that the results of the this study of Five year longitudinal study of physical activity status and the determinants of health in adolescents attending high school in Potchefstroom area of South Africa (*PAHL 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's rights as a participant in this study can be addressed to MsHannekie 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)